OBSERVATIONS ON SOME ARCTIC SOILS OF SOUTHWEST DEVON ISLAND, N.W.T., CANADA

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OF
SOUTHWEST DEVON ISLAND, N.W.T.,
CANADA

By

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SCOPE AND CONTENTS:

An investigation into some arctic soils located on Southwest Devon Island. Some aspects of chemical weathering in the area are considered and detailed studies of patterned ground are undertaken. A terrain map was compiled to locate the major areas of soils and mineral and organic covers and to show this relationship to relief units.

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CHAPTER I

THE STUDY AREA AND THE NATURE OF THE RESEARCH

Nature and Scope of the Investigation

The main aims and purpose of the study are to explain the nature of the soil cover of a limited part of Southwest Devon Island, namely the peninsula between Gascoyne Inlet and Radstock Bay. The geochemical and mineralogical nature of some loose materials will be related to the area's bedrock or mode of geomorphic origin and later development. It is assumed that any weathering sequence could be determined using pedological criteria and methods. The soil forming process consists of fresh bedrock being either chemically weathered in situ or through physical processes the rock surface may be broken up into debris and loosened material. This material, through time, may be altered by pedogenesis in situ or transported by geomorphic processes to the lowland area. These materials are then redeposited where further pedogenic processes may act upon them. The resulting soils may thus be described with respect to a) the morphology of the soil and b) the origin of the parent material as follows:

a) Soils developed on new parent materials (i.e., broken up in situ)

b) Soils developed on gravel ridges or other transported debris.

The in situ debris and loosened material imply a third type of material on which the soil may form which is soil locally transported or sorted on the same bedrock. Within the pedogenic areas provision will also be made for:

a) mineral sorting (patterned ground)
b) the presence or lack of organic matter
c) the presence, if any, of chemical mobilization of various elements especially drainage seeps.
d) wet and dry sites and associated soil features grouped within soil associations or catenas.

Location and Description of the Study Area

Devon Island (the southeasternmost and second largest of the Queen Elizabeth Islands) consists of an area of approximately 25,800 square miles. The landforms of Devon Island are the result of stream and marine processes, with local modifications by glaciation and frost action with landforms bearing evidence of uplift and depression of the island with respect to sealevel since the Pleistocene. More than half of Devon Island is plateau 500 to 2000 feet in elevation and is characterized by a well-preserved, relatively featureless inland surface and continuous coastal cliffs, indented by fiords and steep-walled bays (Roots, 1963). This is also true of the study area located between Gascoyne Inlet and Radstock Bay in the southwestern sector of Devon Island. Here, two erosional remnants of the inland plateau remain: Caswell Tower and South

Plateau. These are separated by a low coastal plain known as Bear Valley (Figure 1).

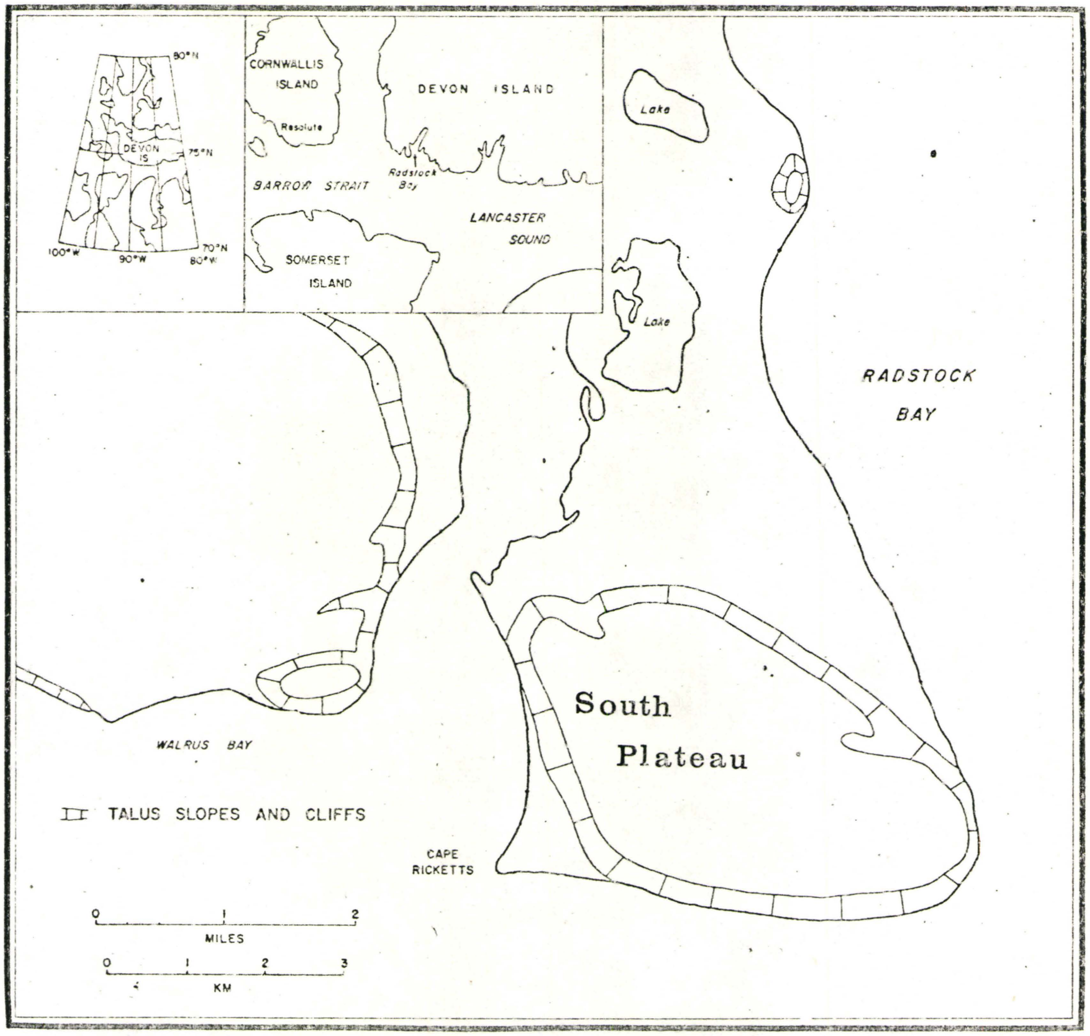
Geology

The geologic history has been outlined by Fortier and Morley (1956). Sedimentation occurred over the Franklin Geosyncline from the Cambrian through to the Devonian Periods. The bedrock of the study area lies to the south of the Franklin Dome and is composed of the Read Bay Formation (limestone and argillaceous limestone marine) which is Upper Silurian to lower Devonian in age (Roots, 1963). Fossils collected during the field season were identified by Dr. Westermann (personal communication) and these also reflected the above time period.

Roots (1963), in a transect of the mainland plateau north of the study area found the lowest exposed bed to be argillaceous limestone. Overlying this, he found approximately 250 feet of silty limestone with beds of argillaceous limestone, and conglomerates and breccias formed the upper section of this bed. The uppermost 270 feet were composed of thicker bedded crinoidal limestone. Stata of the area were within the regional homocline of Devon Island and had a gentle westerly dip.

Rock samples collected by the author on the South Plateau and in the stream valley located on its eastern margin showed the following results. The uppermost bed

FIGURE 1. Location of the study area.



was crinoidal limestone containing gastropods, forams and very small pelecypods. The matrix was composed of carbonates, quartz, clays, and shells which were filled with sparry calcite. Underlying this was a bed of medium to coarse-grained sparry calcite (possibly recrystallized). There was some clay included in the crystals. Beneath this bed was a well banded limestone containing 1-2% quartz and some micas. There were few fossils. The thickness of the above beds could not be approximated since the samples were collected on the plateau surface and no lithologic structure could be found. The only outcrop visible was approximately 300 feet thick, underlying the above beds and was composed of argillacious limestone. Pellets, shell fragments and forams were present. It was well banded with about 8% quartz localized in some bands. About 2% clays were also present. No sulphides were detected in any of the samples. The bedrock of South Plateau also showed a gentle westerly dip.

Geomorphology

The character of the coastlands is essentially that of an upland plateau area truncated by cliffs which were cut back either by marine processes or glaciation The plateau is highest in the eastern sector of Devon Island where, mostly buried under ice, it is transitional to the highland part of Baffin - Ellesmere mountains of crystalline rocks (Fortier, 1963). At the edge of the ice cap the plateau surface is about 2,000 feet above sea-level and from there it slopes gently westward until, near the west coast, it is 500 to 800 feet high. The plateau surface is smooth and relatively featureless and has been preserved with very little modification to the very edge of the coastal cliffs or dissecting valleys (Roots, 1963).

Opinion varies on the extent of glaciation during the Pleistocene in the Queen Elizabeth Islands though consensus is for a series of local ice caps (Craig and Fyles, 1960) which only modified the land-scape in slight detail, the greatest effect being in terms of isostatic recovery. Roots (1963) found glacial striae with a westerly trend on top of Beechy Island, about 8 miles to the west of the study area. Some erratics were noted on the surface of the South Plateau, however no glacial depositional features were noted either there or in the lowland areas.

Isostatic recovery in the study area is very pronounced especially to the north of Caswell Tower and to the northeast of South Plateau where longshore drift, followed by isostatic recovery has resulted in raised strandlines 60-80 metres above sea level. There is little information on the present rates of recovery.

Henoch (1964), from archeological sites on Melville Island, found the maximum possible emergence to be 1.8 metres in the past 1500 years. Owens' results (1969) suggested continuing emergence at the present time although it is very slow.

Roots (1963) states that most of the streams on Devon Island are in the late youth stage of their erosion cycle and have developed cliff-walled valleys, tapering headward to sharp ravines.. In their lower courses many of the valleys have flat floors of fluviatile material some of which has formed from deltas that grew progressively seaward apparently as sea level receded from a position relatively higher than it is today. The gorge-like valleys (east and north sides of the South Plateau) narrow upstream to V - shaped ravines and end abruptly on the smooth plateau, although many of the streams can be traced headwards, meandering without a well-defined valley usually over solifluction debris and fed by water from long stone stripes. The fjords and valleys along the southwest side are spaced at roughly equal intervals, and give the impression that they may have developed from short consequent streams on the scarpe or steep slope resulting from the uplift of the land.

Climate

Southwest Devon Island is subjected to a severe arctic climate. Only 3 months of the year have average temperatures above 0°C while 6 months have average temperatures less than -20°C. Of the 541 degree days with mean daily temperatures above 0°C between 1951 and 1960 : 96 occurred in June, 258 in July, 177 in August and 10 in September (Thompson, 1967). Table 1 illustrates the average number of days of precipitation for each of the four "summer" months. The average for last frost in Spring is July 9 while the average for the first frost in Fall is July 25 (Hannell, 1969 - unpublished). During the 1969 field season between July 21 and August 30, there were 13 days of rain and 3 of snow while 9 of these days had fog or low cloud. However, the precipitation occurred in the first 3 weeks with August 12 though August 28 being precipitation-free.

TABLE I

PRECIPITATION (AVERAGE FIGURES FROM 1960 TO 1968)

Month	Rain	No. of Days	Snow	No. of Days	No. of Days Fog.
June	0.3 in.	2	1.5 ins.	4	5
July	0.8 "	8	0.4 "	1	8
August	1.22 "	8	1.1 "	3	9
September	0.13 "	2	4.8 "	10	5

The uniform summer temperature (Table 2) is due to the cooling effect of the cold sea which surrounds Devon Island and is largely ice-covered even in July. Warm air currents from the continent to the south are rapidly cooled when passing over the colder sea. The sea's cooling influence results in the formation of low cloud cover in July and August which prevails over most of the Archipelago and absorbs a large part of the solar heat that otherwise would have reached the surface. Thus Cornwallis Island, during August 1948, reported only 48 hours of sunshine out of a possible 662 hours (Porsild, 1964).

TABLE 2

TEMPERATURES (^{o}F MEASURED IN STEVENSON SCREEN)

Month	Mean Daily Maximum	Highest Recorded	Mean Daily Minimum	Lowest Recorded
June	37.2	57	28.8	8
July	45.1	61	35.4	28
August	41.4	59	33.2	17
September	27.6	48	20.6	0

Review of Literature

Within the high arctic, pedogenic weathering is reduced considerably. Any weathering taking place is dominated by the mechanical disintegration of the parent material by frost action. Certain frost processes are said to be constructive while others are destructive with respect to soil development (Tedrow, 1968a). The constructive processes are size reduction of soil particles, arrangement of soil particles and the formation of structural aggregates. Destructive processes centre around physical displacement of the soil through frost action, frost-stirring and ice wedge growth. This latter process adversely affects pedogenesis such as formation and decomposition of humus, leaching and translocation of mineral and organic components from one horizon to another, soil acidity, and formation of structural units (Tedrow, 1968a).

One type of "soil" considered in this thesis is polygonally patterned ground and especially those forms usually known as stony earth circles. In general, most hypotheses of polygon formation are based on some form of pressure generated by frost and caused by the expansion of volume on freezing and subsequent reduction of pressure on melting. Washburn (1956) believes the development of polygons to be a result of many processes acting together. He concludes that the two dominant processes are multi-gelation (ejection of stones from fines) and cryostatic pressure. However, it is necessary to have heterogeneous particles for polygons to form. Corte (1962) has shown that vertical sorting by frost action can occur within a soil. As a result of the migrating freezing plane, fine particles were shown to move downward and coarse particles upward within a soil profile. Federoff (1966) on the other hand, describes the formation of polygons by differential sorting in which the fine material is thrust to the surface. Corte's methods of vertical sorting can occur as long as the material is saturated with water since he found the degree of sorting to decrease as the amount of moisture decreases (Corte 1963).

Ugolini (1966) found that when cryogenic processes have ceased to act because of changes in climate or moisture regime, then that particular type of patterned ground becomes relict. This then allows pedogenic processes to progress undisturbed. Ugolini (1966) illustrates an inactive net with four types of arctic soils formed within it. However, renewal of frost action may cancel any incipient soil development. Svatkov (1958) noted that the humus horizon of polygonal soils is thin or often missing.

Unfortunately, little research has been undertaken to investigate pedogenic weathering in the Canadian high arctic. Thus it is necessary to take into account observations from other arctic areas. Meinardus (1930-cited in King) in a study of the effects of pedogenic weathering in Spitzbergen found that the chemical processes involving the solution of carbonates were prominent.

Drew and Tedrow (1957) in an investigation of an Arctic Brown Soil near Point Barrow, Alaska, showed that there was a slight translocation of iron, aluminum, and magnesium in the profile together with the leaching of dolomite from the upper horizons.

Solution and leaching of carbonates from surface horizons has also been reported from Polar Desert Soils on Prince Patrick Island (Tedrow, 1968b) but removal was never complete as reprecipitation took place on the undersides of stones. Svatkov (1958) believed that salination of arctic soil is caused both by transport onto land of ocean spray and by chemical solution of parent rocks. Douglas (1961 cited in Tedrow, 1968a) has shown that solution of carbonates in certain Tundra Soil profiles in Alaska has been followed by reprecipitation as clay-sized particles at depth. Although evidence of chemical weathering in these soils was abundant, Douglas did not observe mineral alteration in situ. The only in situ clay mineral alteration found by Douglas was the chloritization of montmorillonite. Hydrolysis, which is associated with clay mineral formation in soils appears to be poorly expressed in the arctic environment (Hill and Tedrow, 1961). Their conclusion was that most of the clay in the profile was allogenic in origin. Similarly Tedrow and Cantlon (1958) concluded that soil texture appeared to be a reflection of the grain size of the rock.

Day (1964) found that soil profiles located over argillite and dolomite of the Devonian Age, had high clay contents. This would also imply that particle size is controlled by bedrock.

Organic Matter Decomposition

As a result of low soil temperatures and a relatively short growing season, processes of organic matter synthesis are slow (Douglas and Tedrow, 1959). The presence of permafrost at shallow depth impedes drainage of the soil and near-surface horizons are saturated with water throughout much of the summer. This tends to prevent decomposition of organic matter causing peaty material to accumulate on the surface. The slowness of orgainc decomposition is illustrated by a radiocarbon age of 2000 ± 150 years B.P. for surface organic matter from an Arctic Brown Soil, Alaska (Douglas and Tedrow, 1959). An important effect of the progressive accumulation of peat over permafrost is its insulating effect. Thus the permafrost table rises and incorporates the organic material inhibiting or reducing further decomposition.

Many investigators have found buried organic layers at varying depths in the soil profile. Tedrow (1963) found a permanently frozen organic layer in Arctic Alaska with a C_{14} age of 8150 to 10,600 years B.P. but its genesis was not established. Tedrow et. al (1958) found C_{14} dates for two buried organic layers in tundra soils of Alaska to range from 5300 to 10,900 years B.P. Tedrow (1965) found a C_{14} age of 2300 ± 110 years B.P. for organic matter in northern Alaska. Tedrow (1963) believes that the buried organic matter coincides with a warming trend during late Wisconsin time. However, Mackay (1958) believes that the organic layers resulted from progressive burial of the organic tongues that extend downward in depressions between hummocks. He further notes that this process is continuous, further suggesting that C_{14} dates should be considered critically.

Gleization

The presence of permafrost results in the water-logging of those horizons immediately above the permafrost creating an anaerobic environment wherein the free access of oxygen is impeded and the reduction of various compounds takes place.

Svatkov (1958) notes that depending on locality, thickness of snow cover and extent of soil moisture, the basic arctic types of soil formation may take on a more or less definite characteristic of waterlogging with the result that various arctic gleyed soils are formed. According to Tedrow (1968b) a mottled appearance in gleyed soils in the high arctic is commonly lacking: on Prince

Patrick Island the waterlogged mineral soils are not gleyed or mottled. But gleization is present in all Tundra Soils of northern Alaska (Douglas, 1961) and it would appear that a pedogenic gradient exists poleward in which the effects of gleization are progressively lessened (Tedrow, 1968a).

Translocation

Chemical data from the Polar Desert Soils on Prince Patrick Island showed no trends in the amount of reducible iron. This was attributed to the effects of frost action (Tedrow, 1968b). In some profiles, there also appeared to be no trend in particle size distribution with depth and it was considered by Tedrow that any reduction in particle size, within the surface horizons by pedogenic processes, would probably be obscured by strong wind action.

The translocation of water-soluble salts in the profiles of high arctic soils has long been recognized. Saline and alkaline soil conditions have been reported from Greenland (Ugolini, 1966), Ellesmere Island (Day, 1964) and Prince Patrick Island (Tedrow, 1968b). At Lake Hazen, on Ellesmere Island, saline and alkaline soils cover saline lacustrine deposits (Day, 1964). According to Tedrow (1968b) salt crusts begin to form on Prince Patrick Island after 2 or 3 days of rain-free, windy conditions. It would appear that surface efflorescences are the result of precipitation following the rise of capillary moisture.

King (1969) in his work on North Devon Island, found that the major pedogenic processes contributing to the morphology of the soils were restricted to the decomposition of organic matter and gleization. He also concluded that the lack of structure in the mineral portion of the profile was due to the large moisture content. Day (1964) found that the morphological and chemical characteristics of the soils indicated that there was no significant development of genetic horizons and hence all profiles were classed as Rhegosols.

Arctic Soil Classification

A classification of arctic soils has been devised by Tedrow and Cantlon (1958) and Douglas and Tedrow (1960) as follows: Lithosols (Douglas and Tedrow, 1960) are mainly an assemblage of cobbles and pebbles with small amounts of fines. The morphology of these soils is closely related to the nature of the underlying bedrock. Barren conditions are common with a vascular plant cover not exceeding 3%. Rhegosols (Douglas and Tedrow, 1960) include those soils found on recent alluvium, on water-worked glacial deposits, and those which have been kept immature by cryopedogenic processes and gelifluction phenomena. Vascular cover from 0 - 30% is found on their surfaces.

Tedrow and Cantlon (1958) classified the Tundra Soils as intrazonal and further divided them into Meadow and Upland Tundra Soils. The Upland Tundra is poorly drained while the Meadow Tundra is very poorly drained. The Meadow Tundra Soils are found in low relief areas where very poorly drained conditions exist. They are generally associated with sedges and mosses with only restricted areas showing tussock-forming vegetation. Upland Tundra Soils occupy gentle slopes or flat areas underlain by clayey substrata. Some profiles show a distinct zone of mottling with yellowish-brown streaks.

Tedrow and Cantlon (1958) also classified Soils of gelifluction slopes and soils associated with patterned ground features as Tundra Variant Soils. The soils of gelifluction slopes reflect burial and overturning processes. Buried organic layers, abrupt changes in texture and lobes of intruding material indicate the disruption of normal soil morphology. The prominent characteristic of the soils associated with patterned ground features is the massiveness of the soil and the presence of voids in the form of vesicles or alveoli.

Douglas and Tedrow (1960) classified as Protoranker Soils, those soils which have a "cushion" shape and that are found in the inner edges of the stony borders of sorted nets and circles. These soils consist of loose organic material in which mosses are the major constituents. The soil is so shallow that it cannot be separated into horizons. Their Tundra Ranker Soils were those soils found on bedrock ledges, benches and in bedrock niches.

The 7th Approximation (1960) would classify arctic soils as Inceptisols or Entisols. The Entisols replace soils previously called Regosols and Tundra Soils. The Inceptisols include the soils that have previously been called Tundra Soils Lithosols, and Regosols. Three suborders of Entisols apply to arctic soils: the Aquents, the Ustents and the Udents while two suborders apply to arctic Inceptosols: the Aquepts and the Umbrepts. These suborders are further subdivided into great groups which are designated by prefixes added to the suborder name. The following are the great group prefixes that apply to arctic soils:

Cry	(cold)
Psamm	(sand texture)
Hapl	(minimum horizon)
Hydr	(presence of water)
Ochr	(presence of ochric epipedon)

The National Soil Survey Committee of Canada (1968) classes arctic soils pertinent to the study area under the Rhegosol Great Group. The subgroups which apply to arctic soils are: Saline Rhegosol, Cryic Rhegosol and Lithic Rhegosol. The Saline Rhegosol is a soil having salinity exceeding 4 mmhos /cm^2 within 24 inches of the surface. The Cryic Rhegosol includes those soils with permanently frozen layers in which the temperature is $0^{o}C$ or lower two months after the summer solstice. The Lithic Rhegosol is a soil that has a lithic contact at a depth greater than 4 inches but less than 20 inches. Classification of the soils from the Southwest Devon area will be that of the Canadian Soil Survey above.

CHAPTER II

PHYSICAL AND CHEMICAL WEATHERING PROCESSES IN THE AREA

The nature and forms of physical and chemical weathering of the bedrock and loose deposits in the area are important to the study of the soils of Southwest Devon since most of these soils are still too immature to illustrate their own distinctive weathering or profile sequences. Many of these soils are Rhegosols or Lithosols which imply that their formation is closely linked to the geomorphic origin or geologic nature of the materials rather than the result of marked pedogenesis. Thus some consideration must be given to the forms of mechanical weathering, the types of geomorphic sediment transportation, and the movement of material in drainage and subsurface moisture derived through initial chemical weathering.

Forms of Mechanical Weathering and Transportation

One must assume that the dominant mechanical processes in the disintegration of bedrock are those related to frost-heave and frost shatter since the surface debris is extremely angular (Plate 1). The absence of consolidated bedrock on the surface except in the stream valleys, would also imply that disintegration of material

PLATE 1. Initial breakup of argillaceous bedrock on the North Plateau.

by frost processes is present. Once break-up of the bedrock occurs, one may assume that this debris is eventually transported to the lowlands by one of three major processes a) movement to the base of the talus where longshore drift by marine processes occurs, b) fluvial transportation, and c) solifluction. Solifluction will be omitted from further discussion since R. L. Cox (1969) has adequately discussed this aspect.

a) Talus and Beach Processes

Since talus and marine movement are not related to the soils, these processes will be omitted from this discussion. Suffice it to say that in the past a combination of longshore drift and isostatic recovery since the Pleistocene have been responsible for the deposition of the rhegosolic material comprising the coastal lowlands. For further information of the marine processes one is referred to the paper by McCann and Owens (1969).

b) Fluvial Processes

Although only silt and clay was observed to move in the streams during the period of field study, it is believed that a bedload movement of gravel and stones was in operation.

Fine material may originally be fed into the stream systems either through the stone stripes or the downslope sludge-like movement of material between on the upper surface of South Plateau. Fines were observed adhering to the scalloped surfaces on the undersides of some snow bridges covering the stream bed while others a short distance downslope were completely sediment-free. This may be caused by the supply of fines from the talus slopes on either side of the stream. From here, the fines gradually penetrate through the snow until they are exposed on the undersides of the snow tunnels. As melting proceeds, these fines would be supplied to the stream.

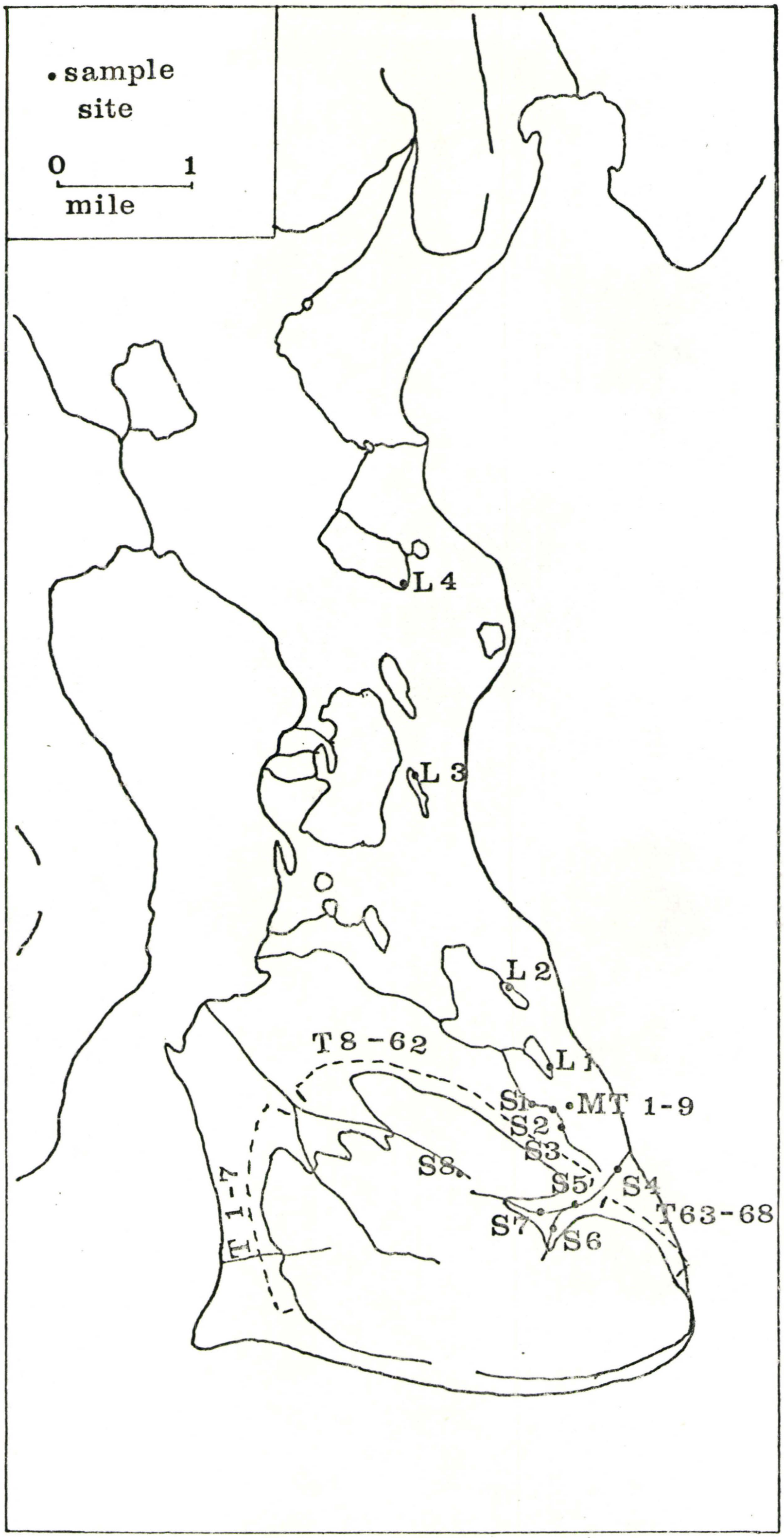
The stream-beds showed characteristics of braiding and meandering especially in their lower reaches. The stream material was light gray in colour as compared to the brown colour of the more weathered surrounding materials suggesting that this process of braiding and meandering is active. However no braiding or channel changes were observed during the study period. It is thus concluded that any channel changes and boulder movement are likely to occur in spring when maximum snowmelt would supply a volume of water great enough to transport particles of gravel size and larger.

Chemical Weathering and Transportation in Solution

The coastal lowland is composed of beach sediments deposited by former marine action. The large variety of surface patterns found in this area would tend to indicate that changes in weathering by solution may be present. In order to study this phenomenon more fully it was proposed that water samples be collected from these various features. Rainwater and snow samples were collected to determine if there was any external supply of ions to the area. Water samples were also taken from lakes, streams, and drainage seeps in order to observe any changes in the ion content at different locations.

Drainage samples were collected from the base of the talus surrounding South Plateau. Water samples were also collected from snow, rainwater, lakes and streams. Water samples were taken from the surface of a Meadow Tundra Soil (see chapter IV for profile description) at two-day intervals over a period of ten days. Samples from the talus, lakes and streams were stored in glass bottles (Fisher Laboratory Supplies item number 3-378) or glass vials (Fisher Laboratory Supplies item number 14-207) while the other drainage samples were stored in 6 ounce polyethylene bottles (Canlab. Laboratory Equipment item number 7534-6). These were then analyzed for chloride, calcium, magnesium and nitrate ions and pH. Unfortunately, conditions in the field did not warrant

FIGURE 2. Locations of water samples within the study area.



using the Orion Specific ion Metre (Model 407) resulting in the samples being analyzed in the Pedology Laboratory at McMaster. X-ray diffraction of clay minerals was undertaken to determine if there was any chemical alteration of these clays. The method used was that outlined by R. Vemuri (1967).

Precipitation Samples

Several samples of snow, nevé, and rainwater were collected at the beginning of the study period in order to determine the ion concentrations of the precipitation and its influence on the drainage waters. The locations of these samples are shown in figure 2 with their analytical results listed in Table 3 .

TABLE 3

PRECIPITATION SAMPLES

Sample	pH	Ca^{++} (ppm)	Mg^{++} (ppm)	Cl^- (ppm)	$NO3^-$ (ppm)
Snow Melt 1	7.40	60	5.67	12	<6.2
Snow Melt 2	7.25	40	7.10	13	<6.2
Snow Melt 3	6.95	40	7.57	18	<6.2
Nevé	7.65	40	2.69	2	<6.2
Ice under Nevé	6.70	40	1.08	3	<6.2
Rain water	6.70	40	2.07	13	<6.2

These results illustrate that the measured ions in the precipitation are at extremely low levels. Although the ion concentrations are low there is some indication that the sea has some influence in supplying these ions possibly by winds carrying spray onshore. This mechanism of sea spray entry into the air appears to lie in the bursting of small bubbles at the sea surface (Gorham, 1955). Upon collapse, these bubbles form jets which eject minute droplets of sea water into the air where if sufficiently small, they may be carried away by the wind. Gorham (1958) noted that most of the chloride in rainwater comes from sea spray. No average figures for the pH of rainwater in arctic areas could be found on which to compare the pH figures in this study. However, assuming that the rainwater of this area has absorbed its capacity of CO_2, the pH should be between 5 and 6. Since the above pH values show a near neutral pH, it is possible that the sea spray has some influence in supplying ions to the surrounding area.

Drainage Samples Surrounding South Plateau

Two sets of samples were collected from the seepage along stone stripes at the foot of the scarp bounding the South Plateau. These were sampled at an interval of approximately one week and the intention was to ascertain whether or not such seepage samples contained high amounts of dissolved ions. The weather conditions during the first period were rainy and before the second period were dry and sunny. Hence the possibility of different contents of dissolved ions under different weather conditions could be assessed. The first set of samples was collected during a very wet period (August 9) and it was believed that these samples were in fact precipitation or late snow melt and would not truly represent the chemical weathering of the plateau. Thus after a dry period of 10 days, drainage sites were resampled (August 18) between the stream on the east side of South Plateau and the stream emerging from the northwest sector of South plateau.

Samples T1 to T11 were located at the base of the scarp to the west of the stream flowing northwest from the South Plateau. Samples T63 to T68 were collected from seeps south of the stream flowing eastward from South Plateau. No samples were collected from these seeps during the second set of sampling. As a result these will be omitted from further discussion.

Samples T12 to T22 were collected from seeps fed by a large snowbank. Samples T23 to T25 were from gentle flowing seeps to the east of the above snowbank, These were extremely silty and had large quantities of algae. Samples T26 to T28 were fed from a smaller snowbank. Samples T29 to T33 were located at the northeast section at the base of the plateau around a large solifluction lobe which seems to be stationary. Samples T34 to T37 were from seeps with very little flow. Grass cover was present in all these seeps with seeps T34 and T35 being completely grass-covered. Sample T38 was fed by melt-water from a small snowbank. Samples T39 to T45 were from seeps surrounding a talus cone. Samples T46 to T49 were fed by snowmelt from a snowpatch between the above talus cone and another to the south. Samples T50 to T52 were fed from the base of this second talus cone while samples T53 to T57 were fed by a snowpatch between the second cone and a third talus cone to the south. Sample T58 was collected from a deep rill to the south of the third talus cone. Sample T59 was fed by a small snowbank to the south of the talus cone while samples T60 and T61 were collected from stone stripes near the east flowing stream from South Plateau. Sample T62 was taken from the raised beach material near the scarp to the north of the east-flowing stream. For a more exact location of the above three talus cones one is referred to terrain unit 9a in the terrain map of chapter III. The analytical results of these samples are presented in Table 3 and their general locations are displayed in figure 2 .

The nitrate ion concentrations of the scarp seeps were too low to be determined using the specific ion metre.

Thus this aspect has been omitted from further discussion. During the second set of sampling many of the seeps not derived from snowbanks possessed no surface flow.

TABLE 4

ANALYTICAL RESULTS OF THE SCARP DRAINAGE SEEPS

Sample No.	pH		Ca^{++} ppm.		Mg^{++} ppm.		Cl^{-} ppm.	
	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2
T1	7.95		56		6.04		15	
T2	8.00		52		8.78		17	
T3a	8.20		48		2.73		7	
T3b	8.10		40		2.72		6	
T4	8.20		48		9.05		12	
T5	8.25		52		9.93		13	
T6	8.15		44		4.36		10	
T7	8.20		40		5.08		5	
T8	8.05		52		8.11		9	
T9	8.10		52		7.77		7	
T10	8.05		56		6.51		5	
T11	8.10		52		5.68		6	
T12	8.10	6.95	44	60	3.28	9.36	5	8
T13	8.15	7.20	40	48	4.58	7.95	5	6
T14	8.15	6.90	48	44	4.56	6.62	6	8
T15	8.20	7.25	44	40	4.95	7.76	6	5
T16	8.05	7.10	48	40	6.72	6.35	8	10
T17	8.15	7.40	48	40	5.71	5.94	8	4
T18	7.90	7.55	44	40	3.93	6.27	4	4
T19	8.05	6.90	48	44	6.69	7.06	9	10
T20	8.05	7.15	48	36	5.95	3.31	6	7

TABLE 4 (contd.)

Sample No.	pH Set 1	pH Set 2	Ca^{++} Set 1	Ca^{++} Set 2	Mg^{++} Set 1	Mg^{++} Set 2	Cl^{-} Set 1	Cl^{-} Set 2
T21	7.95	7.40	44	44	4.60	7.61	6	9
T22	7.95	6.90	40	52	3.66	8.67	6	10
T23	7.85	7.30	40	52	3.59	8.86	7	10
T24	8.05	7.35	40	52	3.97	7.61	8	11
T25	8.00	7.15	40	52	4.02	7.60	15	7
T26	7.85	7.45	48	56	5.02	9.07	9	8
T27	8.05	7.15	48	48	6.67	8.35	6	7
T28	7.95	6.80	48	40	6.17	4.05	5	6
T29	8.00	6.95	52	52	5.82	6.20	6	8
T30	7.95	7.15	52	56	5.35	7.59	6	7
T31	7.85	7.25	52	76	2.87	8.39	4	15
T32	7.90	7.45	44	72	5.58	9.52	5	12
T33	8.05	6.95	48	48	5.86	5.94	8	8
T34	7.95	7.85	48	40	4.58	5.59	6	6
T35	7.95	8.00	52	48	5.90	8.74	9	10
T36	8.15	7.35	52	48	6.67	7.66	8	10
T37	7.95	7.40	52	56	6.13	8.59	8	9
T38	8.05	7.60	48	48	6.33	7.64	7	9
T39	8.05	7.65	44	48	7.59	9.58	8	14
T40	7.95	7.40	52	68	6.46	10.29	8	8
T41	7.95	7.95	48	76	7.79	10.21	8	9
T42	7.95	7.75	48	60	7.12	7.37	8	10
T43	7.95	6.90	52	52	7.25	7.95	8	12
T44	8.10	7.40	48	52	6.50	8.66	8	12

TABLE 4 (contd.)

Sample No.	pH		Ca^{++}		Mg^{++}		Cl^{-}	
	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2
T45	7.95	7.85	52	60	8.64	9.24	9	12
T46	8.10	7.30	52	52	8.96	9.12	9	11
T47	8.05	7.70	48	48	8.89	8.49	9	8
T48	8.05	7.45	52	56	9.43	9.61	10	12
T49	7.95	7.55	48	40	6.64	7.08	7	6
T50	7.80	7.55	44	40	8.15	8.27	7	6
T51	7.90	7.65	48	40	8.15	3.47	8	4
T52	8.05	7.30	48	44	9.60	9.52	9	11
T53	8.05	7.15	48	48	9.45	10.36	9	11
T54	8.05	7.75	48	48	9.32	9.95	10	10
T55	8.10	7.55	44	48	8.52	10.02	10	9
T56	8.05	7.65	44	44	9.68	9.67	11	10
T57	8.00	7.70	44	44	7.78	8.35	8	6
T58	7.95	7.70	44	40	8.61	7.94	10	5
T59	8.00	7.65	48	44	9.37	8.90	11	10
T60	7.95	7.90	52	44	10.06	9.79	13	15
T61	8.15	7.90	52	48	8.44	7.78	12	9
T62	8.05	7.65	52	48	7.63	8.26	12	11
T63	7.95		64		9.61		31	
T64	7.75		76		10.53		46	
T65	7.85		68		7.06		13	
T66	7.75		56		7.92		16	
T67	7.75		64		9.16		26	
T68	7.95		56		8.36		18	

However, it was noted that there was still some moisture movement at depth.

These scarp samples have been grouped into 3 classes: a) those seeps fed by snowmelt b) those samples supplied with moisture from the talus and c) those seeps percolating through organic matter or that have algae in the water. Table 5 shows the mean values of the two sets of readings for each of these classes.

TABLE 5.

MEAN RESULTS FOR THE THREE CLASSES OF SEEPS

	pH		Ca^{++}(ppm.)		Mg^{++}(ppm.)		Cl^-(ppm.)	
	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2
Talus Source	7.97	7.49	49.05	53.89	7.24	8.21	8.26	9.89
Snow Bank	8.04	7.31	46.50	46.17	6.56	7.86	7.46	8.08
Organic Matter	7.99	7.49	46.29	49.71	4.98	7.81	7.29	9.00

The averages of the three classes show that generally there is an increase in the ion concentration and a decrease in pH in the second set of samples. The talus and organic matter samples showed the greatest fluctuation while the samples fed by snowmelt show the least although the pH of the latter showed the greatest decrease. This would indicate that the snowbank moisture although decreasing in amount because of the decreased volume of the remaining snow, is still the dominant supply to these seeps. The greater increase in ion concentrations of those samples from the organic matter seeps and the talus seeps would indicate that their supply during the first set of sample collection was derived from precipitation runoff from the South Plateau. The moisture supplied to these two classes of seeps during the second set of sampling may have derived from permafrost melt either within the talus or in the subsurface of South Plateau and from precipitation which had been retained in the soil material.

Samples from Streams and Lakes

Water samples were also collected from some of the streams and lakes in the area to determine any significant concentration or variability of ions. Figure 2 shows the location of these samples while Table 6 lists their analytical results.

The results illustrate a low nitrate content. This is most likely caused by low water temperatures which prevent the growth of organic matter and the lack of microorganic decomposition to produce nitrate and nitrogen in limnic materials. Samples S1 to S3 show a

TABLE 6

RESULTS OF THE STREAM AND LAKE SAMPLES

Sample	pH	Ca^{++} (ppm)	Mg^{++} (ppm)	Cl^{-} (ppm)	$NO3^{-}$ (ppm)	Date of Sampling
S1	7.70	72	7.57	20	<6.2	August 13
S2	7.85	64	7.14	11	"	August 13
S3	7.75	56	6.59	11	"	August 13
S4	6.75	56	7.76	6	"	August 26
S5	7.40	52	7.64	6	"	August 26
S6	7.45	48	6.32	6	"	August 26
S7	7.30	52	7.67	5	"	August 26
S8	7.55	56	7.96	6	"	August 26
L1	7.90	48	6.13	14	"	August 17
2	7.80	52	7.47	13	"	August 17
3	7.75	68	9.28	16	"	August 17
4	7.90	64	7.79	15	"	August 17

decrease in Ca^{++}, Mg^{++}, and Cl^{-} upstream possibly caused by the addition of ions derived from the leaching of water from the Meadow Tundra Soil in the area adjacent to S2. Samples S4 to S8 show no appreciable differences thus illustrating that mobilisation of Ca^{++} and Mg^{++} must have occured before the water entered the streams. The low pH of S4 may be due to human contamination since the base camp was located on the north bank of this stream.

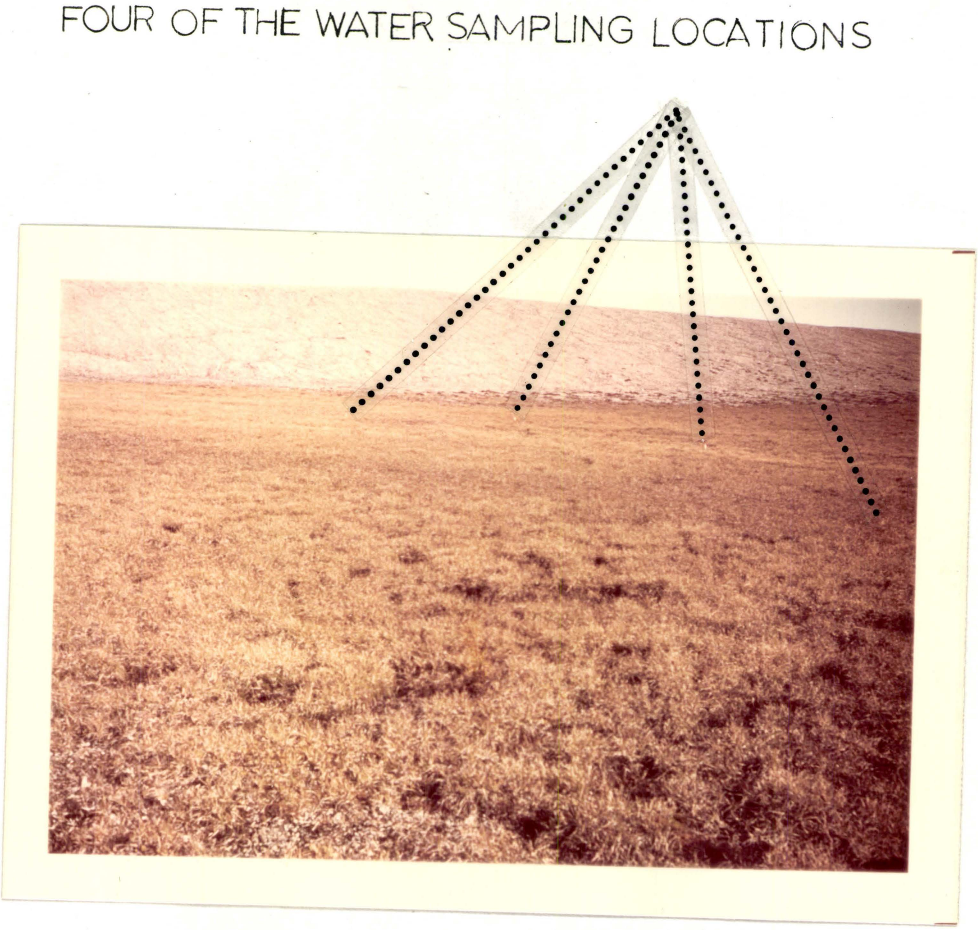


PLATE 2. Meadow Tundra site showing 4 of the water sampling locations and beach ridge in background. The Vertical and Lateral Trenches are to the left out of the photograph. (Location shown in Figure 2).

Very similar conclusions may be drawn from the analyses of lake waters although the chloride ion concentrations are generally higher. No conclusive results can be derived from the above results since the order of magnitude of difference involved in the samples is very low. More samples are needed to prove that the above hypotheses are valid.

Drainage Samples from a Meadow Tundra Soil

In order to determine whether there is immobilization of ions in the more well-developed arctic soils in the area, a site consisting of Meadow Tundra Soil was chosen since it was believed that surface water would be present throughout the study period. Another reason for choosing this site was that the soil displayed a typical soil profile (organic surface layer underlain by mineral material) at its downslope end (Plate 2).

Upslope there was an interjacence from Meadow Tundra Soil to patterened ground rhegosol with less organic matter. It was thought that this transition would be reflected in the change of ion concentrations or that soluble material removed from the upslope rhegosol would travel through the downslope tundra along with laterally seeping soil water. Samples were collected from 9 stations

(Figure 3) at 2-day intervals over a period of ten days. The results for each day are illustrated in Table 7.

A canonical trend surface program was applied to the data. The canonical trend surface chosen (Lee, 1968) is a summarization of area variations of a set of variables from a single population (See Appendix). Using this type of trend, it is possible to reveal the underlying pattern of locational variations common to a set of geochemical variables. The locational coordinates X and Y and their various powers and cross-products constitute one set of variates (V) and the P_2 geochemical variates (U) constitute the second set. The function of canonical trend analysis is to find one linear combination for the (X,Y) coordinates and one for U such that these two linear combinations have a maximum correlation.

The canonical trend surface will show the nature of variations of any number or any type of geochemical variate if they can be amalgamated into a linear function. If the result shows a low canonical correlation it is possible that correlations do not exist between the variates no matter what types of linear combinations are used (Lee, 1969). Lee is convinced that the canonical trend analysis is an adequate technique to evaluate a trend common to a set of variates in preliminary and

FIGURE 3. Locations of the 9 sample sites of the Meadow Tundra area.

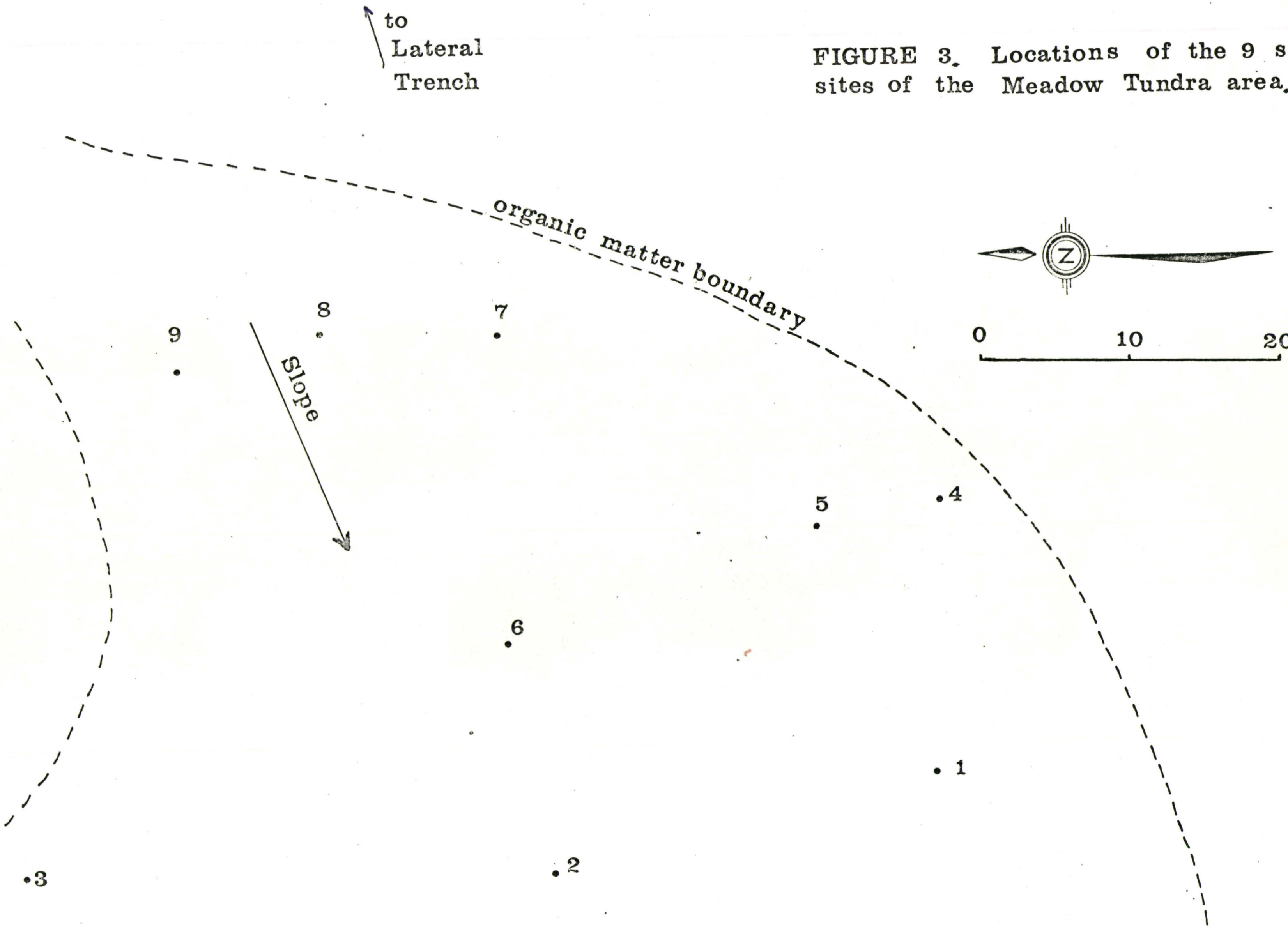


TABLE 7

ANALYTICAL RESULTS OF THE NINE SAMPLE SITES OF THE MEADOW TUNDRA SOIL

Sample Site	pH	Ca^{++} ppm.	Mg^{++} ppm.	Cl^{-} ppm.	$NO3^{-}$ ppm.
Day 1					
1	7.45	84	8.04	40	38.4
2	7.65	56	6.18	13	21.7
3	7.40	52	7.06	20	6.8
4	7.75	68	8.09	19	<6.2
5	8.05	64	7.56	20	"
6	6.95	52	6.49	11	"
7	7.30	48	6.58	12	"
8	7.00	40	4.66	8	"
9	6.66	40	6.23	13	"
Day 2					
1	7.15	60	9.18	17	<6.2
2	7.10	64	7.39	11	"
3	6.90	64	7.86	21	"
4	7.15	76	9.18	20	6.8
5	7.15	76	8.31	21	<6.2
6	7.10	64	6.77	16	15.5
7	6.95	60	9.23	14	9.3
8	6.90	80	5.61	12	68.2
9	7.65	60	7.31	20	9.9
Day 3					
1	7.15	80	9.29	19	<6.2
2	7.10	68	6.94	13	"
3	6.95	88	9.48	17	"
4	6.95	120	9.95	19	"

TABLE 7 (contd.)

Sample Site	pH	Ca^{++}	Mg^{++}	Cl^-	NO_3^-
Day 3					
5	7.55	104	8.51	22	<6.2
6	6.90	76	7.90	23	"
7	7.45	84	9.42	16	6.8
8	6.30	80	6.72	16	<6.2
9	6.85	76	7.99	18	"
Day 4					
1	6.90	88	8.72	21	<6.2
2	7.00	76	6.88	16	"
3	7.70	72	7.57	19	"
4	6.95	88	9.14	20	"
5	7.70	84	8.08	23	<6.2
6	7.35	72	7.78	22	"
7	7.20	160	10.10	17	"
8	7.55	100	6.52	18	"
9	7.05	104	9.01	22	
Day 5					
1	7.05	108	8.67	25	<6.2
2	7.15	76	8.43	17	"
3	7.35	108	8.68	20	"
4	7.30	140	10.18	22	24.2
5	7.65	108	8.07	25	6.8
6	6.75	88	8.38	22	<6.2
7	7.10	168	10.31	26	"
8	7.10	208	7.14	20	"
9	7.90	96	7.65	22	"

concept-formation stages or research as part of a data reduction scheme.

It was believed that applying the above trend surface program to the analyses of the sets of data for each day (Table 7) would show any change in the supply of free ions by changing the resulting trend. As illustrated in the table, the parameters were:

A) chloride ion (ppm)
B) calcium ion (ppm)
c) pH
d) NO_3 (ppm)
E) Magnesium (ppm)

The computer output gives several canonical roots which represent the probability of a significant association between the two sets of variables. Only the first two roots are considered since the smaller canonical roots show different linear functions of the variates and as such are contradictory to the first two (Lee, 1968). The first two roots have a higher probability of approximating real trends whereas the interpretation of smaller canonical roots may be confused by local variations.

The trend for the data of the first day had a canonical root of .9939 (1% probability that the resulting trend is due to chance) with associated canonical variates of:

$$U = -.322Cl^- + .930\ Ca^{++} - .079pH + .150\ NO_3^-$$
$$- .051\ Mg^{++}$$

and $V = .6543\ X - .7652Y$

Since the second canonical root (.5152) was too low to be significant, it was discarded. The first canonical root explained variations of the calcium and chloride ions (Fig. 4)

The resulting trend of the data for the second day had a canonical root of 1.00 (0% probability that the resulting trend was due to chance) with the following equation:

$$U = -.305Cl^- + .531Ca^{++} - .017pH - .031NO_3^-$$
$$+ .790\ Mg^{++}$$

and $V = -.0190\ X - .9950Y + .0051X^2\ X\ .0376\ XY + .0902Y^2$

This canonical trend explained variations of the calcium, chloride and magnesium ions (Fig. 5). Since the second canonical root was also 1.000, Dacey's test for contiguity (Dacey, 1968) was applied to the residual maps for the two canonical roots. The first canonical root was significant but the second was not significant and was not considered.

The trend for the data of day 3 had a canonical root of 1.000 (zero% probability that the resulting trend was due to chance). Its associated equations were:

$$U = .420Cl^- + .599Ca^{++} + .020pH - .403NO_3^-$$
$$+ .550\ Mg^{++}$$

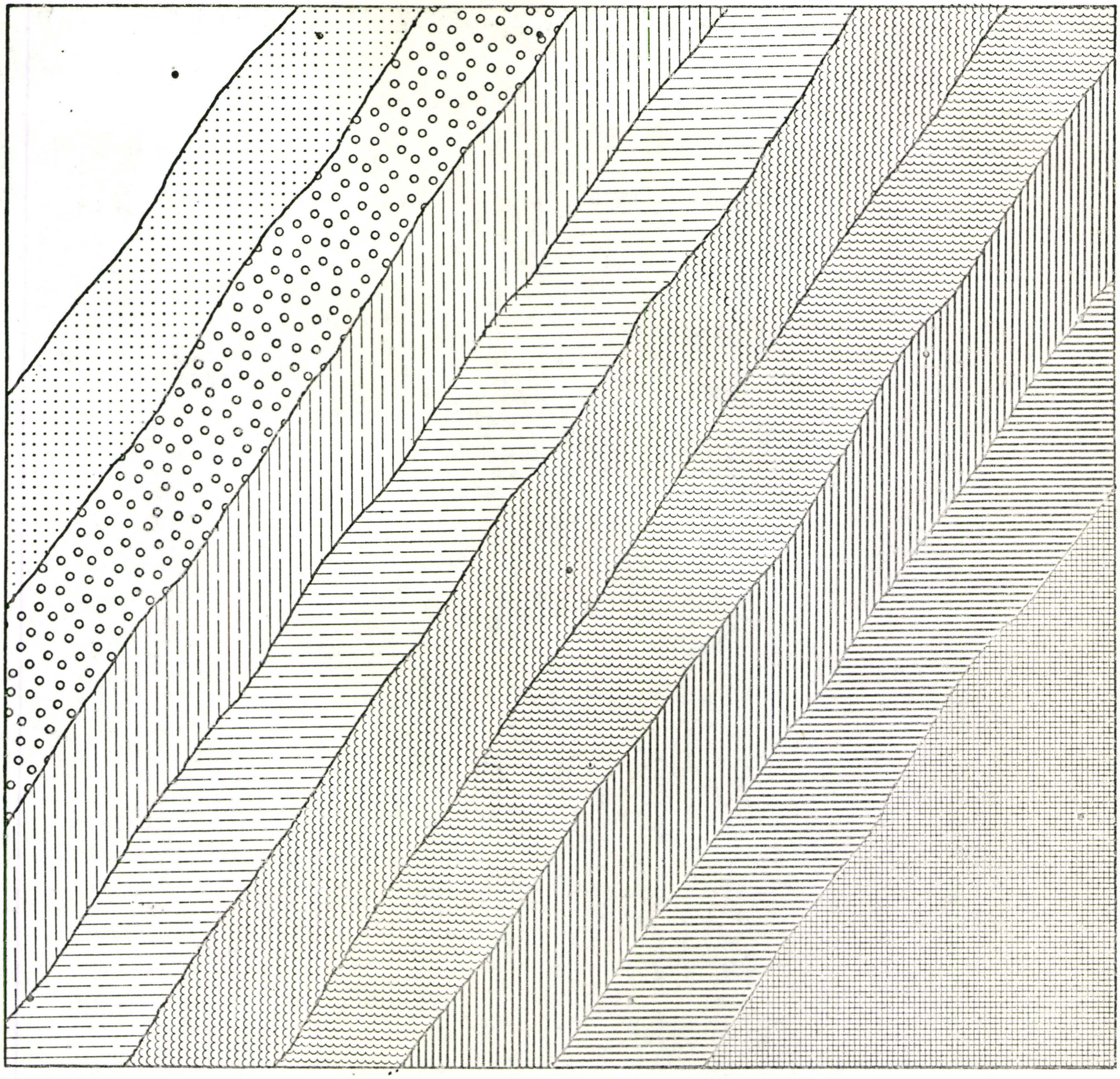
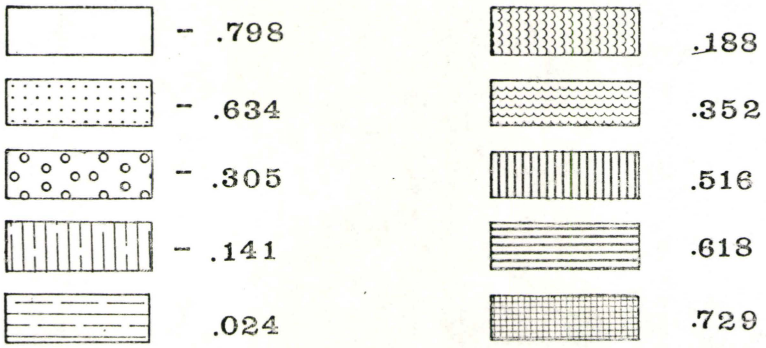


FIGURE 4. Trend Surface pattern of the data for day 1 (canonical root of .9939 - distorted scale).



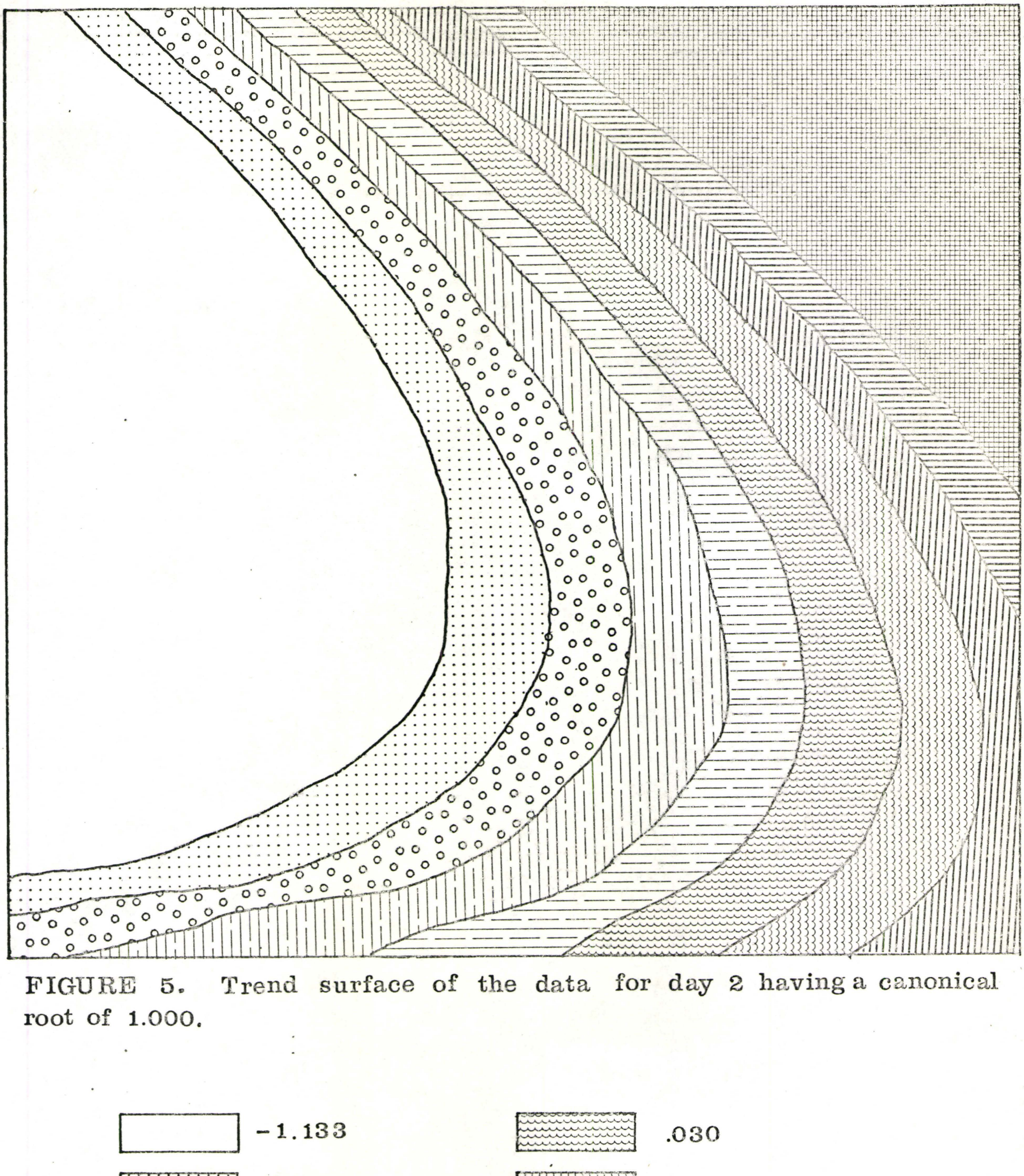
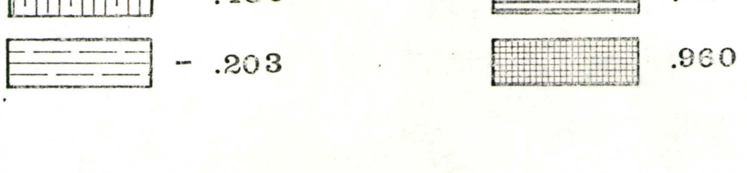


FIGURE 5. Trend surface of the data for day 2 having a canonical root of 1.000.



and $V = -.5971X + .7943Y + .0327X^2 + .0320XY - .1020Y^2$. The variations of all the variables but pH were explained by this canonical root (Fig. 6). Since the second canonical root was 1.000, Dacey's test was again applied to the residuals of both canonical roots. The test also showed that the first canonical root was significant but the second was not.

The day 4 trend illustrated a canonical root of 1.000 (0% probability that the resulting trend was due to chance). Its equations were:

$$U = .589Cl^- + .495Ca^{++} - .359pH - .060NO_3^- - .525Mg^{++}$$

and $V = .0844X + .9930Y + .0057X^2 - .0488XY - .0670Y^2$

The canonical root of the second trend was also 1.000. Dacey's test for contiguity showed that this was not significant. The trend of the first canonical root was explained by the variates Ca, Cl, Mg and pH (Fig. 7).

The results for Day 5 also had two canonical roots of 1.000. Dacey's test illustrated that only the second canonical root was significant. Its equations were:

$$U = .264Cl^- + .714Ca^{++} + .520pH + .370NO_3^- + .110Mg^{++}$$

and $V = -.6942X - .7096Y + .0499X^2 + .0302XY + .1050Y^2$

Its trend (Fig. 8) was explained by the variates Ca, pH and NO_3. Little was contributed to the trend by Cl and Mg.

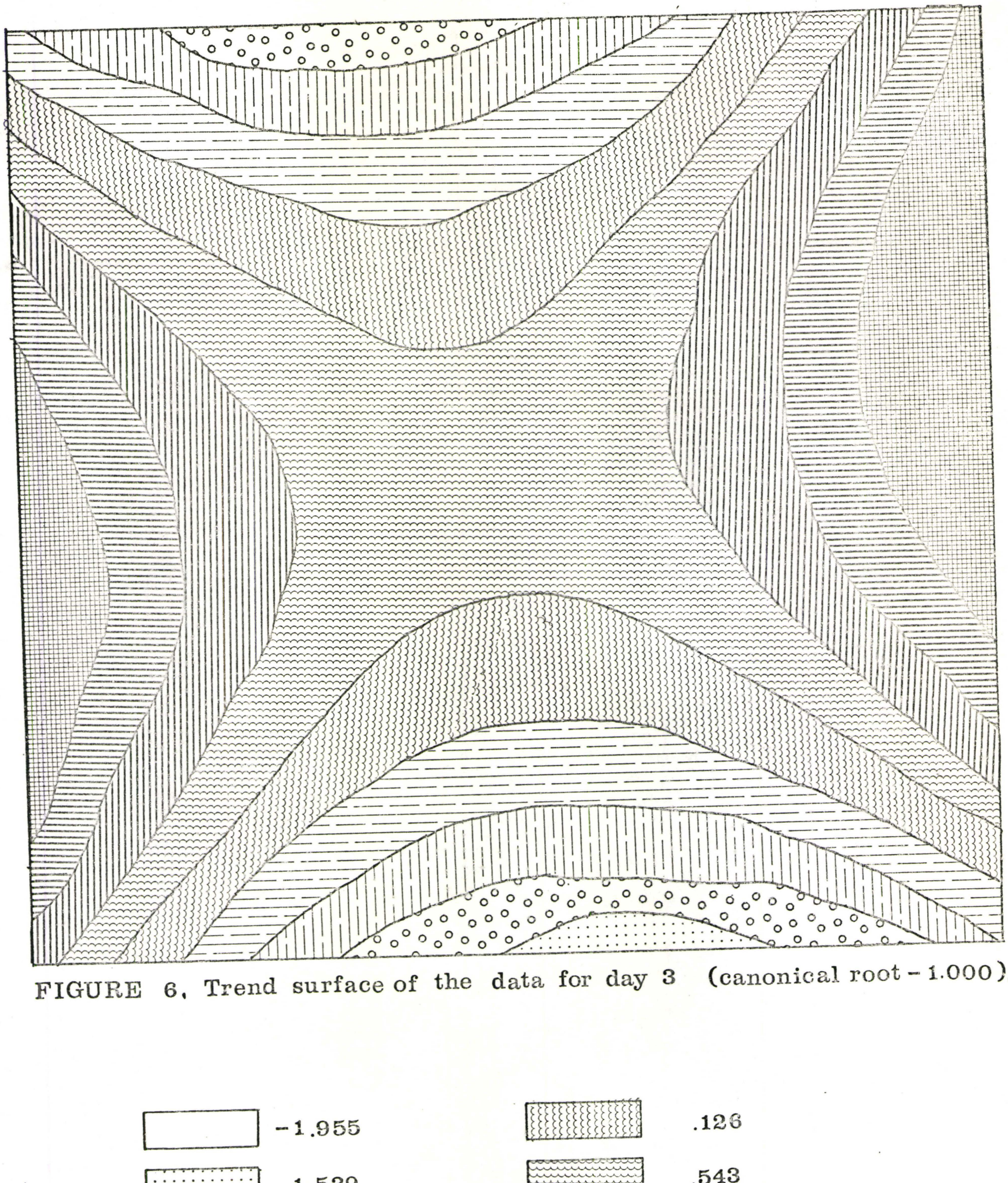
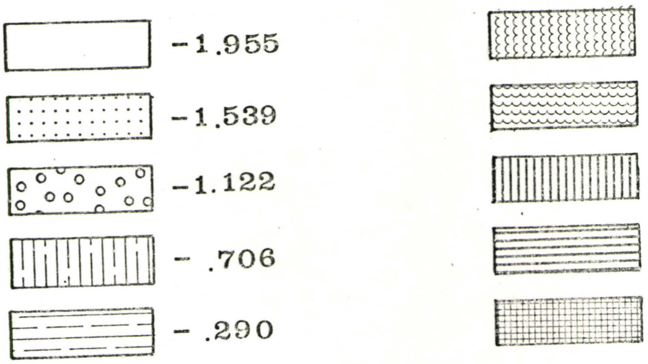


FIGURE 6. Trend surface of the data for day 3 (canonical root - 1.000).



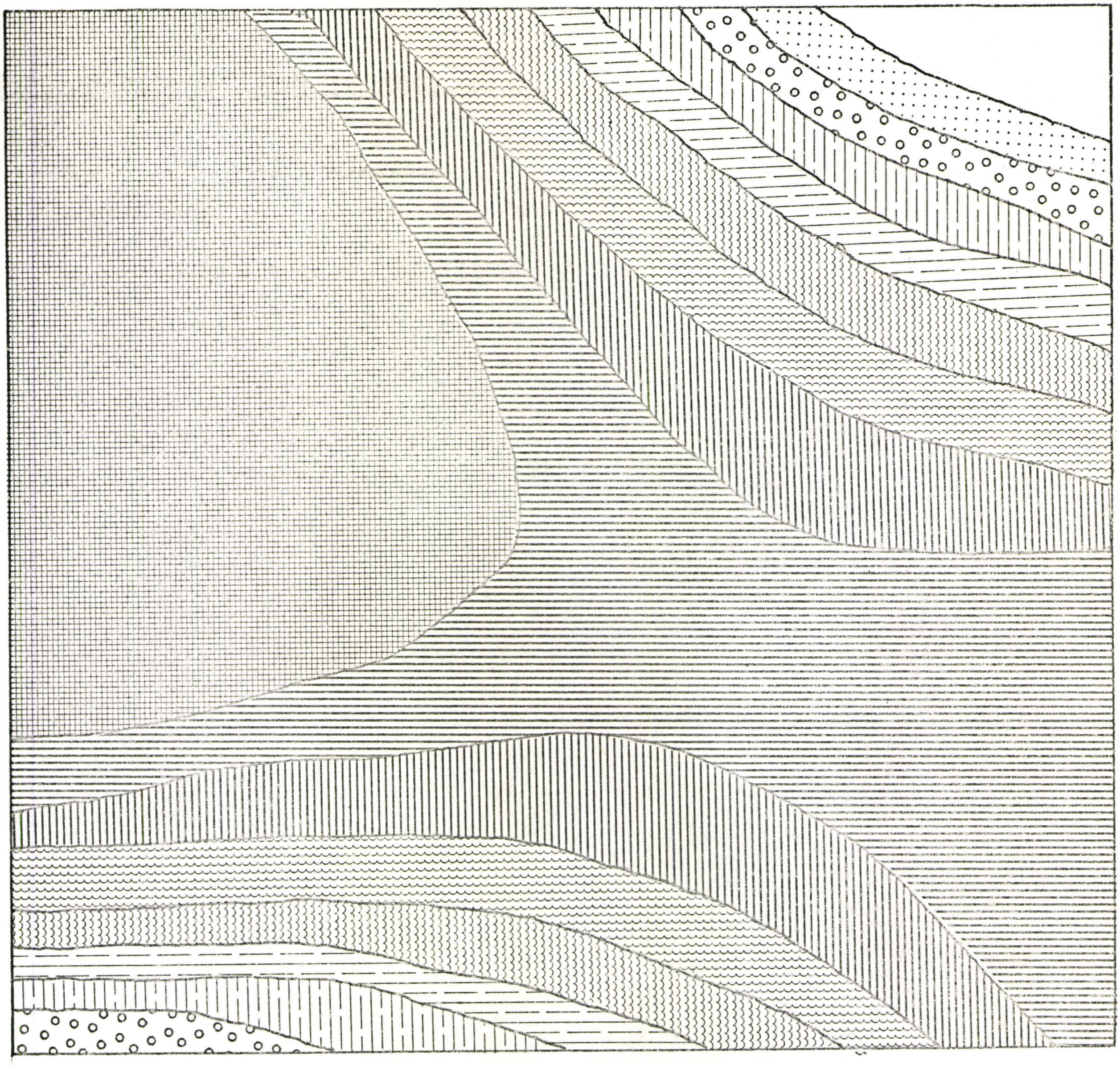
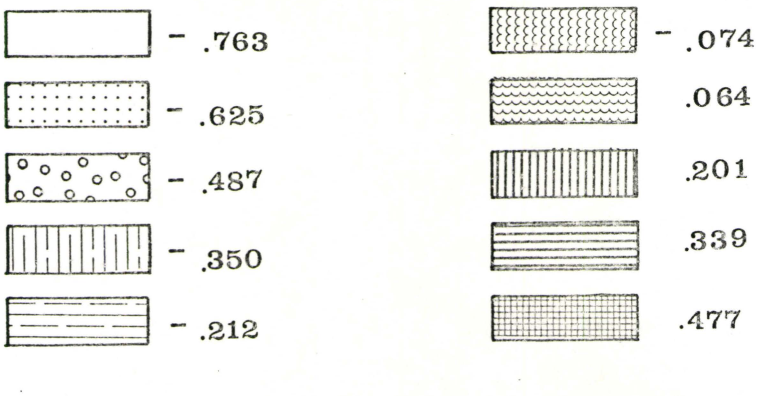


FIGURE 7. Trend surface of the data for day 4 (canonical root of 1.000).



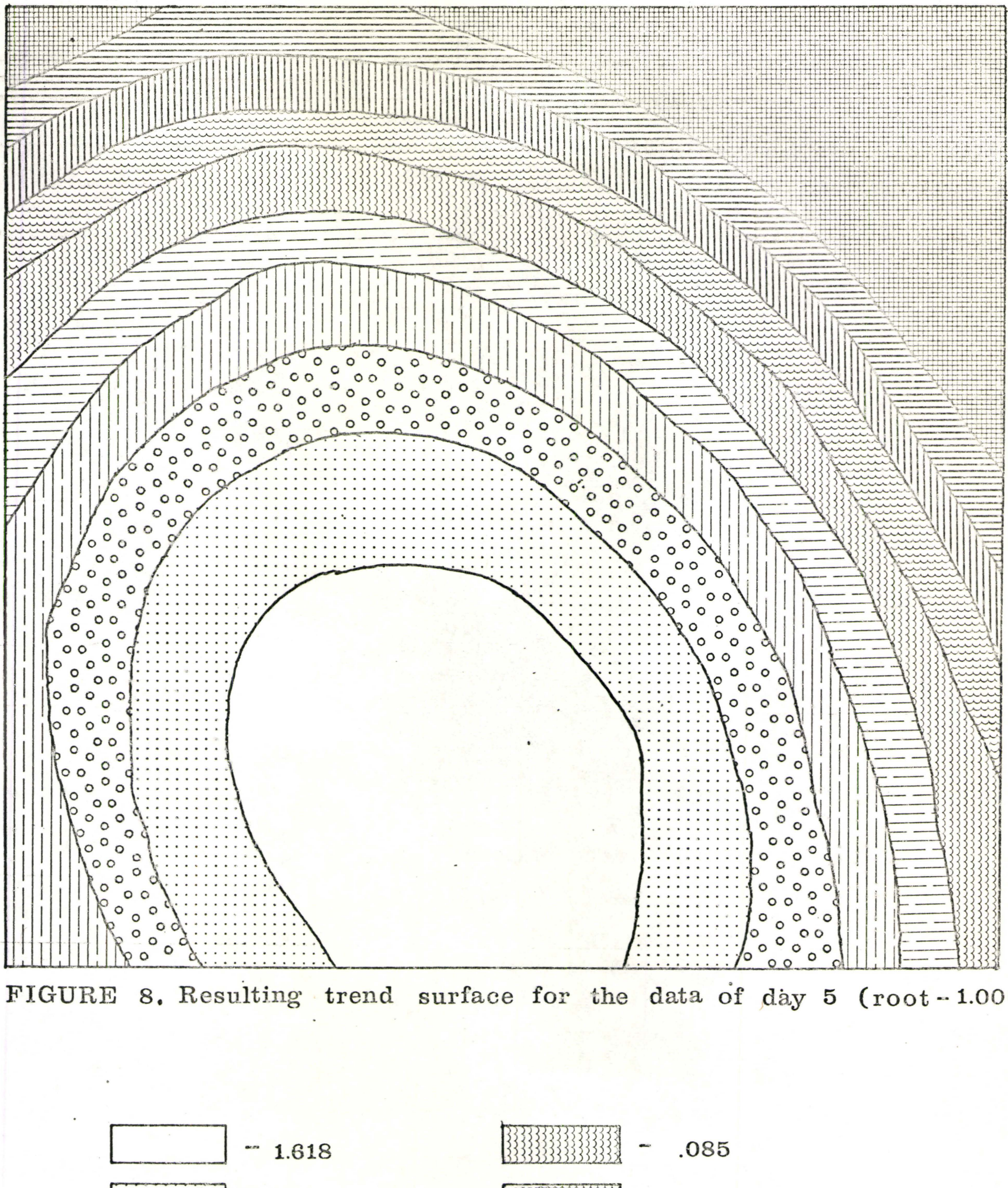
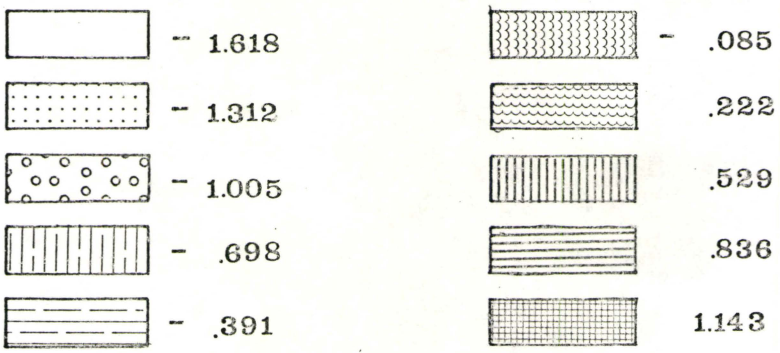


FIGURE 8. Resulting trend surface for the data of day 5 (root - 1.000).



Before discussing the results further, the validity of the results should be mentioned. Lee (1967) notes that too few samples in the trend could produce unreliable results. Canonical roots of 1.000 indicate either perfect correlations or too few sample points. In this particular case the canonical roots might imply too few samples for the trend. Thus Dacey's test for contiguity was applied, as mentioned above to the residual maps to determine the significance of the trends. Although the above trends are significant, the small number of samples (9) has influenced the results by producing trends with perfect canonical roots. Thus only relative comparisons of the trends can be made.

The only contributing variate common to all the trends was calcium. This is most likely a result of the larger variation of the calcium ion than the variations in the other variates. The fact that the NO_3 ion does not contribute to the trends of day 3 and day 4 is a result of the almost constant value of the nitrate ion on these days.

The trend of day 1 shows a very low area in the upper left sector which increases diagonally to a maximum in the lower right hand sector (Fig. 4). The day 2 trend shows a translocation of this low area to the centre left of the trend. The maximum high area in the lower right has been totally removed from the trend with a new maximum beginning in the upper right sector. The trend has now changed from a diagonal to a semicircle in the left of the trend (Fig. 5).

The trend of day 3 now illustrates that the low area has been moved down and to the right from the trend of day 2. The high value in the upper right of trend 2 has now moved down and to the right. A new high has appeared in the left centre sector with another low beginning to appear in the upper centre of the trend. The resulting pattern shows a "saddle" shape (Fig. 6).

The day 4 trend shows a shift of the saddle towards the lower right of the trend. The high in the left sector of the day 3 trend has now moved towards the centre with the low value in the upper centre of the trend for day 3 now shifted downward and to the right. A new low is beginning to appear in the lower left sector (Fig. 7).

The trend for day 5 shows a lateral movement across the study area. The low value which started to appear in the lower left sector of the trend for day 4 is now in the centre of the trend. The high value has moved across so that it occupies the upper right sector in the trend for day 5 (Figure 8).

The results of the above trends would indicate that the movement of ions is from the upper left of the study area (sample site 9) to the bottom right (sample site 1) although the trend for day 5 shows a lateral movement. Assuming the drainage waters derive from snowmelt upslope, their chemical weathering capacity is relatively low and their rate of movement over and through the Meadow Tundra Soil may be too rapid to allow a maximum exchange of ions for their weathering capacity. This would explain in part why the Meadow Tundra Soil does not show an increase of free ions downslope in each trend. Since most of this drainage is on the surface the organic matter may also prevent the interaction of the soil mineral material and the water. The above results at least serve to show that Ca^{++} in ionic form, is liberated from upslope mineral surfaces and a wave of leaching passes laterally through downslope organic materials to the stream.

Clay Minerals

X ray diffraction of clay minerals was employed as a method of detection of any further chemical weathering. The method used was a semi-quantitative analysis of clay minerals by x-ray diffraction (Vemuri, 1967). Six Samples were used in the analysis: two were from the argillaceous bedrock containing 10% quartz and clays: two samples were from the silty material within two drainage seeps (T2 and T23 noted in the earlier section of this chapter) at the base of the South Plateau scarp and two samples were from the soil-like material on the plain to the left of the Meadow Tundra area (see terrain unit 3 and figure 7 in Chapter III).

The argillaceous limestone samples contained the clay minerals chlorite, kaolinite, illite, mica and quartz. An extremely high peak of calcite was also present but this resulted from the inadequacy of acetic acid in removing a large amount of calcite from the sample. The same clay minerals in approximately the same proportions were present in the silty material from the drainage seeps and the silt plain soil as well but no other minerals were observed. No calcite was present in the latter two sets of samples since it had been removed by acetic acid.

The above results would indicate that there is no observable clay mineral alteration or weathering during any of the transportation processes in this area. However the amount of quartz in these samples (approximately 30%) poses an interesting aspect of the nature of chemical weathering in the area. The argillaceous limestone bedrock contains 8% quartz and 2% clays.

In order to produce the amount of clay in the soils (see Chapter IV for the % clay in the soil profiles) a large amount of chemical weathering of the limestone bedrock and from the surface debris must have taken place by the well-known mechanisms shown in the following chemical equations:

$$CaCO_3 + H_2O + CO_2 \quad Ca(HCO_3)_2$$

$$Ca(HCO_3)_2 \quad Ca^{++} + 2HCO_3^-$$

Hence solution over a long period of time is necessary. Carbonic acid is formed in precipitation by its absorption of carbon dioxide. The source of a large volume of CO2 is not present since there is very little vegetation. Thus in order to obtain this large amount of clay and quartz from the bedrock and loose surface material a long time interval is needed. To support this view a large number of limestone pebbles on the terrain surface illustrated the chemical solution of carbonates on their exposed surfaces with redeposition of calcareous efflorescences on their undersides.

If weathering of the chlorite clay was present, the chloride in the water samples could be a result of this weathering. However, since there is no evidence of chlorite weathering, the chloride present in the water samples must originate from sea spray. To further substantiate this, two sea-water samples were analyzed for chloride. One showed a Cl^- content of 8800 ppm. while the other sample contained 9400 pmm. chloride.

Conclusions

Chemical weathering in the study area is low with Ca^{++} being the only ion to show significant solution weathering. The drainage seeps which are dominantly supplied by snowmelt at the base of the South Plateau scarp show almost constant concentrations of the measured ions. The drainage seeps supplied by moisture from the talus and those seeps containing organic matter show an increase of ions after a one-week interval of no precipitation indicating that the moisture supply may be derived from permafrost melt and retained rainwater after the precipitation has ceased.

Water samples collected at various locations from one stream system show that there is no observable increase in ion concentrations downstream indicating that the mobilization of calcium and magnesuim ions occurred before the water entered the streams. The study of a Meadow Tundra area showed that Ca^{++} ions were liberated from upslope mineral surfaces and passed laterally through the organic matter to the stream downslope. Samples collected from this stream showed an increase in ion at and downstream from this Meadow Tundra area.

Bedrock and transported sediment show no differences in either the kind or the amount of their clay mineral contents indicating that the chemical weathering of these clays is extremely low. In order to produce the larger amount of quartz in the transported clay than in the source bedrock, a large amount of calcite must have been removed either from the bedrock or from the transported sediment.

From sea water and precipitation sample results it is concluded that there is some supply of ions (particularly chloride ions) from the sea possibly in the form of air-born sea spray.

CHAPTER III

THE TERRAIN MAP OF THE STUDY AREA

The terrain map (Figure 7) serves as a method of portraying the positions of the terrain units within the study area as well as an introduction to their profile descriptions and analytical results.

The amount of detail which can be presented in a terrain map depends largely on the scale of mapping. Vertical aerial photographs (scale 1:13,000) adequately suited to include all details necessary to provide a basis for the explanation and description of the soils of the area are available. Mapping was accomplished in the field directly onto the photographs. The soils and the boundaries of the pedomorphic units were then transferred to a base map drawn from the air photographs which is not corrected for the vertical distortion inherent in these aerial photographs. This base map was then reduced to a scale of 1:18,750. In the course of soil mapping, representative soil profiles of the various terrain units were collected, described and analyzed.

The study area is divided into three major terrain sectors: a) the Coastal Lowland; b) the South Plateau, and

c) Caswell Tower.

The following are the terrain units delimited in the lowland area:

1) Present Beach area: This is an active beach zone comprising a narrow band stretching for 5 to 10 metres inland and surrounding the peninsula.

2) Raised Beaches: The raised beach zone is adjacent to the active beach area. This terrain unit is 20 to 50 metres in height and 200 to 300 metres in breadth. However the northern sector of the study area is almost entirely raised beach material. This terrain unit has, in some cases, been divided into a) raised beaches with polygonal formations and b) raised beaches with stone stripes. The polygonal type is found on flatlying areas with very little slope ($4-6^{\circ}$) whereas the stone stripe variety is located on steeper slopes (7°).

3) Silt Plain: This terrain unit may be classed provisionally as an Arctic Brown Soil. Buried peat is present at 10" depth with permafrost just beneath this layer.

4) Meadow Tundra Soil: The Meadow Tundra terrain unit has a surface organic layer 5 to 8 centimetres thick. It is located in low-lying areas with very poor drainage. Marine shell particles are common throughout the mineral material underlying the organic layer.

5) Palsa Peat: Palsa peat occurs only in two locations in the area. These are characterized by a 10 inch layer of peat overlying ice lenses and have diameters of 7 feet with vertical heights of 2.5 to 3 feet.

6) Discontinuous Gravels Over Fines: This terrain unit consists of gravels overlying silt or fines. Although this was not sampled, it tended to have similar surface characteristics to that of terrain unit 3.

7) Stone Stripes With Fines: Stone stripes with fines are located along the base of South Plateau on moderate slopes. These bear some similarity to the second subtype of terrain unit 2.

8) Other Forms of Patterned Ground: Patterned ground is located in low areas with poor drainage. These features range from sorted circles and nets to polygons. Their surfaces show large variations in the amount of organic cover. Some are completely void of organic cover while others have stone borders almost completely covered with vegetation ranging from mosses to carex grasses and Papaver Radicatum.

9) Talus: Talus slopes are located at the base of the cliffs surrounding South Plateau and Caswell Tower as well as on the sides of river valleys. A variation of this -talus cones (9a) are located directly beneath rock funnels cut back along joints in the bedrock.

10) Coarse Fluvial Debris: This material is located in all the stream beds. The material frequently shows forms of braiding and meandering in the study area.

11) Solifluction Lobes: These are located on Cape Ricketts and the northeast sector of the South Plateau.

The following are the decriptions of the terrain units of the South Plateau (the prefix K is used to distinguish these terrain types from those of the coastal lowland.

K1) Angular Gravel with Non-sorted Hummocky Relief: This is located at the Plateau margin and has an angular gravel surface with no vegetation. No patterned ground sorting is observable but there is a hummocky relief.

K2) Small Stone Nets: These consist of small stone nets and hummocks with rounded gravels. Their matrix is composed of moist Silt.

K3) Stone Stripes: This terrain unit is composed of stone stripes with gravelly silt loam between the stripes. Some organic matter was present on the stone stripes.

K4) Dry Loose Gravel: The dry loose gravel surface contains dominantly fine gravel and coarse sand pale yellow in colour. This is slightly hummocky and has numerous calcite concretions on the undersides of some of the surface gravels.

K5) Coarse Stone Nets and Rock Debris: This terrain unit is essentially coarse stone nets and rock debris with sandy loam matrices. The fine gravel and stones are angular in shape. The profile depth is approximately 30 cm.

K6) Sorted Gravels Tending to Stone Stripes: This consists of stone stripes with little vegetation in contrast with terrain unit K3.

K7) Polygonal Patterned Ground: These are polygonal features with coarse stone centres.

K8) Lenticular Gravel Ridges: This terrain unit consists of lenticular gravel ridges with silt covered depressions.

The terrain units of Caswell Tower have very little differentiation in their surface features. The main criteria for designating the three separate terrain units are texture, colour, and depth to bedrock. One profile showed a marked horizon change (CT1 - see profile description in Chapter IV for further details) possibly due to variations in moisture content between the different horizons.

Conclusions

A contrast exists in types of soil and surface features between South Plateau and the coastal lowland. Whereas the coastal lowland is characterized by an extremely complex assemblage of surface conditions, the plateau is somewhat more uniform with soils derived from shattered bedrock or locally transported debris (Plate 3). This is partly a reflection of the geomorphic evolution of the present day landscape. The coastal lowlands are mantled by material with a well-differentiated range of textures such as solifluction, scree, and beach gravels, the silt plain material, and patterned ground. Obviously the plateau has not been affected by marine processes. Instead, the widespread influence of frost action and patterned ground has left marked topographic irregularities and differences in textural composition of the surface material (Plate 4). The almost complete absence of vascular plants resulted in the dominance of mineral soils associated with patterned ground. Within the coastal lowland, the influence of continuous permafrost and numerous depressions resulted in a predominance of poor drainage and accumulation of organic matter.

The distribution of well-drained soils is largely determined by the texture of the substrata, particularly in the raised gravel beaches. Plant cover is very sparse, occurring only in major depressions and around the small lakes located on the marine gravels. The finer products of surface weathering are either blown from the surface where they are not held by vegetation or translocated on or near to the surface by snowmelt and precipitation.

PLATE 3. View of the coastal lowland looking north toward Caswell Tower.

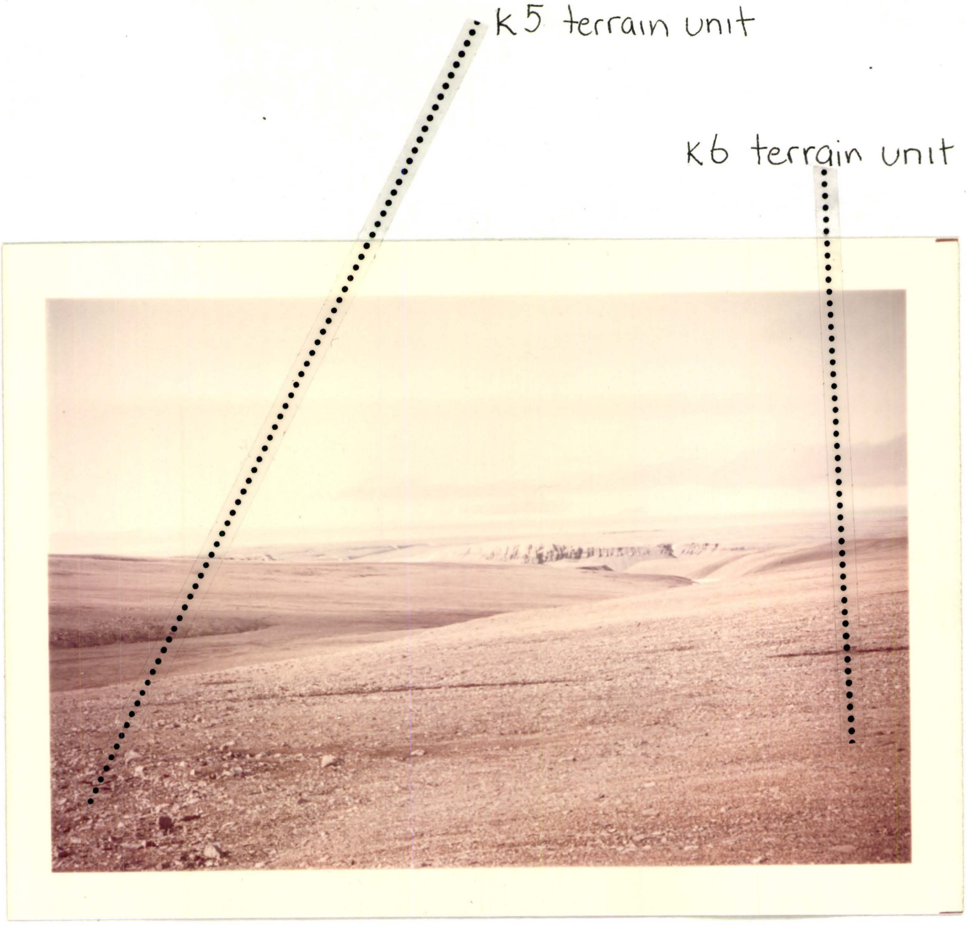


PLATE 4. View of South Plateau looking west toward Gascoyne Inlet and beyond. Terrain unit k6 is in the immediate right foreground. The boundary of k5 is in the lower left of the photograph. (See Figure 7 for location).

Frost-induced soil instability is not as marked on the raised beaches as it is in the saturated soil. However there does appear to be a movement of material from the raised beaches to the lower elevations on the western side of the beach ridges along Radstock Bay (terrain unit 6).

CHAPTER IV

PEDOGENIC PROCESSES AND PROFILE DESCRIPTIONS OF THE TERRAIN UNITS

The terrain map has shown a variety of terrain units associated with the study area. This chapter will describe these terrain units in greater detail as well as their physical and in some cases, their chemical properties. These soils will be classified using the classification proposed by the National Soil Surveys Committee of Canada (1968). In addition to the above observations, the pedogenic processes implied by the analytical data will also be mentioned.

Methods

Samples collected in the field from the above terrain units were placed in air-tight polyethylene bags. In the laboratory, these samples were analyzed for water content, organic matter, texture, bulk density, liquid limit, pH, electrical conductivity, cation exchange capacity, calcium, and alkalinity. Dry and moist soil colours were also determined in the laboratory in most cases.

The source for the methods outlined above was Methods of Soil Analysis (Black et al. 1965) except where mentioned.

Water content of the soil samples was determined gravimetrically by oven-drying the soil at 105°C. The organic matter method was that using hydrogen peroxide and a 1N solution of $MgCl_2$. Texture was determined using the B.S sieves with sizes decreasing to the 200 micron screen diameter. To determine the silt and clay fractions, a pipette apparatus (M.&L. Testing Equipment Co. Model) was used. The textural divisions are as follows:

gravel	>2 mm.
coarse sand	2 mm.-.5 mm.
medium sand	.5 mm.-.2 mm.
fine sand	.2 mm-.05 mm.
coarse silt	.05 mm-.02 mm.
medium silt	.02 mm.-.005 mm.
fine silt	.005 mm.-.002 mm.
clay	<.002 mm.

The soil pH was determined using a soil: water ratio of 1:2.5 and a Fisher Accumet pH meter. Bulk density (gms./C.C.) was derived using the Clod Method. Liquid limit (one of the consistency limits) was determined using a mechanical liquid limit device. Electrical conductivity (mmhos/C.C.), calcium (p.p.m.) and alkalinity (p.p.m.) were determined from the soil leachate (soil: water ratio of 1:5). A conductivity bridge (Yellow Springs Instrument Co. Model 31, 1968) was used to determine the electrical conductivity (mmhos/CC at 25°C). The calcium and alkalinity methods used are those outlined in the U. S. G. S. Water Supply Paper 1454(Rainwater and Thatcher, 1968).

The cation exchange capacity (meq/100 gms) was determined using the Ammonium Acetate Saturation Method.

A representative group of profiles from the plateau and lowland areas were sampled for total sesquioxides. Results indicate that no sesquioxides are present in these soils. Neither ferric nor ferrous minerals were present in the area's bedrock (Chapter I:Geology) which would support the above analytical results.

Description and Origin of the Soil Units

Description and origin of polygonal patterned ground (terrain types 2a and 8) have been omitted from this chapter since the number of samples collected from these features and their treatment warrant a separate chapter (Chapter V). The discussion of the terrain units has been divided into three groups: a) Soils of the coastal lowland b) Soils of the South Plateau and c) Soils of Caswell Tower.

A) Soils of the Lowland Area

Peat Samples

Peat samples from the Meadow Tundra, Palsa and Silt Plain terrain units were treated differently from the mineral samples. Thus these sample results have been placed in Table 8 and will be referred to in the text under their respective profile descriptions.

TABLE 8

PHYSICAL PROPERTIES OF THE PEAT SAMPLES

Sample	Dry Colour	Field Moisture	Saturated Moisture	Bulk Density	Fibre %	Histic Suborder
A) Meadow Tundra	10YR6/3	148	385	.175	69	Hemic
B) Palsa Peat	5YR3/1	66	387	.288	22	Sapric
C) Silt Plain 25-30 cm	5YR4/2	47	525	.180	78	Hemic-Fibric
D) Silt Plain 45-50 cm	10YR5/3	49	398	.125	48	Hemic

Source: Bunting and Hathout, 1970.

1 and 2 Recent Beach and Raised Beach Terrain Units

Samples were not collected from present beach material (Terrain Unit 1) since the probability of having a soil profile typical of a beach is nil. This results from having different sorting processes acting at different points up the beach from the waters edge. Also the water would make excavation and sampling virtually impossible. For a more thorough discussion of this terrain unit, one is referred to the paper of Mc Cann and Owens (1969).

The raised or fossil marine beach (Terrain Unit 2) consists of gravel ridges 200 to 300 metres in breadth and up to 60 metres in height. One can see from the terrain map (figure 9) that the areal distribution of the raised beaches is very extensive. Its profile description follows:

Horizon	Depth	
1	0-5 cm.	light gray when dry (2.5Y7/2) becoming brown (10YR5/3) when wet, gravelly loamy sand with granular structure, no roots and no distinct boundary to:
2	5-10 cm.	light gray (2.5Y7/2) when dry and brown (10YR5/3) when moist, some gravel with a sandy loam matrix, indistinct boundary to:
3	10-20 cm.	same as above with a granular structure, merging to:
4	20-30 cm.	same as above with no structure merging to:
5	30-50 cm.	same colour as above, structureless gravelly sand.

Table 9 illustrates the analytical results of the horizons from the raised beach profile. There is an increase in finer material from 5 to 20 centimetres in depth with an increase in coarse material. Moisture content is also greater at the 5-20 centimetre depth than elsewhere in the profile.

The origin of this beach material is from the cliffs of the South Plateau. Longshore drift followed by isostatic uplift have resulted in this feature being formed. Since this material has no observable pedogenic processes and has not resulted from the in situ weathering of bedrock, it is classed as a Cryic Rhegosol.

Stone stripes and polygons have developed in some areas of the raised beach especially where a large amount of moisture is present in hollows, at changes of slope or on

TABLE 9

PHYSICAL PROPERTIES OF TERRAIN UNIT 2 RAISED BEACH

Sample No.	Depth Cm.	% Mois.	% O.M.	Texture							
				Gravel	C. Sand	M. Sand	F. Sand	C. Silt	M. Silt	F. Silt	Clay
1	0-5	2.9	0.0	67.7	47.4	27.6	12.4	5.1	1.4	0.8	5.6
2	5-10	9.9	0.0	30.4	16.3	19.7	21.1	16.2	12.8	7.8	6.2
3	10-20	8.2	0.0	55.5	35.2	23.8	13.9	8.9	6.8	6.1	5.6
4	20-30	3.4	0.0	72.4	30.2	30.6	15.3	5.8	5.3	5.1	7.7
5	30-50	3.7	0.0	56.0	55.3	21.9	10.4	4.9	2.6	1.8	3.1
6	50-70	5.5	0.0	58.3	41.9	23.4	12.8	6.5	5.4	4.6	5.4

Sample No.	Bulk Density	Liquid Limit	pH
1	1.80	16.7	7.95
2	1.36	17.5	8.10
3	1.21	16.4	7.45
4	1.94	12.8	7.95
5	1.32	10.8	8.65
6	1.97	16.0	8.65

contact areas between two beach ridges of differing age. The polygon features are discussed in Chapter V. Where there is a gradation to a slope on the raised beaches, the polygons tend to form stone stripes. A profile description taken in the centre of the material between these stone stripes follows.

Horizon	Depth	
1	0-10 cm.	light gray (2.5Y7/2) when dry and light brownish gray (10YR6/2) when moist, loam with little gravel, massive compact structure merging to:
2	10-25 cm.	light gray (2.5Y7/2) when dry and pale brown (10YR6/3) when moist, structureless loam merging to:
3	25-50 cm.	same as above with some fine gravel and massive structure.

Table 10 illustrates the physical properties of the stone stripe profile. The gravel content is much lower than in the unsorted raised beach material as a result of frost action and gravitational processes. The pH and liquid limit increase with depth. Moisture and clay content and bulk density are greater in the area of 10-25 cm. depth than in the surface and lower horizons.

3 Silt Plain

The silt plain showed a very marked difference from the other terrain types by its finer texture. Its surface

TABLE 10

PHYSICAL PROPERTIES OF STONE STRIPE
RAISED BEACH MATERIAL

Sample No.	Depth Cm.	% Mois.	% O.M.	Texture: Gravel	C. Sand	M. Sand	F. Sand	C. Silt	M. Silt	F. Silt	Clay
1	0-10	19.4	0.0	1.9	12.3	13.1	15.5	14.3	15.9	11.4	17.5
2	10-25	52.5	0.0	2.1	7.6	9.5	14.8	14.9	18.4	14.2	20.6
3	25-50	20.3	0.0	2.7	15.3	11.4	15.4	17.7	14.2	11.1	14.9

Sample	Bulk Density	Liquid Limit	pH
1	1.68	30.9	8.35
2	1.93	31.7	8.25
3	1.41	32.1	8.05

is composed of ice-wedge polygons approximately 10 metres in breadth. The areal extent and the number of occurrences of this terrain unit in the study area is fairly small. (Plates 5, 8, 9, and 10). Vegetation cover was mosses, grasses, and Papaver Radicatum with arctic willow in depressions. This terrain unit was sampled in the central section of a polygon between the ice wedges. Its profile description follows:

Horizon	Depth	
A_{21}	0-5 cm.	light gray (2.5Y7/2) when dry and very dark grayish brown (2.5Y3/3) when wet, loam, coarse angular blocky units, some plant roots, undulating distinct boundary to:
A_{22}	5-8 cm.	light gray (2.5Y7/2) when dry and very dark grayish brown (2.5Y3/2) when wet, gravelly clay loam, fine platy and medium subangular blocky units, wavy boundary, merging to:
O_{16}	8-24 cm.	fibrous peaty material, dark brown (5YR4/2) when dry merging to:
A_C	24-30 cm.	pale yellow (2.5Y7/4) when dry and very dark grayish brown (2.5-Y3/2) when moist, loam, coarse, subangular blocky when dry, compact and massive when moist, weak fine crumb to granular structures along main channels, fine roots and round to elongate peaty channel linings, undulating boundary to:
C_{11}	30-38 cm.	light brownish gray (2.5Y6/2) when dry and very dark grayish brown (2.5Y3/2) when wet, loam, crumb structure, undulating to:

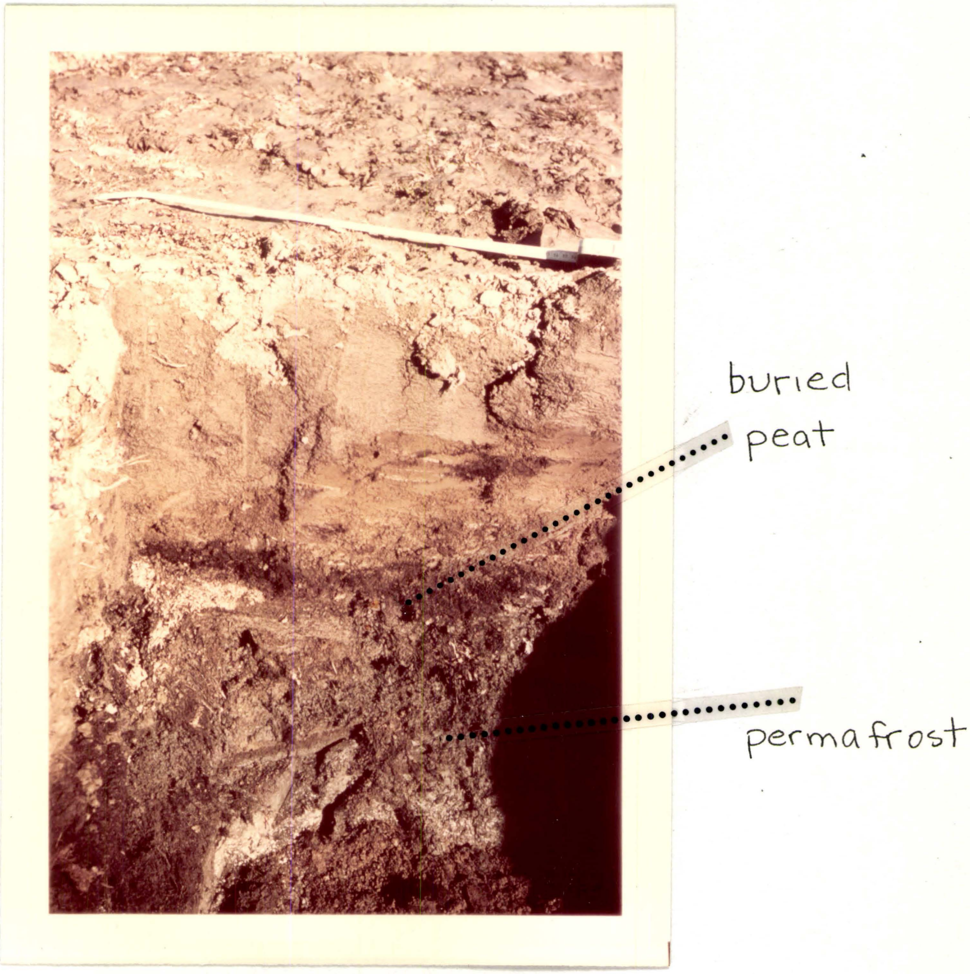


PLATE 5. Profile of the Silt Plain showing the buried peat layer and permafrost.

C_{26}	38-45 cm.	hemic peat, brown (10YR5/3) when dry distinct boundary to:
C_{12}	45-50 cm.	same as C11 some roots undulating boundary to:
C_{13}	50-55 cm.	same as C11 structureless, indistinct boundary to:
C_{14}	56-60 cm.	same as C13 with slight mottling (2.5Y6/2) brown to olive yellow distinct boundary to:
O_{36}	60-61 cm.	thin fibrous peat.
C_{15}	61-65 cm.	same colour as C_{11} silt loam, no structure, no roots indistinct boundary to:
C_{16}	65 cm.	light gray (2.5Y7/2) when dry and dark grayish brown (2.5Y4/2) when moist, loam (permafrost) no structure

Table 11 illustrates the chemical and physical properties of the silt plain soil. Permafrost was located at a depth of 32 cm. when first excavated. The depth of the thawed material was gradually deepened enough to enable the profile to be described and analyzed to a depth of 65 centimetres. Gravel was found only in the A22 horizon. Liquid limit values are very high as a result of the extremely fine texture. Bulk density is low in the surface horizons increasing with depth. The pH is acid in the horizons immediately overlying the buried peat layers whereas in the other horizons it is basic. Electrical conductivity and cation exchange capacity also illustrate an increase in value in the horizons immediately overlying the buried peat layers. Although sesquioxides were not

TABLE 11

PHYSICAL AND CHEMICAL PROPERTIES OF THE SILT PLAIN PROFILE

Sample	Depth	% Mois.	% O.M.	Texture: Gravel	C. Sand	M. Sand	F. Sand	C. Silt	M. Silt	F. Silt	Clay
A_{21}	0-5	51.4	2.6	-	5.1	8.8	19.4	21.8	13.8	10.4	15.7
A_{22}	5-8	96.3	3.4	23.6	3.9	8.7	13.8	16.0	16.5	13.8	27.3
O_{16}	8-24	See Table 7 M									
A_C	24-30	35.6	1.0	-	7.9	12.3	16.1	16.8	15.6	12.2	19.1
C_{11}	30-38	32.5	1.4	-	12.4	15.3	20.1	16.1	16.4	9.9	9.8
O_{26}	30-45	See Table 7									
C_{12}	45-50	36.9	0.9	-	5.3	8.6	18.4	18.8	17.8	11.5	19.6
C_{13}	50-55	38.6	0.0	-	17.6	12.0	6.6	8.6	16.3	15.2	23.7
C_{14}	55-60	45.0	1.3	-	17.2	13.0	6.0	11.2	18.8	13.1	20.7
C_{15}	61-65	53.1	1.5	-	6.8	6.4	12.4	20.3	20.2	11.8	23.1
C_{2f}	> 65	33.7	4.1	-	7.1	7.8	17.2	25.8	9.9	9.6	12.6

Sample	Bulk Density	Liquid Limit	pH	E.C.	Ca^{++}	H_2CO_3	CEC
A_{21}	1.03	58.9	7.65	1.6	162.5	303.7	15.2
A_{22}	1.02	61.3	6.75	14.6	352.5	452.5	18.2
O_{16}	0.18		7.30	26.3	29.0		11.0
A_C	1.43	51.6	7.35	9.6	227.5	441.5	16.6
C_{11}	1.98	50.9	6.90	8.6	187.5	303.5	19.8
O_{26}	0.125		6.10	19.0	56.0		16.0
C_{12}	1.28	48.9	7.35	5.8	92.5	99.9	19.4
C_{13}	1.83	48.8	7.60	7.4	182.5	243.9	13.4
C_{14}	1.32	52.1	7.30	7.2	182.5	234.1	23.4
C_{15}	1.53	59.7	7.30	5.6	127.5	211.6	9.2
C_{2f}	1.67	34.7	7.95	7.6	167.5	204.8	6.2

detected in this profile, pH, electrical conductivity and cation exchange capacity values indicate that this may be compared to an incipient form of Arctic Brown Soil (Tedrow and Cantlon, 1958). Its parent material is rhegosolic however the processes leading to its deposition are unknown. One would assume that the processes of transportation are either loessic or fluvial. In any case the origin of this fine material is the local argillaceous limestone (see Chapter II: X ray diffraction of the clay minerals). Electrical conductivity values would indicate that this is a Saline Rhegosol.

4 Meadow Tundra Soil

This terrain unit is predominant in the very poorly drained section of the lowland area (Plate 2). The profile described below corresponds to site 4 of the Meadow Tundra drainage investigation in Chapter II. Its surface is almost completely covered with organic matter composed of mosses, some species of grass and saxifrage. Papaver Radicatum are associated with the drier surface areas. Its profile description follows:

Horizon	Depth	
F_1	0-7 cm.	very compact black (10YR2/1) when wet, fibrous peat with an undulating boundary to:

A_1	7-12 cm.	very dark grayish brown (2.5Y3/2) when dry and very dark brown (10YR4/2) when moist, loam, blocky structure, some fine roots, wavy boundary to:
C_{11}	12-24 cm.	light brownish gray (2.5Y6/2) when dry and dark grayish brown (10YR4/2) when moist, loam, no structure some fine roots, merging to:
C_{12}	24-40 cm.	same as C_{11} with undulating permafrost boundary to:
C_F	40-45 cm.	light brownish gray (2.5Y6/2) when dry and grayish brown (10YR5/2) when wet, silt loam with ice lenses, no roots, permafrost.

Table 12 illustrates the analytical results of the Meadow Tundra profile. The pH increases with depth to the permafrost layer then it decreases. Calcium, alkalinity, and cation exchange capacity are highest in the A1 horizon and decrease to the C1 horizon. Below the C1 horizon the cation exchange capacity continues to decrease, while the calcium and alkalinity values increase. The content of the fines (silt and clay) increases to the C2 horizon and then decrease. No organic material other than fine roots is found in the mineral material underlying the surface organic layer.

This soil is a Meadow Tundra Soil (Tedrow and Cantlon, 1958) and is characterized by its poor drainage. Its parent material, originating from local bedrock, was deposited by longshore drift throughout the lowlands in the study area.

TABLE 12

PHYSICAL AND CHEMICAL PROPERTIES OF MEADOW TUNDRA SOIL

Sample No.	Depth cm	% Mois.	% O.M.	Texture							
				Gravel	C. Sand	M. Sand	F. Sand	C. Silt	M. Silt	F. Silt	Clay
F_1	0-7			See Table 7							
A_1	7-12	162.9	9.8	22.9	20.7	15.9	11.8	10.5	13.6	13.8	13.7
C_1	12-24	20.9	0.0	49.5	12.5	11.6	11.5	9.3	14.6	19.8	20.9
C_2	24-40	21.1	0.0	28.2	13.2	13.4	11.3	10.4	15.4	16.6	19.7
C_F	40-45	33.1	0.0	13.8	9.0	9.3	14.4	17.5	26.0	11.2	12.6

Sample No.	Bulk Density	Liquid Limit	pH	E. Cond	Ca^{++}.	H_2CO_3	CE.C.
F_1							
A_1	1.23	44.7	5.85	.76	192.5	340.2	30.0
C_1	1.61	47.9	7.85	2.5	37.5	172.1	16.6
C_2	1.52	36.4	8.00	1.70	102.5	246.8	14.8
C_F	1.44	33.8	7.70	1.38	157.5	202.0	13.2

5 Palsa Peat

The palsa consisted of a circular shape approximately 7 feet in diameter and 3.5 feet in height. It consisted of a layer of peat 32 centimetres in thickness overlying an ice lens. The analytical results of the peat layer are listed in Table 7.

Originally this consisted of a peat overlying a mineral layer. Its formation is the same as that for a pingo: essentially water under hydrostatic pressure forces its way up through a weakness in the permafrost where it breaks out beneath the organic matter. Although the temperature of the water is below freezing, the hydrostatic pressure is great enough to maintain the moisture in a liquid state. When it breaks through the permafrost layer the sudden decrease in pressure enables this water to freeze immediately (Palmer, 1967).

6 Discontinuous Gravels Over Fines

This unit occurs wherever gravel-sized material from the adjacent higher gravel beaches has moved and been deposited over the underlying finer material. Since this finer material is similar to that of the silt plain terrain unit, no profile description or physical properties of this terrain unit are given. Also its thixotropic nature made it difficult for undisturbed samples to be collected.

Essentially this material is considered to be a marine deposit and as such can be classified as a Cryic Rhegosol. It is possible that patterned ground may eventually form on this material judging by its unstable nature as a result of excess moisture. No further observations can be presented here except that its surface displayed enough contrast from the other terrain types to warrant a separate terrain unit.

7 Stone Stripes

This terrain unit was most prevalent at the base of the talus surrounding South Plateau and it displayed a more gentle gradient than the talus slopes above. Vegetation was common on the stone stripes whereas the finer material separating the stone stripes had no vegetation.

No sampling was undertaken for this terrain unit since the K3 and K6 terrain units of the South Plateau showed similar features (see the South Plateau Terrain Units in the following section). The only differentiation between this terrain unit and those of K3 and K6 is the distinction between lowland and plateau sites. This material may have undergone some marine movement. However its source is essentially from the talus and South Plateau bedrock. The increased amount of fines in this material may have been washed from the talus. It is classified as a Cryic Rhegosol.

8 Polygonal Patterned Ground

As was the case for terrain unit 2a) this profile and its description is discussed in Chapter V in the sections under Lateral Trench, and the Trend Surface Analysis of Two Polygons. This is classed as a Cryic Rhegosol since its parent material was deposited by marine processes. Vegetation, in most cases, covers the stone margins of the Polygons.

9 Talus Material

This terrain unit is associated with the cliffs of South Plateau and Caswell Tower. Since the processes and description of this terrain unit are geomorphic rather than pedogenic these will be omitted from discussion.

Although this is not a soil unit, its areal extent and importance in explaining movement from the South Plateau to the coastal lowland necessitates its inclusion in the terrain classification. This is unconsolidated rock debris and is classified as a Cryic Rhegosol. However, since there are processes which are still very active in sorting and adding material to this terrain unit the above classification may be too refined.

10 Fluvial Debris

Fluvial debris is present in all the streams in the area. The material varies in size from boulders 1 metre in diameter to silt and clay-sized particles. Because of the variations in particle size and the varying carrying capacity of the water no profile representative of this terrain unit could be presented.

The origin of this material depends on the headwaters of the respective stream. Clearly material in streams whose headwaters are located in the South Plateau originated directly from the South Plateau. Streams which are fed from the coastal lowland transport material previously deposited by marine processes. This material is classified as an Alluvial Rhegosol.

11 Solifluction Lobes

The solifluction lobes were not sampled or described. From past research (Cox, 1969, Brown, 1962) these features tend to have buried organic matter and many involutions- the size of which may be governed by the size of the solifluction lobe. For further description and research on the features in the study area, one is referrred to the study by R. L. Cox (1969).

B) Soils of the South Plateau

K1 Hummocky Non-Sorted Ground

This terrain unit was located on the plateau margin. It consisted of an angular gravel surface (>2 cm.) with frequent stones larger than 10 centimetres. It was virtually void of organic cover and non-sorted. Its surface was often irregularly stepped down on hard rock bands or altiplanation terraces on upper thick limestone bands. Some small dessication cracks were present as well as straight runnels with no humus. The following is its profile description.

Horizon	Depth	
1	0-6 cm.	continuous cover of stones and gravel, coherent, sticky when wet, sandy loam, grayish brown (2.5Y5/2) matrix, no roots, no distinct boundary to:
2	6-15 cm.	weak, coarse granular sandy loam with fine gravel same colour as above, moderately friable, indistinct boundary to:
3	15-30 cm.	same as 2, very gravelly merging to:
4	> 30 cm.	very compact sandy loam grayish brown (2.5Y5/2) matrix, rounded gravel present.

Table 13 illustrates the laboratory results of this profile. There is a decrease in moisture content with depth. Bulk density decreases with depth while liquid limit increases. No pedogenic processes were present. The permafrost table was located at 60 centimetres depth.

This is essentially unconsolidated bedrock weathered in situ. It is classified as a Lithic Rhegosol.

TABLE 13

PHYSICAL PROPERTIES OF HUMMOCKY NON-SORTED GROUND

Sample No.	Depth	% Moist.	% O.M.	Texture: Gravel	C. Sand	M. Sand	F. Sand	C. Silt	M. Silt	F. Silt	Clay
1	0-6	9.0	0.0	40.7	34.2	22.1	8.7	6.8	11.4	9.5	7.3
2	6-15	6.1	0.0	49.1	42.2	19.4	10.6	3.6	9.3	8.8	6.1
3	15-30	3.8	0.0	73.6	28.8	20.8	18.7	4.8	8.7	10.8	7.4
4	-30	3.6	0.0	54.6	27.5	44.4	19.4	6.8	8.0	6.3	7.6

Sample No.	pH	Bulk Density	Liquid Limit	Penetrability Kg/cm^2
1	8.20	1.97	16.5	1.2
2	8.25	1.86	25.9	2.0
3	8.20	1.86	23.1	2.3
4	8.25	1.49	30.6	3.0

K2 <u>Small Stone Nets</u>

This terrain unit has developed on crinoidal limestone. Small hummocks with a local relief of 30-40 centimetres are present. Some organic cover (mosses and lichens) is found on the surface of the stone margins. The following is a profile description of the net centre.

Horizon	Depth	
1	0-10 cm.	white (10YR8/2) when dry and grayish brown (10YR5/2) when moist, sandy loam matrix with some fine gravel, no roots, crumb structure merging to:
2	10-30 cm.	same colour as in 1, sandy loam to loamy sand matrix gravelly, no structure.

Table 14 illustrates the analytical results of the above profile. The moisture and clay contents decrease slightly with depth while there is an increase in pH. Bulk density decreases with depth while liquid limit increases.

Depth to permafrost was 60 centimetres when it was sampled at the beginning of August. On August 26 after the first freeze, the above terrain unit was again investigated. Frost had penetrated to 13 centimetres in the finer centre of the net and from 5 to 6 centimetres in the gravel. New ice lenses approximately 1.5 cms. thick were located in the subsurface. These had increased the height of the silty centres by 6 to 8 centimetres. Late in the afternoon there was 5 to 6 centimetres of surface melting with ice crystals at 7-15 centimetres.

TABLE 14

PHYSICAL PROPERTIES OF SMALL STONE NETS

				Texture							
Sample No.	Depth cm.	% Mois.	% O.M.	Gravel	C. Sand	M. Sand	F. Sand	C. Silt	M. Silt	F. Silt	Clay
1	0-10	11.3	0.0	18.6	26.6	24.2	14.4	3.7	7.4	15.9	7.8
2	10-30	9.7	0.0	28.4	27.7	24.9	20.2	8.9	3.4	7.8	7.1

Sample No.	pH	Bulk Density	Liquid Limit
1	8.25	2.00	17.6
2	8.30	1.88	21.3

The parent material results from the in situ weathering of bedrock. Little movement occurs other than frost heave. It has been classed as a Lithic Rhegosol.

K3 Stone Stripes With Very Little Organic Matter

This terrain unit consisted of thin stone stripes of angular gravel with a discontinuous gravel surface overlying wet cohesionless thixotropic silt loam. These are developed on slopes of 2 to 4°. (Bunting, 1961). There were occasional percolines with some organic cover, but very little organic matter was found on the stone stripes. The following is the modal profile description.

Horizon	Depth	
1	0-10 cm.	white (10YR8/2) when dry changing to pale brown (10YR6/3) when moist, sandy loam matrix, gravelly, compact, merging to:
2	10-20 cm.	same colour as 1, structureless gravelly loamy sand.

Table 15 illustrates the physical properties of this terrain unit. Clay content, bulk density and liquid limit decrease with depth while pH and moisture content increase. This material is classed as a Cryic Rhegosol since the presence of the stone stripes implies movement downslope. The occurence of the stone stripes is a result of a gentle slope and an excess of moisture content.

TABLE 15

PHYSICAL PROPERTIES OF STONE STRIPES

Sample No.	Depth cm.	% Mois.	% O.M.	Gravel	C. Sand	M. Sand	F. Sand	C. Silt	M. Silt	F. Silt	Clay
1	0-10	5.1	0.0	52.4	27.7	19.2	14.0	10.7	11.0	9.8	7.6
2	10-20	5.3	0.0	23.7	42.5	20.1	13.6	6.7	7.7	5.2	4.2

Sample No.	pH	Bulk Density	Liquid Limit	Penetrability Kg/cm^2
1	8.05	1.98	19.1	0.5
2	8.10	1.86	17.1	0.0

K4 <u>Dry Loose Gravel Surface</u>

This terrain unit forms an association with K1. It is composed mainly of crinoidal limestone particles with a slightly hummocky surface with no sorting present (Plate 6). Its profile description follows.

Horizon	Depth	
1	0-10 cm.	light gray (10YR7/2) when dry and brownish yellow (10YR6/6) when moist, gravelly sand with no organic matter, granular structure, indistinct boundary to:
2	10-20 cm.	same colour as 1, gravelly loamy sand, granular structure merging to:
3	20-30 cm.	same colour as 1, granular sand matrix with some fine gravels, indistinct boundary to:
4	30-35 cm.	same as horizon 3 merging to:
5	35-45 cm.	same colour as horizon 1, gravelly sand, granular structure, indistinct boundary to:
P.F.	45 cm.+	light gray (10YR7/2) when dry becoming brownish yellow (10YR6/6) when wet, granular sand with some dry permafrost.

Table 16 lists the physical properties of the above horizons. Moisture content is low but gradually increases with increasing depth. However the other results show no definite trends with differences in depth. The profile is dominated by gravel and coarse sand.

The K4 terrain unit is a Cryic Rhegosol since its parent material is crinoidal limestone derived through frost

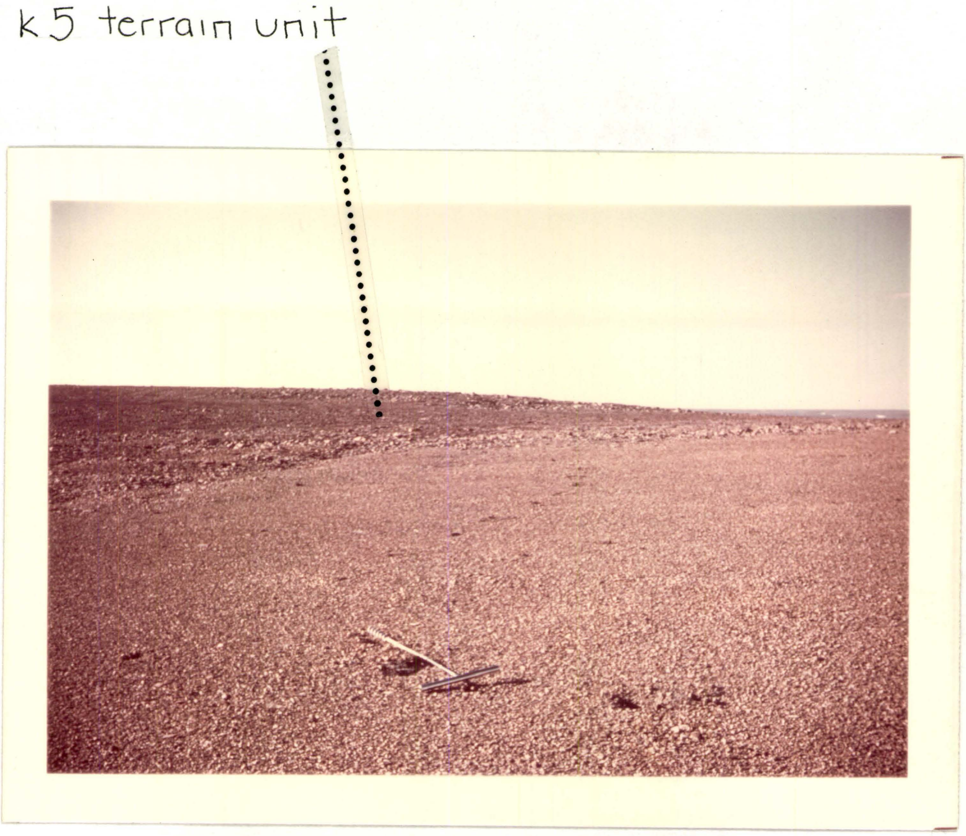


PLATE 6. View of the k4 terrain unit on the South Plateau. The k5 terrain unit is in the middle background.

TABLE 16

PHYSICAL PROPERTIES OF THE TERRAIN UNIT COMPOSED OF A DRY LOASE GRAVEL SURFACE (K4)

Sample No.	Depth cm.	% Mois	% O.M.	Texture Gravel	C. Sand	M. Sand	F. Sand	C. Silt	M. Silt	F. Silt	Clay
1	0-10	2.9	0.0	45.4	52.2	20.7	15.4	3.9	1.7	2.3	3.8
2	10-20	3.6	0.0	32.1	42.1	26.2	16.8	3.8	3.4	2.9	4.8
3	20-30	4.0	0.0	25.4	50.3	24.6	12.6	2.3	2.4	3.2	4.6
4	30-35	5.1	0.0	20.5	42.2	30.0	15.3	2.4	3.7	2.7	3.7
5	35-45	6.8	0.0	32.9	62.3	21.4	11.2	1.7	0.5	0.8	2.1
PF	45+	6.3	0.0	28.0	47.5	27.2	12.8	1.4	3.0	3.1	5.0

Sample No.	pH	Bulk Density	Liquid Limit
1	8.15	2.14	14.2
2	8.25	2.23	16.7
3	8.45	2.17	19.5
4	8.30	1.86	14.9
5	8.45	2.26	14.1
PF	8.10	2.23	13.7

processes from the underlying bedrock. It displays good drainage and an absence of organic matter.

K5 Coarse Stone Nets and Rock Debris

This K5 terrain unit consists of rock debris apparently in situ (Plate 7). The stone nets have vertically oriented large stones in their margins with regularly layered large stones in their centres. These are infrequent 2 feet by 1 foot sandy loam matrices with fine gravels.

Figure 10 is a model diagram for the terrain unit K5. The following is its profile description.

Horizon	Depth	
1	0-5 cm.	very pale brown (10YR7/3) when dry becoming brown (10YR5/3) when moist, gravelly sandy loam, very compact and granular with very fine pores, wavy distinct boundary to:
2	5-14 cm.	pale brown (10YR6/3) when dry becoming grayish brown (10YR5/2) when wet, gravelly sandy loam, straight boundary to:
3	14-20 cm.	light gray (10YR7/2) when dry becoming yellowish brown (10YR5/4) when wet gravelly loam with subangular blocky units and some pores, friable undulating boundary to:
4	20-25 cm.	very pale brown (10YR7/3) when dry becoming dark yellowish brown (10-YR4/4) when wet, loam with many coarse gravels and stones having calcite efflorescences, merging to:

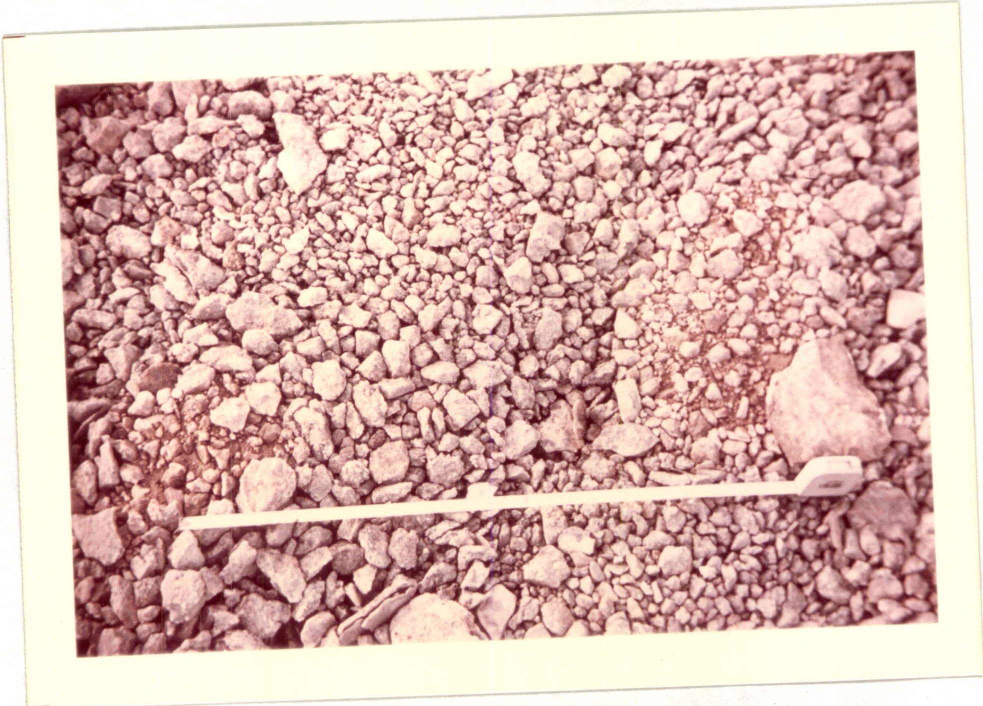


PLATE 7. A variant of terrain unit k5 showing polygonal cores and coarser wider margins.

FIGURE 10. COARSE STONE NETS & ROCK DEBRIS PROFILE (TERRAIN UNIT K5).

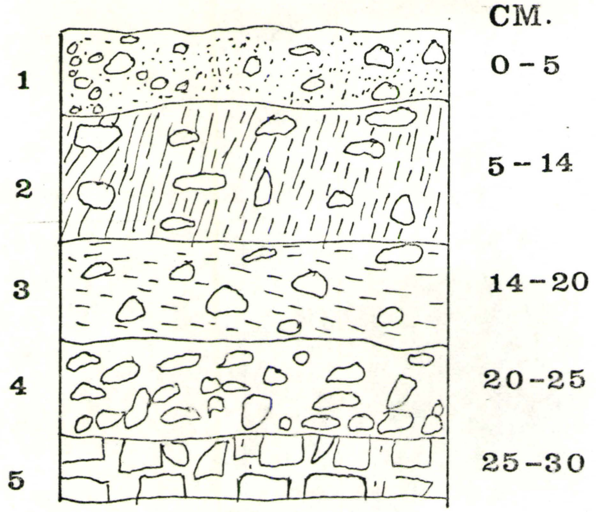
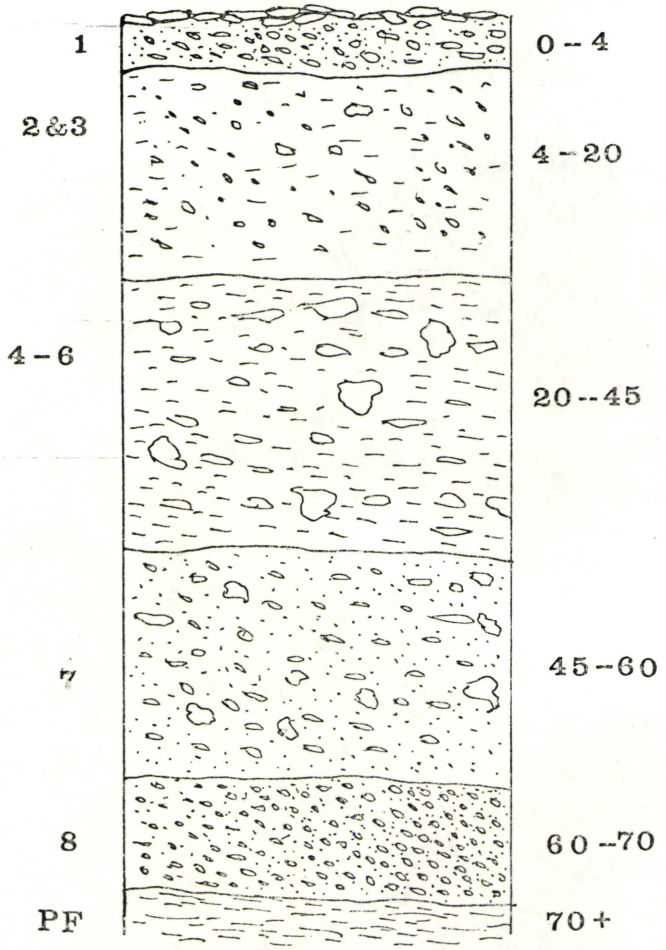


FIGURE 11. PROFILE OF SORTED GRAVELS TENDING TO STONE STRIPES.



5	25-30 cm.	very pale brown (10YR7/3) when dry becoming yellowish brown (10YR5/4) when wet, stony material, sub-angular with joint infillings of sandy clay loam, sharp textural boundary to:
6	30 cm.+	very pale brown (10YR7/3) when dry becoming yellowish brown (10YR5/6) when moist, compact gravels with a sandy loam matrix.

Table 17 lists the physical properties of samples from the above horizons. No organic matter is present. Gravel content decreases with depth until at 26 centimetres depth it greatly increases. There appears to be a movement downward of the clay material to a depth of 30 centimetres. Below this level the clay content decreases. Liquid limit and bulk density illustrate a tendency to increase with increasing depth.

The K5 terrain unit has developed from the in situ weathering of bedrock. The patterned ground surface designates it as a structural soil and can be classified as a Cryic Rhegosol.

K6 Sorted Gravels Tending to Stone Stripes

This terrain unit consists of partly sorted gravel, sometimes linear, with vegetation streaks. Its surface is slightly hummocky. Figure 11 shows the model profile as drawn from a monolith. The profile description follows:

TABLE 17

PHYSICAL PROPERTIES OF COARSE STONE NETS AND ROCK DEBRIS (K 5 TERRAIN UNIT)

Sample No.	Depth cm.	% Mois	% O.M.	Texture Gravel	C. Sand	M. Sand	F. Sand	C. Silt	M. Silt	F Silt	Clay
1	0-5	2.7	0.0	44.4	37.3	13.8	11.3	6.2	11.4	9.9	10.1
2	5-14	3.3	0.0	40.1	32.4	21.3	9.5	7.7	6.4	8.0	14.7
3	14-20	2.7	0.0	36.9	14.4	17.7	20.4	13.4	11.2	8.7	16.2
4	20-25	3.7	0.0	29.1	16.9	20.2	14.7	7.1	4.3	15.8	21.0
5	25-30	6.7	0.0	56.3	32.8	17.4	7.7	3.7	4.4	8.7	16.3
6	> 30	3.6	0.0	38.8	28.2	21.9	11.7	5.4	13.1	9.6	10.1

Sample No.	pH	Liquid Limit	Bulk Density
1	8.40	15.4	2.23
2	8.05	12.6	2.17
3	7.95	14.7	2.08
4	8.15	17.0	1.19
5	8.25	26.8	2.23
6	8.30	21.4	2.10

Horizon	Depth	
1	0-4 cm.	discontinuous surface of flat stones (5 cm. diametre) light gray (2.5-Y7/2) when dry becoming dull yellowish brown (10YR5/4) when moist gravelly sandy loam, no roots, occasional faint smears of calcite nodules, dry surface cracking, diffuse boundary changing to:
2 3	4-10 cm. 10-20 cm.	same colour as 1, sandy loam with fine gravels, crumb-like, pseudo-structures are fine gravel bridged by wet silty material, clear boundary to:
4 5 6	20-25 cm. 25-40 cm. 40-45 cm.	light gray (2.5Y7/2) when dry becoming light yellowish brown (10-YR6/4), sandy clay loam-stony, relatively non-compacted massive structure, large pohyhedral masses when dry, gradually merging to:
7	45-60 cm.	very wet stony rounded coarse gravel in a gray reduced sandy clay loam matrix varying in colour from gray (10YR6/1) to light brownish gray (2.5Y6/2) merging to:
8	60-70 cm.	very wet thixotropic sandy clay loam, gravelly, light gray (2.5Y7/2) when dry and gray (10YR6/1) when wet, some small rounded stones, sharp boundary to:
9	70 cm.+	permafrost, light gray (2.5Y7/2) when dry and gray (10YR6/1) when wet, gravelly sandy clay loam, no structure, some ice lenses.

Table 18 illustrates the physical properties of this terrain unit. Moisture content gradually increases with depth where, in the permafrost, it more than doubles that in any other horizon, as a result of the ice lenses.

TABLE 18

PHYSICAL PROPERTIES OF SORTED GRAVELS
TENDING TO STONE STRIPES

Sample No.	Depth (cm.)	% Mois.	% O.M.	Gravel	C. Sand	M. Sand	F. Sand	C. Silt	M. Silt	F. Silt	Clay
1	0-4	0.5	0.0	57.9	30.3	17.3	9.6	5.4	8.3	9.3	19.8
2	4-10	6.3	0.0	61.8	36.2	17.7	8.5	7.7	7.4	7.6	14.9
3	10-20	6.1	0.0	74.1	52.1	17.8	5.1	1.2	2.8	7.2	13.8
4	20-25	4.1	0.0	52.7	26.9	19.0	7.3	8.4	7.4	9.3	21.7
5	25-40	5.2	0.0	42.8	18.8	20.9	13.1	9.1	10.0	11.4	16.7
6	40-45	7.4	0.0	50.3	29.9	15.4	9.9	7.4	7.7	7.3	22.4
7	45-60	5.6	0.0	54.2	32.3	14.9	6.7	2.3	11.4	7.2	22.5
8	60-70	6.5	0.0	37.2	36.7	16.2	9.2	3.8	6.9	7.2	22.5
9	> 70	15.9	0.0	12.7	36.2	21.6	6.2	3.5	5.6	8.3	18.6

Sample No.	Bulk Density	Liquid Limit	pH	Penetrability
1	1.93	28.1	8.35	1.4
2	2.10	24.4	8.60	2.2
3	2.02	19.3	8.80	3.0
4	2.17	17.4	8.85	0.8
5	1.89	22.4	8.80	0.0
6	1.59	22.9	8.80	0.8
7	1.92	25.4	8.85	0.0
8	2.16	19.1	8.85	0.0
9	1.84	23.2	8.65	>5.0

Gravel tends to decrease with increasing depth with a corresponding increase in clay content to the permafrost layer. Bulk density and liquid limit show no definite trends with depth though the former is high (1.8 except at 40 cm.). The pH of this terrain unit tends to increase with depth, however there is a decrease of pH in the permafrost.

The parent material originated from in situ weathering of bedrock on the plateau surface. The material shows a colour change with depth indicating slight gleying. As a result it is classified as a Gleyed Cryic Rhegosol.

K7 <u>Polygonal Patterned Ground With Coarse Stone Centres</u>

No vascular plants are found on this terrain unit. Sorting was not observed. The profile description for the centre of one of these features follows:

Horizon	Depth	
1	0-10 cm.	white (2.5Y8/2) when dry becoming pale brown (10YR6/3) when wet, gravelly loam, structureless, merging to:
2	10-25 cm.	same colour as above, structureless sandy loam with angular fine to medium gravels merging to:
3	25-40 cm.	light gray (2.5Y7/2) when dry becoming gray (10YR6/1) when moist, loam with fine gravel.

Table 19 displays the physical properties of this polygon terrain unit. Movement of clay to depth occurs in this profile. The pH becomes very alkaline at depth. Bulk

TABLE 19

PHYSICAL PROPERTIES OF POLYGONAL PATTERNED GROUND WITH COARSE STONE INNERS

Sample No.	Depth cm.	% Mois.	% O.M.	Texture: Gravel	C. Sand	M. Sand	F. Sand	C. Silt	M. Silt	F. Silt	Clay
1	0-10	12.0	0.0	42.3	18.9	17.4	14.9	13.3	13.8	10.4	12.3
2	10-25	6.5	0.0	45.9	26.1	20.8	13.7	9.4	6.2	9.1	14.7
3	25-40	9.0	0.0	36.3	18.8	17.2	12.3	10.1	10.9	9.8	20.9

Sample No.	Bulk Density	Liquid Limit	pH
1	1.65	28.8	8.35
2	2.20	18.3	8.90
3	1.97	24.6	9.00

density increases with depth while gravel content decreases. Some gleying is present as shown by the slight colour change in the above profile description. This is classed as a Gleyed Lithic Rhegosol since the parent material is derived from the in situ weathering of bedrock.

K8 Lenticular Gravel Hills With Silt Covered Depressions

As the terrain unit title implies this feature consisted of ridges with silt-covered depressions between. Presumably the silt originated in the upslope ridge. The following is its profile description.

Horizon	Depth	
1	0-15 cm.	light gray (2.5Y7/2) when dry becoming light yellowish brown (2.5Y6/3) when moist, structureless loam, indistinct boundary to:
2	15-25 cm.	light gray (2.5Y7/2) when dry and light brownish gray (2.5Y6/2) when moist, sandy loam with some fine gravels merging to:
3	25-40 cm.	same colour as horizon 2, structureless sandy loam, indistinct boundary to:
4	40 cm.+	same colour and texture as horizon 2.

Table 20 illustrates the physical properties of the above profile. Gravel content decreases with depth as does bulk density. The silty material suddenly decreases beneath the surface horizon (profile is from one of the silt

TABLE 20

PHYSICAL PROPERTIES OF LENTICULAR GRAVEL HILLS WITH SILT DEPRESSIONS

Sample No.	Depth cm	% Mois.	% O.M.	Texture: Gravel	C. Sand	M. Sand	F. Sand	C. Silt	M. Silt	F. Silt	Clay
1	0-15	11.4	0.0	15.0	13.7	18.6	17.3	14.5	13.1	9.9	14.9
2	15-25	13.8	0.0	13.8	33.9	16.8	11.2	8.0	7.6	7.8	14.7
3	25-40	11.6	0.0	5.3	44.6	15.3	9.3	5.6	6.2	6.5	12.4
4	40+	13.1	0.0	4.2	26.3	19.8	13.8	8.0	8.2	7.9	15.0

Sample No.	Bulk Density	Liquid Limit	pH
1	1.71	24.5	8.65
2	1.53	21.4	8.90
3	1.74	32.4	8.95
4	1.94	18.2	8.85

depressions). From the change in colour illustrated in the profile description above, gleying is present in the subsurface.

C) Soils of Caswell Tower

Three different terrain types were found on the surface of Caswell Tower. Surface vegetation was rare on all three of these terrain units. Differentiation between these three terrain units was by colour, though some minor differences in texture are noted. Caswell Tower 1 was in the central portion of the plateau with a depth of 20 cm. to unfrozen bedrock, while the other two were shallow plateau margin sites.

Caswell Tower 1

Very little organic matter covered the surface of this terrain unit. Its colour tended to be higher in value than the other two Caswell Tower terrain units. The following is its profile description.

Horizon	Depth	
1	0-3 cm.	gravel surface (1.3cm. diameter) with fine gravel fragments (0.4 cm. diameter) and occasional silty pseudogranular material, hard crusts of calcite efflorescences on the lower surfaces of large gravel and stones, colour of the sandy loam matrix is light gray (10YR7/2) when dry becoming light yellowish brown (10YR6/4) when moistened.

2	3-10 cm.	sandy loam with weak medium crumb to weak rounded and subangular blocky structures, some fine roots are present, grayish brown (10YR-5/2) when dry and grayish brown (2.5Y5/2) when moist sharp undulating boundary to:
3	10-25 cm.	uniform gray brown (10YR5/2) loam matrix, rootless subangular blocky material, fine gravel and a few small stones are present merging to:
4	25-35 cm.	gravelly loam with stones, dark grayish brown (10YR4/2) in colour, granular structure, sharp boundary to:
5	35-45 cm.	very gravelly loam, dark grayish brown (10YR4/2) when dry changing to grayish brown (2.5Y5/2) when moist, large cobbles present

Figure 12 shows the above horizon sequence. Table 21 presents the physical properties of Caswell Tower 1. Some increase of clay with depth is present. The parent material has developed from in situ weathering of limestone bedrock and is classed as a Lithic Rhegosol.

Caswell Tower 2 and 3

Caswell Tower terrain units 2 and 3 illustrate minor colour changes from Caswell Tower 1. However there are no differences in their profile descriptions which follow.

Caswell Tower 2

Horizon	Depth	
1	0-10 cm.	pale yellow (5Y7/3) when dry becoming light brownish gray (2.5Y6/2)

FIGURE 12. CASWELL TOWER 1. PROFILE.

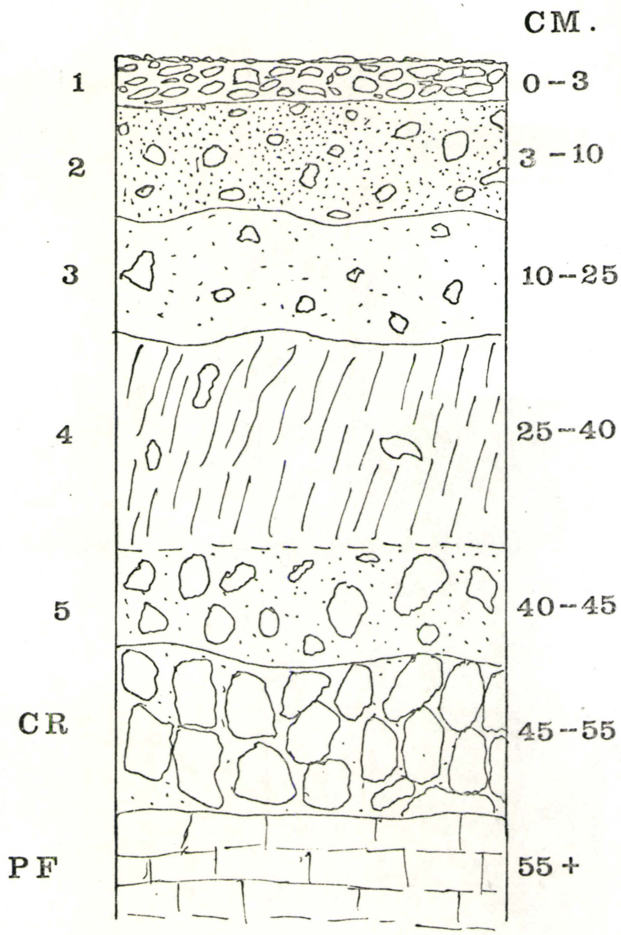


TABLE 21

PHYSICAL PROPERTIES OF CASWELL TOWER TERRAIN UNIT 1

Sample No.	Depth cm.	% Mois	% O.M.	Texture Gravel	C. Sand	M. Sand	F. Sand	C. Silt	M. Silt	F. Silt	Clay
1	0-3	8.3	0.0	45.7	12.5	16.5	26.0	22.5	10.1	5.5	6.9
2	3-10	10.3	0.0	50.4	10.0	16.1	27.6	16.6	11.9	7.7	10.1
3	10-25	12.3	0.0	42.0	7.5	15.2	24.8	14.4	13.1	8.2	16.8
4	25-35	11.9	0.0	23.2	12.0	14.3	19.7	17.4	13.6	10.8	14.2
5	35-45	5.0	0.0	72.3	12.8	14.7	16.2	16.5	18.2	11.5	10.1

Sample No.	pH	Bulk Density	Liquid Limit
1	8.25	1.62	31.7
2	8.20	1.66	36.4
3	8.25	1.29	43.3
4	8.20	1.66	21.3
5	8.10	1.34	35.6

		when moist, gravelly sandy loam with a lenticular structure, indistinct boundary to:
2	10-25 cm.	same colour as horizon 1, sandy loam matrix, granular structure with some medium-sized gravel.
Caswell Tower 3		
1	0-15 cm.	pale yellow (5Y7/3) when dry and light brownish gray (2.5Y6/2) when moist, coarse subangular gravel with a sandy loam matrix having a crumb structure.

Table 22a) and b) illustrates the physical properties of these two terrain units. Organic matter is present in both of these soils. Although as in Caswell Tower 1, vegetation cover was rare. In Caswell Tower 2, moisture content increased with depth as did liquid limit. Bulk density and clay and gravel contents decreased with depth while the silt content increased. As one would expect from the positions of these two profiles at the margin of the plateau surface, their profile depths were much shallower than that of Caswell Tower 1. These, according to the National Soil Survey Classification (1968), are Lithic Rhegosols.

Moisture Samples From Some Terrain Units

Water samples were collected at depth from some of the terrain units using a pipette for moisture collection in the active layer or a polyethylene tube inserted in permafrost with a plastic bag attached to the protruding end to catch the permafrost melt. These samples were then analyzed for pH,

TABLE 22a

PHYSICAL PROPERTIES OF CASWELL TOWER TERRAIN UNIT 2

Sample No.	Depth cm.	% Mois.	% O.M.	Texture							
				Gravel	C. Sand	M. Sand	F. Sand	C. Silt	M. Silt	F. Silt	Clay
1	0-10	15.0	0.3	26.9	9.6	14.8	27.4	23.9	14.2	6.1	4.0
2	10-25	17.6	0.0	15.3	8.2	11.8	27.5	27.2	16.1	5.6	3.6

Sample No.	pH	Bulk Density	Liquid Limit
1	8.40	1.93	36.8
2	8.40	1.43	38.6

TABLE 22b

PHYSICAL PROPERTIES OF CASWELL TOWER TERRAIN UNIT 3

Sample No.	Depth cm.	% Mois.	% O.M.	Texture							
				Gravel	C. Sand	M. Sand	F. Sand	C. Silt	M. Silt	F. Silt	Clay
1	0-15	6.8	0.1	45.8	32.9	24.8	7.6	8.3	9.2	7.5	9.7

Sample No.	pH	Bulk Density	Liquid Limit
1	8.15	1.87	32.8

calcium, magnesium, chloride and nitrate ions as outlined in Chapter II. Table 23 illustrates the analytical results.

TABLE 23

CHEMICAL PROPERTIES OF SOME SOIL MOISTURE SAMPLES

Lowland Samples	pH	Ca^{++}	Mg^{++}	Cl^-	NO_3^-
			(ppm)		
Terrain Unit 2	7.25	60	10.19	20	0.0
Silt Plain 35-40 cm.	7.45	76	10.88	70	35.9
" " 40-45 cm.	6.95	248	10.89	52	10.5
" " 45-50 cm.	6.85	200	10.88	80	22.9
" " Permafrost 70 cm.	7.10	208	10.79	110	15.5
" " " 75 cm.	7.10	160	7.30	73	6.8
" " " 90 cm.	6.55	360	10.85	190	7.4
" " Aug. 22, 50 cm.	7.00	76	7.76	25	0.0
South Plateau					
K1 15 cm.	7.45	48	8.75	10	0.0
K2 20 cm.	7.50	60	9.43	11	0.0
K3 10 cm. (stone stripes)	7.35	88	7.78	13	0.0
K3 10 cm. (fines)	7.15	68	7.60	8	0.0
K3 20 cm. (fines)	7.25	64	8.79	6	0.0
K4 40 cm.	7.40	64	5.23	8	0.0
K6 10 cm.	7.25	64	8.76	5	0.0
K6 40 cm.	7.30	60	8.52	16	0.0
K6 50 cm.	7.30	84	9.84	15	0.0

These results reflect some of the characteristics of the respective terrain units. No nitrate ion is present in the moisture of the South Plateau terrain units or in the lowland terrain units where surface vegetation is sparse. Values are low for those moisture seeps of the plateau terrain units with pH values nearly neutral. The K6 (50 cm.) sample from permafrost shows slightly higher values than the others. However there are no marked differences between the samples from the active layer and those of permafrost as there is in the Silt Plain permafrost moisture samples. The permafrost moisture samples from the silt plain show very high values of calcium and chloride ions compared to the samples near the surface. The pH values also tend toward the acidic. It is suggested that this phenomenon is possibly a result of the deeper thawed layers which existed in the post glacial climatic optimum where depth to permafrost was greater than it is at present. Since it is possible that the mean annual temperature was higher in the past, it would be a reasonable supposition that the chemical weathering capabilities under such a regime would be greater and leached material would have accumulated at a depth in the soil now frozen.

Conclusions

The soils of Southwest Devon Island show little pedogenesis both in the coastal lowlands and the plateau areas. Textural differentiation (increased clay content and decreased gravel content with depth) is the only pedogenic process present on the South Plateau. However, this is present in only some of the plateau soils.

The soils of Caswell Tower show profile development similar to the soil units of South Plateau. Very little organic matter was present in these or in the plateau soils. There is some increase of clay with depth as well as some colour changes. However it is thought that these differences in colour are a result of differences in moisture content rather than being indicative of variations in the intensity of weathering.

The soils of the coastal lowlands show more evidence of pedogenic alteration and in some cases have 2 to 3 inches of in situ organic cover. However most of these soils illustrate only minor or no profile development. In some of these soils, colour changes at the permafrost table indicate that gleying is present. Since no mottles are present in the gleyed layers this would indicate seasonal or periodic aeration or partial waterlogging. Increase of clay with depth is also a feature of some of the coastal lowland soil profiles. Only partial decomposition of organic matter was present in these soils, this fibrosity being a further indication of the incipient nature of the pedogenic processes.

Moisture samples from some of the terrain units possess higher ion concentrations in the coastal lowland than on the South Plateau. The permafrost samples have higher salt contents than in the active layer possibly resulting from influences already discussed.

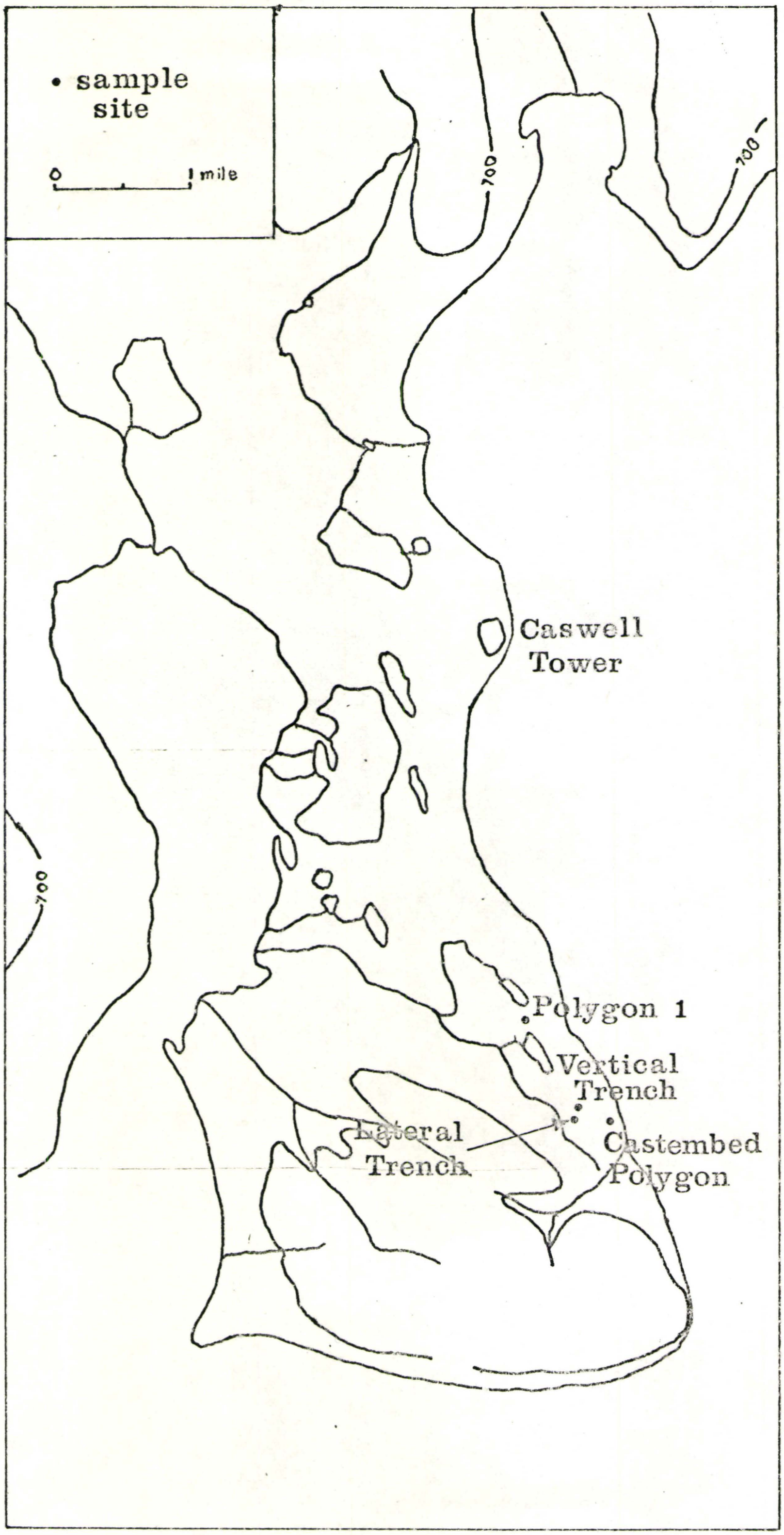
CHAPTER V

POLYGONAL PATTERNED GROUND ON SOUTHWEST DEVON ISLAND

Polygonal patterned ground is very common in the area and the patterns and profiles in these terrain features were investigated.

Several polygons at different sites, both wet and dry (figure 13), were sampled and the laboratory analyses of these samples have been subjected to various forms of statistical testing. A method was evolved of presetting dry granular polygon features with Castembed, this in order to facilitate more precise sampling (Bunting and Jackson, 1970 in press). This treated polygon was located on a low (16 metre elevation) marine strandline on the seaward side of the major beach ridge 200 metres north of the main base camp. This beach ridge is designated as terrain type 2a. The Vertical Trench and Lateral Trench which will be referred to repeatedly and which were dug to reveal the structural sequence of a polygonally arranged area were located on the inland side of this major marine beach upslope from the Meadow Tundra site discussed in Chapter II (Terrain unit 8) and 600 metres NNW of the base camp. Polygon 1 was located on the same western inland side of the raised beach approximatly 400 m.

FIGURE 13. Locations of the polygon sites.



north of the Meadow Tundra Site. The soil samples collected from these polygons were analyzed using the methods outlined in Chapter III. Some water samples were collected from these features at the stone borders and centres to determine whether the nature of the solution would indicate any chemical weathering or mechanical transport between the two parts of these features - the fine core and the stone rim.

Water Samples

The following table (Table 24) illustrates the properties of the water samples determined in the field and allots these to the respective polygons. Water from the Castembed-treated polygon was not sampled as a result of contamination from the polyester resin.

These results illustrate that there is no significant difference between samples taken from the borders of the polygons and those from the polygon centres. It is concluded that the source of the water which is snowmelt or permafrost melt is the same for the stone margins and the centres.

Castembed Polygon

Castembed was used to keep the polygon material in situ while it was sampled. (Plate 11). The samples were then analyzed for texture, organic matter, moisture

PLATE 11. View of the Castembed Polygon before impregnation and excavation.

TABLE 24

POLYGONAL WATER SAMPLE RESULTS

Sample Number	pH	Ca^{++} (ppm)	Mg^{++} (ppm)	Cl^{-} (ppm)	NO_3^{-} (ppm)
Vertical Trench					
Border	7.25	48	6.12	13	6.2
Lateral Trench					
Centre Aug. 3	6.55	56	7.14	12	6.2
Border July 29	7.10	52	7.30	11	6.2
" Aug. 1	7.30	44	6.55	10	6.2
" Aug. 3	6.85	48	7.25	13	6.2
" Aug. 8	7.65	52	7.99	15	6.2
" Aug. 11	7.50	48	7.91	22	6.2
" Aug. 15	6.90	56	8.47	19	6.2
" Aug. 23	6.80	60	7.87	16	6.2
Polygon 1					
Border	7.45	72	9.18	13	6.2
Centre	7.60	76	9.24	13	6.2

content, bulk density and liquid limit. The results are illustrated in Table 25. Table 26 shows the particle size distribution expressed as a percentage of the total mass while Table 27 displays the particle size distribution recalculated to 100% within each group. The particle size figures were then converted to units (gravel and sand and fines) and the results are expressed in Table 28.

Roundness and sphericity values are shown in Table 29.

Figure (14) shows the cross-section of the castembed polygon with the permafrost table at depth. The stone border tapers off approximately at the permafrost table. From the analyses there seems to be an organic-rich clay core as illustrated in figure 14. A comparison of the analytical results between the stone margin samples and those from the centre of the polygon are illustrated in figure 15. The percentage of cobbles in the stone border is higher than in the centre near the surface. At approximately 25 cm. depth, the cobbles in the stone margin are replaced by coarse gravel while the percent cobbles increases with depth in the polygon centre. The percentage of coarse gravel is higher in the polygon border than in the centre and there is a tendency for the amount of coarse gravel to decrease with depth in both the polygon border and centre. Medium and fine gravel increase with depth in the border but this texture size remains almost constant with depth in the polygon centre. Total sand, silt, and clay increase suddenly in the stone border at 35 centimetres depth with a decrease in this size fraction in the polygon centre at approximately the same depth.

Organic matter content decreases with depth in both the polygon centre and border until at a depth of

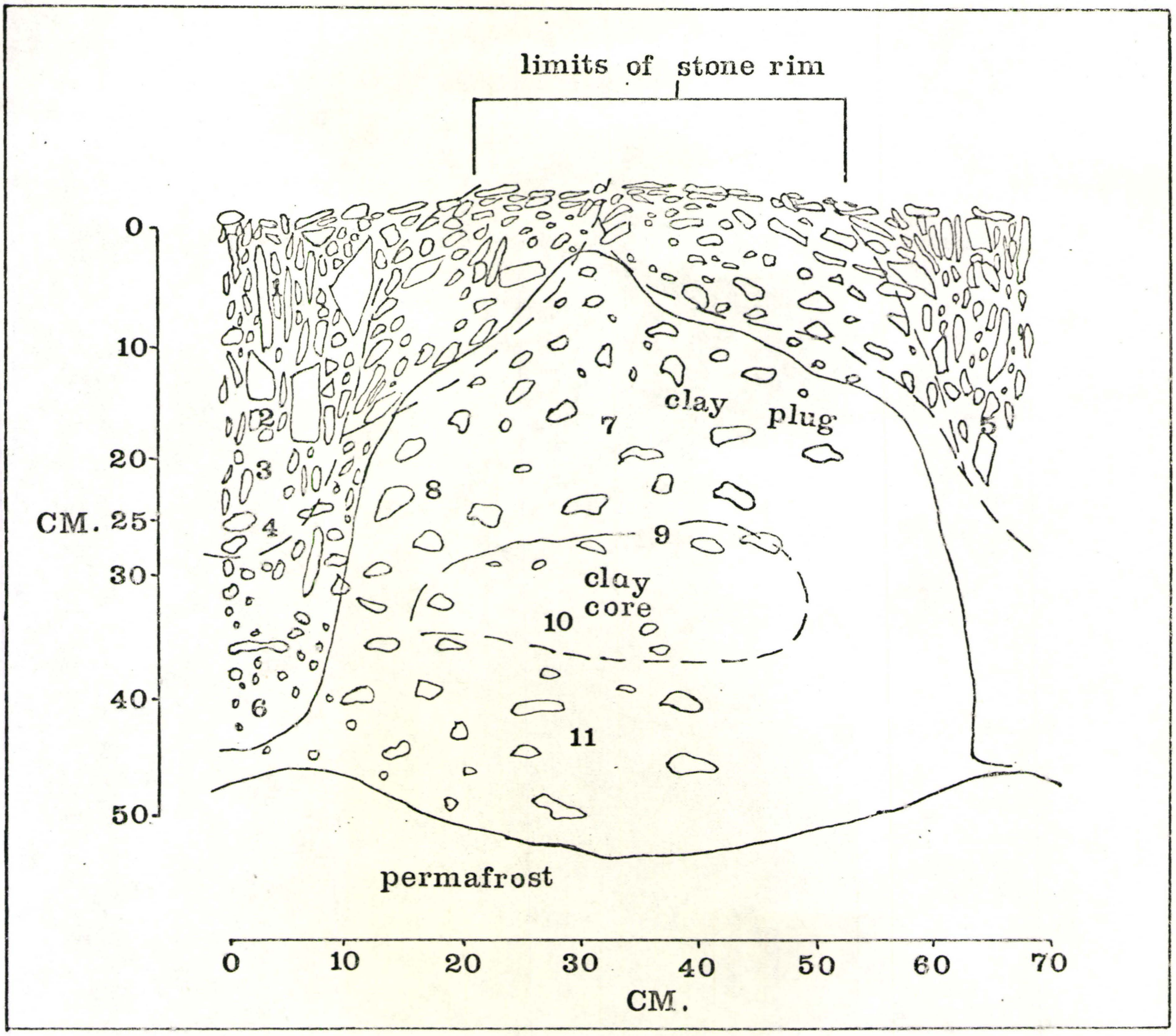
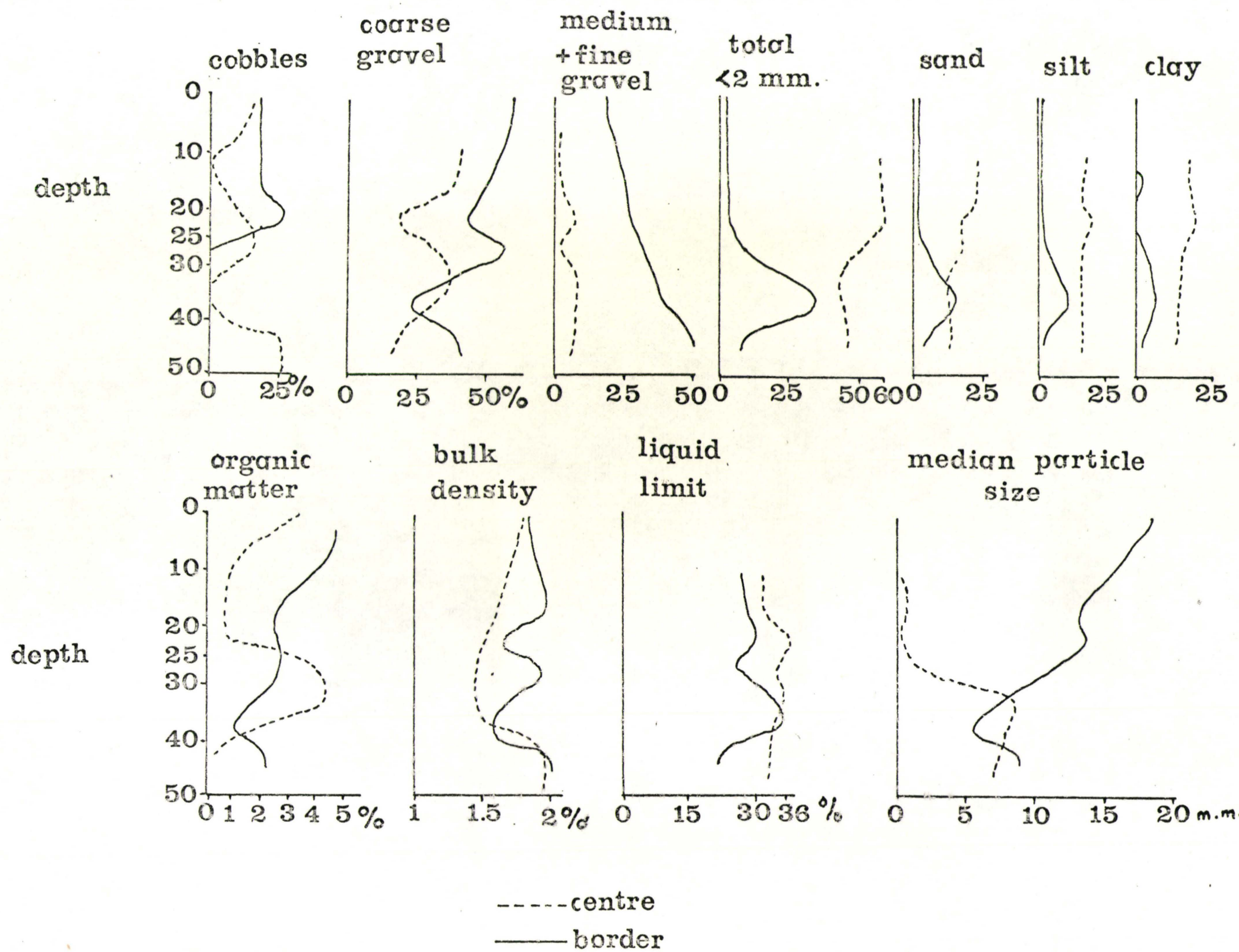


FIGURE 14. CROSS-SECTION OF THE CASTEMBED POLYGON SHOWING THE SAMPLE LOCATIONS.

FIGURE 15. COMPARISONS OF THE ANALYTICAL RESULTS FOR THOSE SAMPLES FROM THE POLYGON CENTRE AND THOSE FROM THE STONE RIM.



approximately 30 centimetres the organic matter content shows a marked increase in the polygon centre with a slight increase of organic matter in the stone border. The bulk density values show a slight decrease while there is an increase in organic matter content with depth in both the border samples and those in the polygon centre. Generally the bulk density values are higher in the polygon border than in the centre. Liquid limit is higher in the polygon centre than in the border possibly because of the greater quantity of fines. Generally, the median particle size decreases with depth in the stone border but in the polygon's centre the median size increases with depth.

Mean sphericity (Rittenhouse, 1943) and roundness (W. C. Krumbein, 1941) values for the clay plug and the stone margin are shown in Table 29. These values are lower in the stone margin than in the clay plug indicating that the stones are more disc-shaped at the margin. This may be related to the sorting due to frost action.

To further determine any significant relationship of particle size between the polygon's margin and centre, tests for skewness and kurtosis were applied to particle size data. The equation for skewness was that of Folk and Ward (1957) which they named Inclusive Graphic Skewness. It is as follows:

$$S_k = \frac{P_{16} + P_{84} - 2\,P_{50}}{2(P_{84} - P_{16})} + \frac{P_5 + P_{95} - 2\,P_{50}}{2(P_{95} - P_5)}$$

TABLE 25

PHYSICAL CHARACERISTICS OF SAMPLES
TAKEN FROM AN ARCTIC POLYGON

1 Sample number	2-3 Color dry/moist (Munsell)	4 % organic matter a.	b.	5 moisture	6 bulk density g/c.c.
1	--	4.6		1.6	1.85
2	10YR6/3 5/2	2.4	2.0	1.8	1.95
3	10YR7/3 5/3	2.5	2.9	1.9	1.63
4	10YR7/4 5/3	2.7	2.3	3.3	1.93
5	10YR7/4 5/2	0.8	- -	9.5	1.56
6	10YR7/4 5/2	2.1	2.0	4.2	1.97
7	10YR7/3 4/3	0.7		5.9	1.65
8	10YR7/3 5/3	0.7		8.6	1.53
9	10YR6/4 4/2	3.7		9.6	1.46
10	10YR7/4 4/3	4.3		9.7	1.48
11	10YR8/3 6/4	0.4		9.9	1.95

Sample number	7 liquid limit (%)	8 Median particle (mm)	9 Quartile 25% (mm)	10 distribution 75% (mm)
1	- -	17.7	14.0	23.0
2	28.0	13.1	9.1	21.2
3	30.2	14.5	8.9	26.7
4	22.4	10.3	6.3	12.8
5	35.4	5.1	0.16	9.2
6	23.5	8.6	4.4	11.5
7	31.7	0.4	0.006	13.1
8	36.7	0.2	0.003	13.8
9	33.8	1.7	0.01	16.9
10	35.8	8.7	0.08	13.6
11	32.8	7.2	0.014	13.5

a) Using hydrogen peroxide. b) Calculation after determination of organic carbon. c) Calculated on the matrix material retained on the no . 70'sieve.

TABLE 26

PARTICLE SIZE DISTRIBUTION OF POLYGONAL MATERIALS
(a) EXPRESSED AS PERCENTAGE OF TOTAL MASS

1	2	3	4	5	6	7	8	9	10
		Gravel size in mm.							
Sample No.	Depth (cm)	'cobbles' 25	coarse 25-10	medium 10-5	fine 5-2	Total gravel	sand 2-0.05	silt 0.05-0.002	clay <2u
Polygon border samples									
1	0-10	19.3	59.6	14.9	4.1	98	1.0	1.0	0.0
2	15-20	18.0	52.5	22.0	4.5	97	1.1	1.2	0.8
3	20-25	27.3	42.5	22.5	4.6	97	1.2	1.8	0.0
4	25-30	0.0	57.3	23.8	9.6	91	3.6	2.7	3.1
5+	35-40	0.0	22.2	23.3	17.4	63	15.3	12.1	9.6
6	40-45	0.0	37.7	34.7	16.5	89	5.0	2.5	3.0
Polygon centre - 'clay plug'									
7	15-25	0.0	39.1	1.6	0.9	42	22.5	16.5	19.4
8*	20-25	13.2	18.9	5.2	2.7	40	16.6	20.3	22.9
9	25-30	15.5	30.9	1.8	0.4	49	17.2	16.6	17.1
10	30-35	0.0	47.9	5.8	2.6	56	10.9	15.9	16.7
11	40-45	25.7	20.5	5.8	2.0	54	13.9	16.5	15.4

\+ Sample 5 was slightly offset into the clay plug in two of three sub-samples

* Sample 8 was taken from an adjacent clay plug for purposes of comparison

TABLE 27

PARTICLE SIZE DISTRIBUTION (MM) OF GRAVEL AND OF SAND AND FINES RECALCULATED TO 100 PERCENT WITHIN EACH GROUP

1	2	3	4	5	6	7	8	9
			Gravel					
Sample No.	Depth Cm.	Cobbles 25	coarse 25-10	medium 10-5	fine 5-2	sand 2-0.05	silt 0.05-0.002	clay <0.002
2	15-20	18.5	54.2	22.8	4.4	33.3	40.0	26.7
3	20-25	28.1	43.8	23.2	4.7	37.9	62.1	0.0
4	25-30	0.0	63.2	26.1	10.4	35.8	29.3	34.8
5	35-40	0.0	35.9	36.6	27.2	39.9	33.5	26.6
6	40-45	0.0	42.1	38.8	18.2	45.0	25.0	30.0
7	15-25	0.0	94.1	3.9	1.9	38.4	28.3	33.3
8	20-25	32.7	47.2	12.9	6.7	27.2	34.1	38.7
9	25-30	31.7	63.2	3.8	0.9	33.7	32.8	33.5
10	30-35	0.0	84.7	10.3	4.4	24.2	37.0	38.8
11	40-45	47.7	37.8	10.7	3.7	30.6	36.5	32.9

TABLE 28

PARTICLE SIZE EXPRESSED AS PHI UNITS AND THE FINES EXPRESSED AS PERCENT TOTAL MASS ON THE INTERNATIONAL SCALE

1 Sample number	2 Phi -4	3 -2	4 0	5 Scale +2	6 +4	7 +8	8 sand 2- 0.02	9 silt 0.02- 0.002	10 clay ∠2u
2	35.1	59.6	3.3	2.0	0.0	0.0	1.5	0.5	0.0
3	46.2	47.1	3.4	1.3	1.0	1.0	1.6	1.1	0.8
4	12.7	71.2	7.1	1.5	3.4	4.1	4.9	1.4	3.1
5	0.0	55.7	10.9	11.6	9.3	12.5	17.5	9.9	9.6
6	0.0	76.7	13.7	5.1	1.3	3.3	7.0	0.5	3.0
7	12.6	28.6	3.7	19.2	15.1	20.8	28.4	10.6	19.4
8	23.8	15.4	3.9	16.1	13.2	27.6	23.7	12.9	22.9
9	28.1	20.3	4.7	11.6	16.1	19.3	20.6	13.8	17.1
10	14.7	40.3	3.8	16.1	6.7	18.4	20.8	6.0	16.7
11	36.1	16.3	3.3	11.1	15.6	17.6	17.9	12.5	15.4

TABLE 29

ROUNDNESS AND SPHERICITY OF COARSE PARTICLES FROM THE STONY MARGIN AND CLAY 'PLUG' (MEAN OF 10x10 SAMPLES)

1	2	3	4	5	6	7	8	9
	Roundness				Sphericity			
Sample number and depth	Co-arse	Me-dium	Fine	Aver-age	Co-arse	Me-dium	Fine	Aver-age
1 0-10	0.35	0.41	0.36	0.37	0.48	0.53	0.51	0.51
2 15-20	0.50	0.53	0.42	0.48	0.57	0.55	0.53	0.55
3 20-25	0.37	0.42	0.37	0.39	0.57	0.62	0.57	0.59
4 25-30	0.42	0.47	0.42	0.44	0.57	0.56	0.52	0.55
5+ 35-40	0.53	0.58	0.45	0.47	0.62	0.59	0.58	0.60
6 40-45	0.45	0.41	0.48	0.44	0.54	0.55	0.60	0.56
Mean	0.44	0.47	0.42	0.43	0.56	0.57	0.55	0.56
Mean Dev.	0.057	0.058	0.033		0.032	0.027	0.032	
Standard dev.	0.065	0.067	0.036		0.042	0.030	0.033	
7 15-25	0.41	0.45	0.47	0.44	0.69	0.68	0.61	0.66
8* 20-25	0.61	0.59	0.57	0.59	0.58	0.57	0.61	0.59
9 25-30	0.48	0.38	0.43	0.44	0.61	0.59	0.57	0.59
10 30-35	0.50	0.45	0.42	0.46	0.56	0.64	0.59	0.60
11 40-45	0.54	0.58	0.56	0.56	0.58	0.59	0.56	0.58
Mean	0.51	0.49	0.49	0.50	0.60	0.61	0.59	0.60
Mean Dev.	0.074	0.08	0.06		0.036	0.036	0.018	
Standard dev.	0.066	0.082	0.064		0.046	0.041	0.021	

	Range of roundness.	Mean	Range of sphericity	Mean
Stone margin:	0.35 to 0.58	0.43	0.48 to 0.62	0.56
Clay plug:	0.38 to 0.61	0.50	0.56 to 0.69	0.60

where P_{16} etc. = the 16th percentile in phi units. The equation for Graphic Kurtosis as developed by Folk and Ward (1957) is as follows:

$$K = \frac{P_{95} - P_5}{2.44(P_{75} - P_{25})}$$

The Skewness and Kurtosis results using the above equations are illustrated in Table 30.

TABLE 30

SKEWNESS AND KURTOSIS VALUES FOR THE CASTEMBED POLYGON

Sample	2	3	4	5	6
Skewness	-.156	+ .109	- .333	- .801	- .375
Kurtosis	+.983	+1.023	+3.484	+1.053	+3.704

Sample	7	8	9	10	11
Skewness	-.061	-.040	-.370	-.645	-.839
Kurtosis	+.641	+.512	+.572	+.901	+.639

Skewness measures the assymetry in the distribution of the particle size in the sample. Positive skewness results from an excess amount of fines while negative skewness illustrates an excess amount of coarse material. (Folk, 1968). Sample 3 is the only one that is fine skewed.

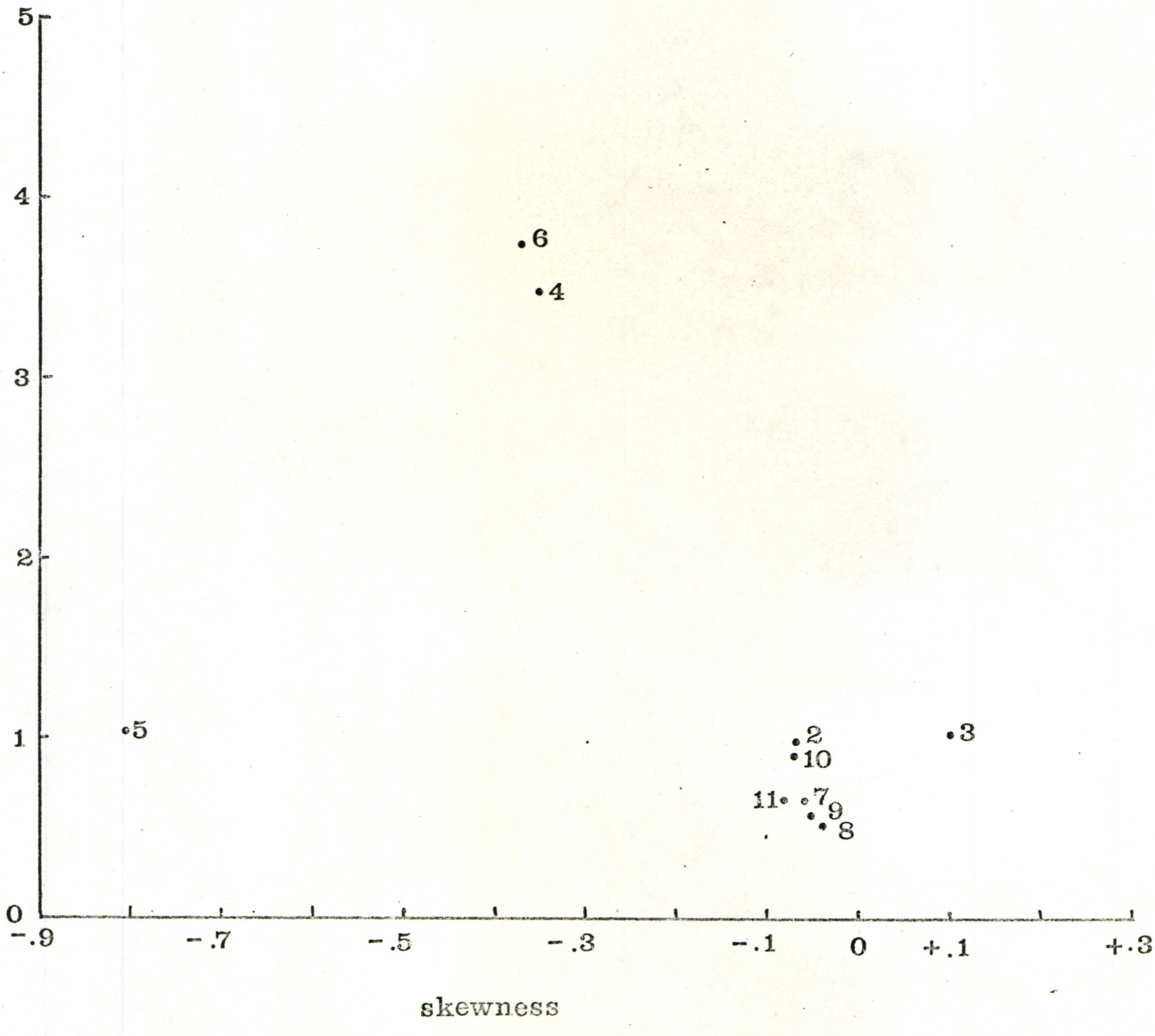
Samples 7 and 8 are near symmetrical while sample 2 is coarse skewed. Samples 4,5,6,9,10 and 11 are stongly coarse skewed. There is no significant distinction in skewness between the polygon border samples and those samples from the polygon centre.

Kurtosis measures the peakedness or compares the sorting in the central part of the distribution with the sorting in the tails. A leptokurtic distribution results from the central portion of the distribution being better sorted than the tails while a platykurtic distribution results from the converse (Folk, 1968). Samples 7,8, and 11 are very platykurtic while samples 2,3,5 and 10 are platykurtic. Samples 4 and 6 are extremely leptokurtic. The distinction between the border samples and those from the centre is still vague with regard to kurtosis.

A plot of skewness versus kurtosis was then employed to enhance any differences between the two sets of samples (Fig. 16). The samples from the polygon centre (7,8,9,10 and 11) showed a near normal distribution and good sorting and were clustered in a small area whereas the samples from the polygon margin illustrated no noticeable pattern.

The sorting in the centre of the polygon may result from the weathering and segregation of the fines

FIGURE 16. PLOT OF SKEWNESS AND KURTOSIS VALUES FOR THE TEXTURE DATA OF THE CASTEMBED POLYGON SAMPLES.



from the larger particles by frost action. The fines are then washed to depth in the polygon. Frost heave then sorts the material, thrusting the coarser material toward the surface and polygon margins.

Polygonal Surface Distribution and Studies in the "Lateral Trench"

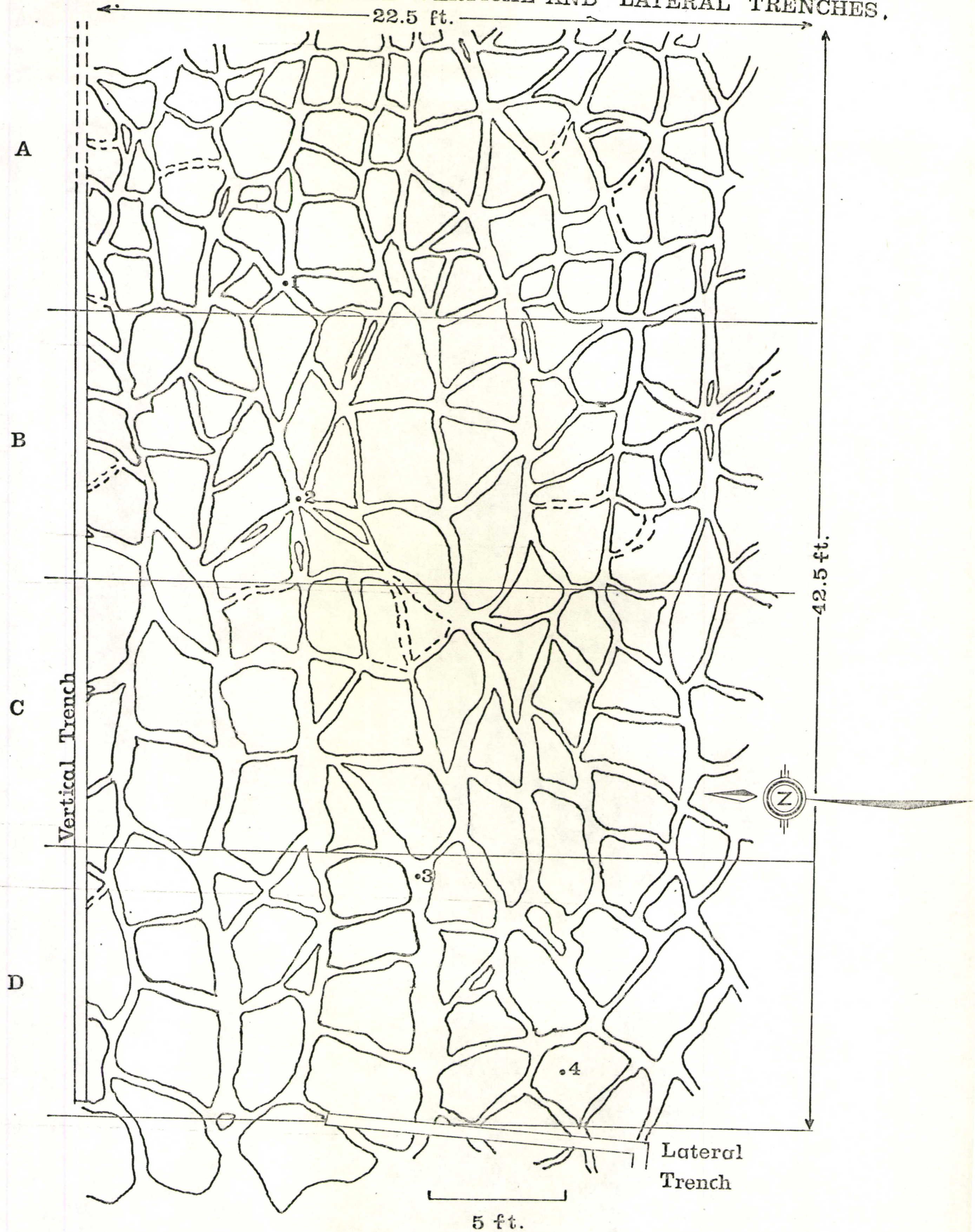
The investigations were aimed at a description of the pattern of a polygonal area or sorted net, the nature of the components of this area and the nature and amount of movement of water in the stony margins. Figure 17 illustrates the surface pattern of the polygonal nets and the locations of the Vertical and Lateral Trenches. It has been subdivided into 4 sections across-slope in order to determine any differences in the distribution of the patterned ground features. Table 31 illustrates the number of polygons, their average width, average length and the length-width ratio for each secton.

TABLE 31

PARAMETERS OF POLYGONAL SURFACE PATTERNS (UNITS OF 15 CM.)

Section	No. of polygons	Ave. width	Ave. length	Ave. Length-width ratios.
A	51	3.55	4.29	1.208
B	35	4.91	6.16	1.255
C	30	5.14	7.33	1.426
D	31	5.84	7.72	1.151

FIGURE 17. SURFACE PATTERN OF THE POLYGONAL NETS AND THE LOCATIONS OF THE VERTICAL AND LATERAL TRENCHES.



These results show that downslope there is a general decrease in the number of patterned ground features or nets with an increase in their size as reflected in the length-width ratios while their degree of elongation tends to increase downslope.

To determine the rate of movement of water along the stone margins eight ounces of Rhodamine W. T. tracer dye was mixed with one gallon of water and inserted at the margins of the patterned ground distribution at the points marked 1,2, and 3 in Figure 17. The amount of time for the dye to appear in the Lateral Trench was then recorded for each point. The times and average velocities are illustrated in Table 32. The dye was also inserted into the centre of one polygon (point marked 4 in Figure 17) using a 12 cm. long bulk density tube to inhibit lateral movement, for the purpose of gaining a rough estimate of vertical percolation.

As the presence of the Lateral Trench may have influenced the seepage velocity in the stone margins leading to it point 3 may be ignored. The readings of 1, and 2a and b may be accepted as typical of the velocities of the water flowing around the polygons in the stone lines. The results from the polygon centre indicated that the centre of a polygon had a permeability of 0.64 in. / min.

TABLE 32

WATER VELOCITIES WITH POLYGONAL PATTERN

Point of Insertion	Time of Traverse Min	Time of Traverse Sec.	Distance Traversed (feet)	Velocity (ft/min.)
1	18	35	25	1.35
2a	12	45	14	1.10
2b	18	30	25	1.35
3	2	40	10	3.75

The results show that the stone margins act as drainage channels for meltwater and precipitation with very high rates of lateral movement while the finer material in the polygon centres is more water holding and has impeded internal drainage.

The Vertical Trench (Figure 17) was dug at right angles to the western face of the raised beach for a distance of 50 feet across the low angled patterned-net or polygon-covered slope upslope from the Meadow Tundra Site (Plates 8,9, and 10). The trench was deepened to permafrost and periodically emptied of water. Table 31 relates to the physical and chemical properties of materials taken from the Vertical Trench. Figure 18a shows the sample locations and a sketch of the texture of the vertical Trench while figure 18b illustrates the pattern of

FIGURE 9

Terrain Map of the Study Area

1	Present Beach
2	Raised Beach
2a	Raised Beach with Polygons
2b	Raised Beach with Stone Stripes
3	Silt Plain
4	Meadow Tundra
5 ●	Palsa Peat
6	Discontinuous Gravel over Fines
7	Stone Stripes with Fines
8	Polygonal Pattern Ground
9	Talus and Cliffs
9a	Talus Cones
10	Course Fluvial Debris
11	Solifluction Lobes
k1	Angular Gravel with Non-sorted Hummocky Relief
k2	Small Stone Nets
k3	Stone Stripes
k4	Dry Loose Gravel
k5	Coarse Stone Nets and Rock Debris
k6	Sorted Gravels Tending to Stone Stripes
k7	Polygonal Patterned Ground
k8	Lenticular Gravel Ridges
CT1	Caswell Tower 1
CT2	Caswell Tower 2
CT3	Caswell Tower 3
▲	Profile Location

SCALE 1:18,750

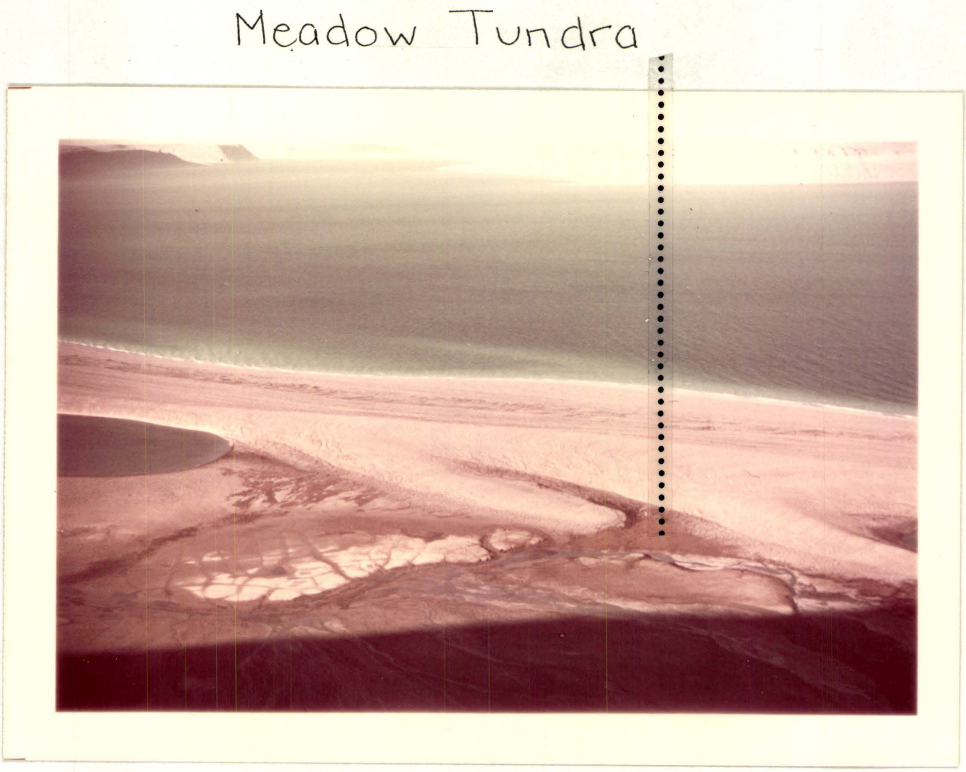


PLATE 8. An oblique aerial view, from the South Plateau, of the main working site. The Meadow Tundra is to the right while the Silt Plain, showing ice-wedge polygon patterns is to the left.

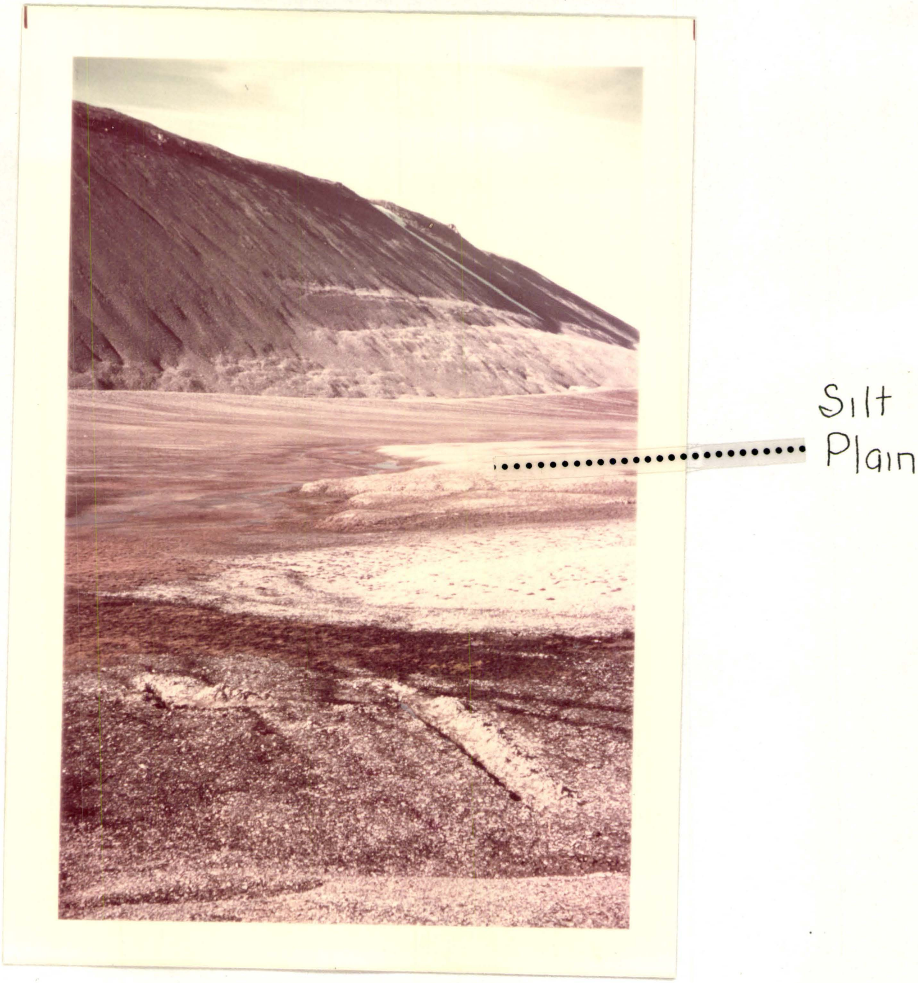


PLATE 9. View of the Lateral and Vertical Trenches at the main working site. The trenches drain left to the Meadow Tundra. The Silt Plain is to the right.

PLATE 10. Close-up of Plate 9 with the Meadow Tundra in the upper left and the Silt Plain in the centre right.

TABLE 33

PHYSICAL AND CHEMICAL PROPERTIES OF SAMPLES FROM THE VERTICAL TRENCH

Sample	Moisture content %	Organic Matter %	Texture (m. m.)							
			Gravel >2	C. Sand 2-.5	M. Sand .5-.25	F. Sand .25-.05	C. Silt .05-.02	M. Silt .02-.005	F. Silt .005-.002	Clay <.002
VT1	14.9	0.3	71.7	16.4	26.5	8.3	5.8	21.1	15.4	14.8
VT2	18.9	0.9	39.4	15.1	11.7	7.1	13.4	28.4	17.1	7.2
VT3	25.5	1.3	82.5	7.5	11.8	17.8	17.2	17.6	16.4	11.7
VT4	21.6	0.8	81.1	25.4	12.2	6.1	11.6	21.4	15.9	7.4
VT5	11.0	0.3	61.1	22.9	14.2	11.2	14.0	25.3	8.8	3.6
VT6	6.7	0-0	87.5	13.3	15.4	12.4	14.2	20.4	13.9	10.4
VT7	10.6	0.3	57.5	33.8	18.3	11.8	8.8	11.0	11.2	5.1
VT8	18.8	0.4	19.1	12.9	14.3	9.7	9.3	27.1	16.6	8.1
VT8B	14.1	0-0	57.2	12.4	15.2	12.6	11.6	25.1	15.9	7.2
VT9	20.1	0.5	30.6	12.1	14.1	15.7	17.5	18.3	14.2	8.1
VT9B	12.1	0-0	67.3	12.2	14.1	11.2	11.4	13.0	15.7	12.4
VT10	65.9	1.1	61.2	13.8	17.3	12.5	10.3	13.4	18.4	14.3
VT10B	14.8	0.3	60.8	6.9	6.7	11.0	19.2	25.1	24.5	7.6
VT11	15.7	0-0	35.5	13.7	17.4	14.0	15.1	18.4	13.6	7.8
VT11B	7.5	2.7	78.7	29.0	21.9	14.4	10.8	11.1	7.7	5.1
VT12	3.5	0-0	94.8	12.4	14.9	15.2	13.7	12.2	16.5	15.1
VT12B	8.4	0.3	71.4	9.8	11.9	11.1	14.3	23.1	19.7	10.1
VT13	21.1	0.8	72.8	17.8	22.1	14.4	11.0	19.8	10.1	4.8
VT13B	15.9	0.4	36.4	9.6	13.2	11.3	17.8	24.4	15.9	7.8
VT13C	8.1	0.3	66.4	8.4	9.5	9.4	18.9	32.9	14.7	6.2
VT13D	8.3	0.3	66.3	13.1	19.0	10.6	13.7	18.2	15.3	10.1
VT13E	5.3	0.4	57.4	26.1	20.1	11.3	10.6	10.3	15.2	6.4

TABLE 33 (contd.)

Sample	Moisture content %	Organic Matter %	Texture (mm.) Gravel >2	C. Sand 2-.5	M. Sand .5-.25	F. Sand .25-.05	C. Silt .05-.02	M. Silt .02-.005	F. Silt .005-.002	Clay <.002
VT15	11.9	0.3	62.8	11.4	9.9	13.9	12.3	20.6	20.1	11.8
VT16	29.1	6.5	79.4	28.7	23.4	14.1	7.4	8.7	12.9	4.8
VT16B	9.3	0.5	65.3	16.4	16.8	14.4	16.2	16.1	11.2	8.9
VT16C	9.4	0.6	73.2	20.1	18.6	13.4	10.5	12.2	13.5	11.7
VT17	13.6	0.5	45.5	10.9	25.2	10.2	12.1	23.9	11.4	6.3
VT18	11.7	0.6	59.7	7.9	15.8	22.5	14.7	15.3	12.7	11.1
VT19	64.7	24.2	79.7	27.4	20.2	12.7	6.8	12.8	12.7	7.4
VT20	3.7	0-0	95.2	17.4	15.5	13.2	11.1	14.7	16.7	11.4
VT21	16.5	0.4	16.5	12.1	13.2	12.5	13.1	18.5	19.5	11.1
VT21B	17.5	0-0	17.5	15.3	17.1	13.3	12.2	19.2	14.8	8.1
VT25:30	8.9	0-0	8.9	21.1	13.2	11.3	10.5	13.5	18.1	12.3
VT25:40	10.8	2.0	10.8	17.2	27.9	11.2	11.6	19.5	14.8	7.8
VT25:50	13.3	0.4	13.3	32.8	22.3	17.4	6.6	5.3	9.4	6.2
VT25:55	6.6	0-0	6.6	19.4	14.7	12.4	5.9	9.7	21.8	15.4
VT38:1	13.6	0-0	13.6	12.9	14.3	10.2	13.0	22.5	15.9	11.2
VT38:2	13.2	0.5	13.2	18.3	18.0	11.6	9.8	15.1	17.4	9.8
VT38:3	15.6	0.4	15.6	12.7	15.4	15.8	13.8	10.7	16.9	14.7
VT99	62.8	0.8	62.8	25.9	17.9	11.5	11.4	28.2	10.4	4.7
VT29.6"	11.5	0-0	11.5	20.9	16.7	13.5	7.1	5.1	20.5	16.2
Mean Centre	11.71	4.56	47.73	14.4	15.5	12.8	13.7	18.4	15.44	9.28
Mean Border	20.31	1.67	51.55	18.5	17.3	12.4	11.1	17.4	15.06	9.35

TABLE 33 (contd.)

Sample	Bulk Density gm./CC.	Liquid Limit %	pH	E.C. mmhos per cm. 25°C.	C.E.C meq/ 100 gm.	Ca PPm	H_2CO_3 PPm
VT1	1.72	23.2	8.10	6.8	6.2	22.5	47.5
VT2	1.93	43.5	8.15	6.6	9.6	17.5	28.8
VT3	1.61	32.8	7.40	.86	7.0	212.5	259.5
VT4	1.58	39.9	7.65	1.8	10.6	77.5	115.5
VT5	1.35	38.9	8.20	4.8	6.8	42.5	60.8
VT6	1.53	37.6	8.20	4.8	7.0	27.5	58.5
VT7	1.81	40.0	8.45	6.2	8.0	22.5	44.1
VT8	1.97	37.4	8.35	6.4	8.8	27.5	39.0
VT8B	1.88	29.1	8.15	6.4	8.4	22.5	36.6
VT9	1.82	42.0	8.15	7.4	10.0	32.5	41.2
VT9B	1.72	26.8	8.20	8.0	5.4	27.5	52.5
VT10	1.42	49.4	6.85	1.42	8.4	122.5	160.9
VT10B	1.44	42.1	8.05	5.2	8.8	27.5	52.7
VT11	1.31	35.5	8.30	6.4	8.8	27.5	45.8
VT11B	2.15	18.5	8.45	13.8	4.0	7.5	18.6
VT12	1.60	43.8	8.15	2.3	9.2	77.5	117.2
VT12B	1.63	23.8	8.30	8.2	7.0	12.5	31.1
VT13	1.42	39.7	7.80	2.4	7.4	77.5	124.8
VT13B	2.04	36.5	8.20	5.6	11.6	77.5	112.1
VT13C	1.76	34.2	8.30	6.4	8.8	32.5	44.2
VT13D	1.88	37.8	8.10	9.0	7.8	22.5	57.4
VT13E	2.01	22.2	8.30	6.6	10.2	22.5	47.2

TABLE 33 (contd.)

Sample	Bulk Density gm./CC.	Liquid Limit %	pH	E.C. mmhos per cm. 25°C.	C.E.C meq/ 100 gm.	Ca PPm	H_2CO_3 PPm
VT15	1.38	37.4	8.40	8.6	7.0	37.5	62.6
VT16	1.26	36.7	6.75	11.8	11.6	187.5	209.0
VT16B	1.89	23.4	8.20	7.2	7.6	12.5	34.0
VT16C	1.20	24.1	8.40	5.8	7.6	42.5	49.3
VT17	1.58	39.3	8.10	7.8	8.8	12.5	16.9
VT18	1.61	20.3	8.20	7.4	8.6	22.5	34.5
VT19	1.62	44.7	7.00	7.6	5.4	252.5	370.8
VT20	1.47	40.3	8.20	4.6	11.6	27.5	43.8
VT21	1.37	38.4	8.20	5.0	11.6	27.5	58.0
VT21B	1.66	33.3	8.35	9.0	11.8	12.5	33.4
VT25:30	1.73	28.8	8.05	7.0	9.2	4.5	9.4
VT25:40	1.87	19.1	8.30	6.6	8.6	32.5	70.4
VT25:50	1.49	18.5	8.50	9.0	5.6	22.5	29.1
VT25:55	1.45	22.9	8.40	6.6	4.8	27.5	42.6
VT38:1	1.31	40.4	7.95	4.3	10.6	42.5	56.6
VT38:2	1.41	35.3	7.25	2.3	11.2	82.5	96.3
VT38:3	1.62	27.1	8.15	8.4	6.4	27.5	80.1
VT99	1.42	51.9	7.85	4.3	16.2	37.5	76.5
VT29.6"	1.86	26.2	8.55	4.7	7.8	32.5	63.5
Mean Centre	1.70	29.68	8.16	7.10	8.49	30.94	52.29
Mean Border	1.58	36.31	8.00	5.67	8.64	59.58	87.84

penetrometer readings at depth along the trench. The low penetrometer readings correspond to the stone borders while the higher penetrometer values reflect the finer centres of the patterned ground features and the compacted fine material at depth. The bulk density and high penetrability reading of this compact material recalls the so-called fragipan or BX horizons in soils on till in temperate latitudes. The form of the permafrost table noted on August 1st is moderately undulating. The influence of the protective cover of the snowbank can be seen in the left (east) side of the diagram where there is a relatively marked decrease in depth to permafrost. The shallowest depths to permafrost correlate with the stone borders. This is a result of the lower thermal conductivity of the coarser areas (the result of increased pore space) when compared to the finer-textured polygon centres which show a greater depth to the permafrost table.

Table 33 shows the physical and chemical properties of the samples from the Vertical Trench. Although all the samples upslope of sample 21 are gravelly, there is still a difference in the percent fines between the margins and the centres. Clay values are generally less than 15%. Samples 13 to 13D show the increase of clay to depth presumably from frost processes and cryoturbation. There is also some indication that this feature is also present in samples 38:1 to 38:3.

There is no colour change in the various profiles (2.5Y5/3) although some surface samples show a slightly darker value possibly as a result of higher organic matter content. The pH of the profiles increases with depth. These high pH values may result from the high quantity of calcite in these features, or the lessened influence of organic matter. Samples 10 and 16 are the only samples which show a slight acidic reaction. This may result from the nature of the organic material on their surfaces or from possible animal contamination. The calcium and alkalinity values indicate a decrease in their concentration with depth. Evaporation may cause these ions to precipitate in the surface and near surface areas.

Bulk density seems to increase with depth while liquid limit tends to decrease. Bulk density figures reflect the increased quantities of fines and the increased values of penetrability with depth.

To detect any further contrasts in the vertical Trench, the samples were classed into two groups: those samples from the polygonal centres and those samples from the margins. Surface samples were included in the class of margin samples because of their high gravel contents. The averages for each property for each of these two classes were then determined. The results are shown in Table 33. Gravel and sand values are higher in the stone borders than in the centres whereas the organic matter content is lower. Moisture content is lower in the centre than in the border as are liquid limit, cation exchange capacity, calcium and alkalinity. Bulk density, pH and electrical conductivity are higher in the centre than at the margins. The organic matter and textural differences may perhaps be related to the cryoturbic action which is responsible for moving the coarser particles to the surface and the margins and also move the organic matter to depth in the margins.

Profile development consists only of an "O" organic layer underlain by a "C" layer. The "O" layer was common to the area but did not completely cover the site. The stone borders had more organic cover than did the polygon centres since soil moisture is more readily available at the margins than in the centres and the cryogenic processes are less active as well. Cryoturbation is the most important factor in explaining the absence of profile development since its churning action would tend to obliterate any evidence of horizonation. Cryoturbation was proposed by Ugolini (1966) as the reason for lack of profile development in active polygons. Vertical Trench profiles show no evidence of pedogenic action other than the higher clay content at depth, the higher pH at depth and the concentrations of salts at the surfaces.

Trend Surface Analysis of Two Polygons

The two polygons chosen for this study of variability of properties within polygon features were the Lateral Trench (Plate 12) and Polygon 1 (Plate 13). Polygon 1 was located approximately 400m north of the Lateral Trench (Figure 13) on the inland side of the beach ridge. The features revealed in the Lateral Trench excavation seemed to be less active than Polygon 1. The surface of its stony borders was overlain by a large amount of organic matter and the whole central part of the structure was dry and firm under a person's weight. Polygon 1, on the other hand, exhibited thixotropic tendencies when weight was added to its surface. Also its surface had no organic matter.

Figures 19 and 20 represent cross-sectional diagrams of the Lateral Trench and Polygon 1 respectively. Tables 34 and 35 illustrate the physical and chemical properties of the Lateral Trench and of Polygon 1 respectively.

The Lateral Trench has a larger amount of gravel extending to depth at its margin than in its centre. There is a higher clay content with depth at its centre.

PLATE 12. View of the Lateral Trench Polygon. Tape measure shows the scale.

PLATE 13. Oblique view of Polygon 1. (See Figure 13 for location.)

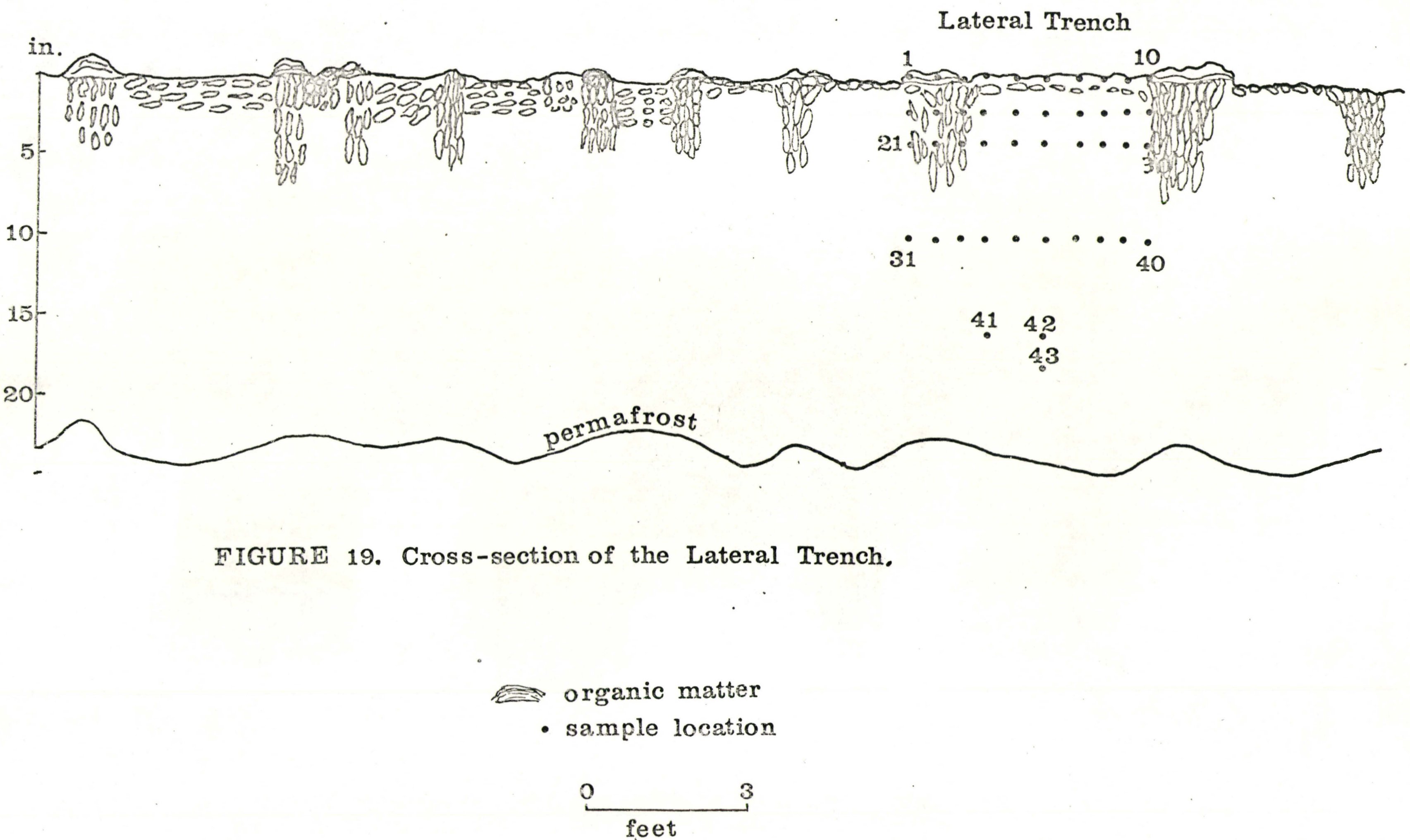


FIGURE 19. Cross-section of the Lateral Trench.

FIGURE 20. CROSS-SECTION OF POLYGON 1.

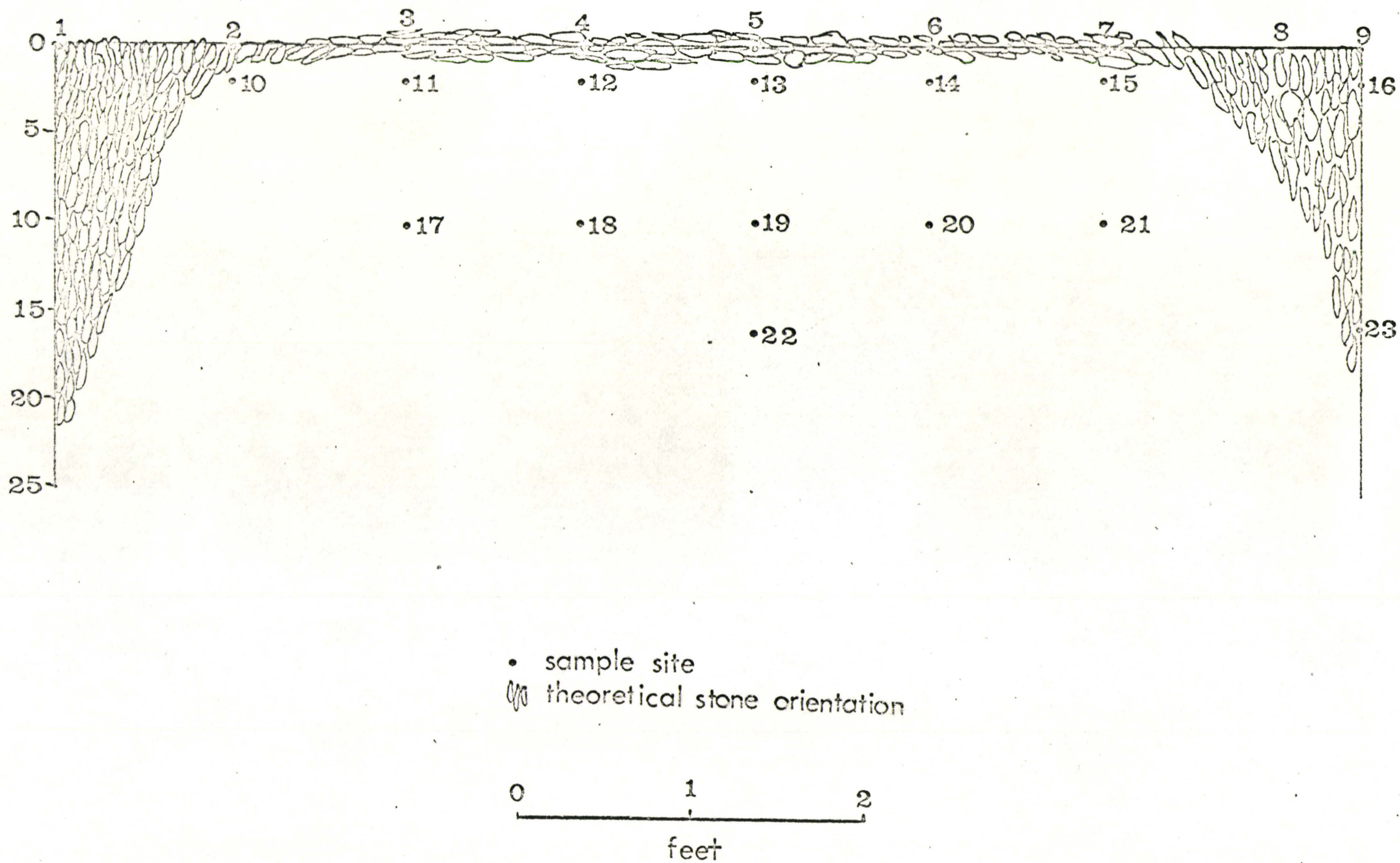


TABLE 34

PHYSICAL AND CHEMICAL PROPERTIES
OF THE LATERAL TRENCH

Sample	Moisture content %	Organic Matter %	Texture (m.m.)							
			Gravel >2	Sand -.5	M. Sand .5-.25	F. Sand .25-.05	C. Silt .05-.02	M. Silt .02-.005	F. Silt .005-.002	Clay <.002
LT1	160.5	29.9	63.3	22.9	21.9	18.1	7.4	7.4	11.1	11.2
LT2	138.1	32.5	46.6	27.2	16.1	11.3	3.3	3.4	18.6	20.1
LT3	84.5	2.4	74.7	42.3	19.9	12.4	2.3	1.0	14.2	7.9
LT4	20.9	0.0	39.3	20.9	14.8	12.2	11.9	11.6	12.7	14.9
LT5	11.7	0.8	75.2	32.7	22.5	18.6	5.9	4.2	8.7	7.4
LT6	20.6	1.7	56.6	27.4	22.6	14.7	9.1	7.1	9.5	8.6
LT7	24.3	0.0	63.2	25.3	21.1	13.9	4.1	5.4	15.2	15.0
LT8	18.1	0.3	59.6	33.2	25.9	13.1	5.4	5.0	9.1	8.3
LT9	15.9	0.0	56.3	25.4	18.5	14.0	11.9	12.3	10.1	7.8
LT10	4.6	34.9	57.9	31.9	23.4	14.6	4.9	4.5	10.9	9.8
LT11	9.9	0.2	75.4	9.9	8.0	9.7	12.2	15.4	25.5	21.3
LT12	8.7	0.7	86.5	22.8	18.5	10.8	5.6	7.4	18.2	16.7
LT13	7.3	1.6	84.2	24.6	18.2	13.4	7.9	9.7	13.9	12.3
LT14	13.6	1.0	60.6	27.8	21.0	13.4	5.7	6.9	12.0	13.2
LT15	14.9	1.0	54.3	27.2	19.3	13.7	10.7	11.9	12.5	8.7
LT16	9.1	0.0	61.7	26.2	17.9	13.4	5.8	8.6	15.9	12.2
LT17	10.8	0.0	52.7	24.1	21.0	14.1	9.6	8.3	9.2	13.7
LT18	9.1	0.0	63.3	23.9	22.4	18.9	7.9	5.2	10.3	11.4
LT19	13.5	0.4	44.4	19.4	16.3	11.5	10.3	11.9	13.9	16.2
LT20	9.2	0.5	88.8	18.1	18.2	13.8	7.5	7.5	17.3	17.6
LT21	10.7	0.0	82.6	17.3	13.8	9.1	11.7	21.9	16.1	10.1
LT22	10.5	0.0	84.9	22.2	25.9	15.8	8.4	5.4	12.6	9.7

TABLE 34 (contd.)

Sample	Moisture content %	Organic Matter %	Texture (mm.) Gravel >2	Sand -.5	M. Sand .5-.25	F. Sand .25-.05	C. Silt .05-.02	M. Silt .02-.005	F. Silt .005-.002	Clay <.002
LT23	12.3	0.0	73.8	26.9	15.9	12.4	9.5	9.4	11.7	14.2
LT24	9.2	0.0	72.4	27.5	27.4	15.4	4.7	2.8	14.1	8.1
LT25	12.4	0.0	65.4	24.8	21.1	16.7	5.0	3.8	16.2	12.4
LT26	10.1	0.0	60.6	26.1	21.8	14.8	7.5	3.6	8.1	18.1
LT27	12.9	0.0	64.3	23.4	18.7	20.4	4.9	11.4	10.8	15.3
LT28	10.5	0.0	57.0	27.8	22.3	16.5	5.3	3.5	17.0	7.6
LT29	13.0	0.0	58.4	26.9	19.5	13.9	6.5	7.1	15.2	10.9
LT30	11.6	0.0	85.5	22.7	19.6	13.1	7.4	9.9	12.6	14.7
LT31	25.0	0.0	65.5	26.3	21.1	17.5	5.2	7.6	15.1	7.2
LT32	10.7	0.0	73.0	34.8	22.4	18.7	5.8	3.2	10.2	4.9
LT33	9.3	0.0	61.6	25.1	20.2	12.6	9.5	8.3	12.7	11.6
LT34	11.0	0.0	66.2	20.9	21.4	17.0	8.6	8.3	10.7	13.1
LT35	11.9	0.0	65.8	28.4	29.5	15.9	7.6	5.9	5.9	6.8
LT36	15.9	0.0	46.9	22.1	21.1	19.2	5.2	4.8	10.5	17.1
LT37	15.4	0.0	49.2	27.5	18.6	13.3	12.9	11.9	9.7	6.9
LT38	13.0	0.0	53.3	23.9	26.3	22.3	3.9	4.5	10.4	8.7
LT39	13.2	0.0	78.8	25.7	24.2	19.5	6.9	6.6	7.3	9.8
LT40	13.3	0.0	75.7	24.9	18.9	18.1	9.8	8.2	6.2	13.9
LT41	14.1	0.0	59.3	22.6	23.7	18.5	7.3	8.1	7.4	12.4
LT42	11.9	0.0	66.1	25.9	26.2	15.5	8.7	5.5	6.6	11.6
LT43	8.7	0.0	73.7	24.7	22.5	22.1	6.8	2.5	11.6	9.8

TABLE 34 (contd.)

Sample	Bulk Density gm./cc.	Liquid Limit %	pH	E. C. mmhos/ cm 25°C.	CEC. meq/ 100 gm	Ca ppm	H_2CO_3 ppm.
LT1	1.01	54.1	6.65	1.0	12.6	152.5	181.9
LT2	1.52	26.6	7.05	3.9	9.4	47.5	82.8
LT3	1.82	35.7	7.55	2.3	9.2	77.5	192.3
LT4	1.71	25.2	8.05	2.3	7.4	32.5	106.7
LT5	1.91	36.9	7.95	2.9	7.6	57.5	137.9
LT6	1.51	26.7	7.75	2.6	9.2	63.5	146.2
LT7	1.42	27.3	7.25	1.16	4.4	152.5	279.8
LT8	1.52	31.4	8.05	3.3	10.0	47.5	120.4
LT9	1.65	32.1	7.90	5.4	5.8	32.5	72.3
LT10	1.49	52.5	6.95	11.6	13.6	182.5	309.5
LT11	1.19	41.1	7.85	1.9	5.4	97.5	200.7
LT12	1.93	51.1	8.25	19.5	12.0	77.5	169.9
LT13	1.54	24.9	8.30	2.9	7.0	67.5	144.9
LT14	1.86	27.6	8.30	6.0	10.2	27.5	69.0
LT15	1.57	30.0	8.15	5.8	9.8	37.5	61.1
LT16	1.73	24.9	8.20	7.6	7.2	17.5	45.8
LT17	1.88	27.2	8.25	6.0	7.6	4.5	8.3
LT18	1.61	31.3	8.65	10.4	8.2	7.5	18.4
LT19	1.68	32.1	8.35	8.2	4.6	22.5	31.6
LT20	1.91	49.8	8.30	3.6	12.8	47.5	74.9
LT21	1.38	46.7	8.20	6.0	10.4	32.5	48.8
LT22	1.74	43.6	8.40	8.0	14.8	32.5	34.5

TABLE 34 (contd.)

Sample	Bulk Density gm./cc.	Liquid Limit %	pH	E. C. mmhos/ cm 25°C.	CEC. meq/ 100 gm	Ca ppm	H_2CO_3 ppm.
LT23	1.36	37.5	8.60	8.4	4.4	7.5	13.9
LT24	1.92	29.6	8.75	14.0	1.6	8.5	15.1
LT25	1.50	30.8	8.55	11.8	9.8	37.5	64.2
LT26	1.79	28.6	8.45	12.8	6.6	27.5	19.9
LT27	1.70	32.6	8.55	12.4	14.4	12.5	26.3
LT28	1.67	28.5	8.65	14.4	4.2	17.5	21.0
LT29	1.58	31.4	8.70	7.0	7.6	17.5	18.1
LT30	1.78	49.6	8.60	8.9	7.8	37.5	46.5
LT31	1.81	32.8	8.00	15.5	9.4	37.5	102.0
LT32	1.39	25.2	8.60	13.0	5.6	17.5	45.0
LT33	1.79	20.8	8.85	10.6	5.8	22.5	42.8
LT34	1.67	28.2	8.55	6.4	8.8	37.5	67.9
LT35	1.76	26.9	8.45	18.0	7.8	27.5	31.9
LT36	1.52	30.0	8.45	11.8	9.6	27.5	31.8
LT37	1.54	26.7	8.55	6.6	5.8	32.5	65.1
LT38	1.38	27.6	8.60	17.0	7.8	27.5	65.1
LT39	1.58	39.3	8.60	10.0	11.4	27.5	62.1
LT40	1.52	40.9	8.60	11.6	12.8	22.5	54.1
LT41	1.55	29.5	8.45	14.2	9.4	17.5	49.1
LT42	1.71	33.6	8.60	15.5	5.4	22.5	54.1
LT43	1.95	31.4	8.70	9.2	9.6	32.5	61.1

TABLE 35

PHYSICAL AND CHEMICAL PROPERTIES OF POLYGON 1

Sample	Moisture content %	O.M. %	Texture (mm.)							
			Gravel >2	C. Sand 2-.5	M. Sand .5-.25	F. Sand .25-.05	C. Silt .05-.02	M. Silt .02-.005	F. Silt .005-.002	Clay <.002
1	6.2	0.0	91.7	12.4	11.3	15.2	13.9	14.9	17.9	17.4
2	16.1	0.0	42.8	15.4	15.7	13.8	15.4	16.0	12.6	11.1
3	11.5	0.0	39.9	24.4	18.4	15.3	8.8	7.8	10.2	15.1
4	12.3	0.0	39.4	14.9	14.7	12.7	12.4	15.5	14.9	4.9
5	10.7	0.0	50.9	17.7	16.7	18.2	13.5	23.0	10.9	8.9
6	13.2	0.0	40.7	17.9	19.3	15.2	12.9	12.2	9.9	12.6
7	13.5	0.0	39.5	13.9	11.2	11.8	12.9	13.0	17.4	19.8
8	14.0	1.1	87.8	20.3	19.8	17.4	9.9	10.3	9.6	12.7
9	14.9	1.4	91.9	17.9	19.7	18.6	8.6	8.1	12.0	15.1
10	23.6	0.0	81.3	13.9	13.7	12.2	9.6	14.2	17.5	18.7
11	11.8	0.0	74.8	11.8	11.1	13.2	12.7	17.6	14.3	19.3
12	9.8	0.0	53.4	18.7	23.5	19.1	6.4	5.1	11.1	16.1
13	11.0	0.0	37.1	22.7	21.1	15.9	7.9	10.1	9.1	13.2
14	11.4	0.3	40.5	20.1	17.3	15.3	9.7	10.4	11.6	15.6
15	16.3	0.4	13.1	14.3	13.3	14.3	16.9	18.4	13.9	8.6
16	3.5	0.0	88.5	30.7	29.6	24.4	5.1	2.7	3.3	4.2
17	8.0	0.4	76.0	17.9	17.7	16.3	9.0	10.2	11.3	17.6
18	18.4	0.0	37.7	22.7	24.8	24.4	7.8	8.0	6.9	13.2
19	2.8	0.0	39.8	19.7	20.1	18.1	8.9	8.3	9.7	15.2
20	12.8	0.3	18.1	19.8	15.3	11.8	10.8	12.4	12.7	17.2
21	11.0	0.3	29.8	19.7	19.9	18.1	10.2	8.7	9.1	14.3
22	9.4	0.0	46.4	27.9	24.9	14.9	7.2	7.9	7.4	9.8
23	10.8	0.0	17.5	22.6	27.2	19.3	9.1	6.6	5.1	10.1

TABLE 35 (contd.)

Sample	Bulk Density gm./CC.	Liquid Limit %	pH	E.C. mmhos per cm. 25°C.	C.E.C meq/ 100 gm.	Ca PPm	H_2CO_3 PPm
1	1.64	30.5	8.55	3.8	5.6	17.5	102.9
2	1.94	20.8	8.55	5.4	5.2	12.5	66.9
3	1.83	16.8	8.60	6.9	3.6	17.5	37.3
4	1.69	17.4	8.65	5.6	4.2	12.5	63.5
5	1.87	19.2	8.70	5.8	4.6	14.8	54.1
6	1.74	16.5	8.70	6.1	4.6	27.5	41.6
7	1.13	19.3	8.45	5.1	5.2	32.5	58.4
8	1.52	34.3	8.00	7.4	5.4	292.5	450.4
9	1.43	32.7	8.45	9.2	3.4	192.5	277.4
10	1.81	24.6	8.45	4.8	4.4	42.5	57.9
11	1.78	27.9	8.65	8.5	6.6	17.5	20.5
12	1.83	19.8	8.80	8.2	6.0	27.5	47.3
13	1.38	13.7	8.90	9.0	5.4	27.5	53.2
14	1.89	18.0	8.75	6.4	4.2	17.5	39.4
15	1.83	19.5	8.70	7.0	3.8	22.5	45.0
16	1.34	23.8	8.60	11.9	5.0	8.5	16.4
17	1.66	22.7	8.90	7.0	3.8	22.5	43.6
18	1.87	14.7	8.75	9.6	4.0	27.5	41.6
19	1.86	15.1	8.70	7.4	4.0	22.5	46.6
20	1.92	17.2	8.65	8.4	3.2	27.5	46.7
21	1.70	19.6	8.45	6.8	4.0	22.5	27.9
22	1.96	15.9	8.50	6.8	4.4	22.5	29.8
23	1.86	14.4	8.80	7.0	3.0	37.5	56.8

However there is no clay increase with depth in the stone margins of the Lateral Trench perhaps the result of the erosive capacity of flowing water which is canalized along its margins. Bulk density and liquid limit increase with depth due to the increased amount of fines or compaction at depth.

The analyses of Polygon 1 (Table 35) also show a greater content of gravel in the stone margins than in the centre. There is also an increase in clay content with increasing depth except in the stone borders for reasons mentioned above. There is a tendency for bulk density to increase towards the centre and to depth in Polygon 1. There is a similar slight decrease in liquid limit with depth and horizontally towards the centre. The pH's of Polygon 1 show no significant change with depth. Calcium and alkalinity values are highest at the stone border surfaces and decrease with depth as well as towards the centre of the polygon as a result of the same process as for the Lateral Trench.

Trend Surface Analysis Results

It was thought that the application of a canonical trend surface analysis (using the procedure outlined in Chapter II on an CDC 6400 computer) to the variates of the two polygons would allow the variates important in the formation of the polygons to be determined and the sampling of polygons for future studies could thereby be reduced. Forty samples from the Lateral Trench were used in the analysis with samples 41 to 43 omitted since their locations were at too great a distance from the other samples and their positions were too close together to give an accurate trend at this depth. The variates used in the analysis are listed as follows:

A) gravel (percent)
B) sand (")
C) silt (")
D) clay (")
E) moisture content
F) organic matter content (% using hydrogen peroxide)
G) bulk density
H) liquid limit (percent)
I) pH
J) electrical conductivity
K) cation exchange capacity
L) calcium ion (p.p.m.)
M) alkalinity (p.p.m.)

In past research, chemical parameters were overlooked in polygonal formation although the writer feels that these may influence or reflect some of the mechanical parameters.

In the first run using all the variates, the Lateral Trench displayed a canonical root of .9643 (10% probability that the resulting trend is due to error). Its associated canonical variates were (letters correspond to the variates in the above list):

$$U = .199A + .197B + .007C + .0450 - .248E - .059F + .032G - .172H + .206I + .067J + .047K + .613L + .631M.$$

and $$V = .4590X - .8838Y - .0037X^2 - .0056XY + .0905Y^2 + .000ZXY^2 - .0019Y^3.$$

The first canonical root (Figure 21) explains the variates calcium and alkalinity. The second canonical root was .9327 (15% probability that the trend is due to chance) with associated equations:

$$U = .629A + .616B + .132C + .150D - .092E - .202F + .014G - .117H - .329I - .029J + .023K - .098L + .050M.$$

and $$V = - .4973X + .8632Y + .0054X^2 + .0155XY - .0807Y^2 - .0001X^2Y + .0012Y^3.$$

This latter root (figure 22) explains variations of the variates gravel and sand. The other variates contribute little to the trend. Similarly for Polygon 1, the first canonical root was .9792 (5% probability that this trend was a result of chance). Its associated equations were:

$$U = .449A - .090B + .288C - .080D + .100E + .152F - .241G - .031H - .153I - .083J + .021K + .479L - .591M.$$

and $$V = - .7359X + .6769Y + .0026X^2 + .0035XY - .0172Y^2$$

FIGURE 21. THE TREND OF THE FIRST CANONICAL ROOT (.9643) USING ALL THE VARIATES FOR THE LATERAL TRENCH.

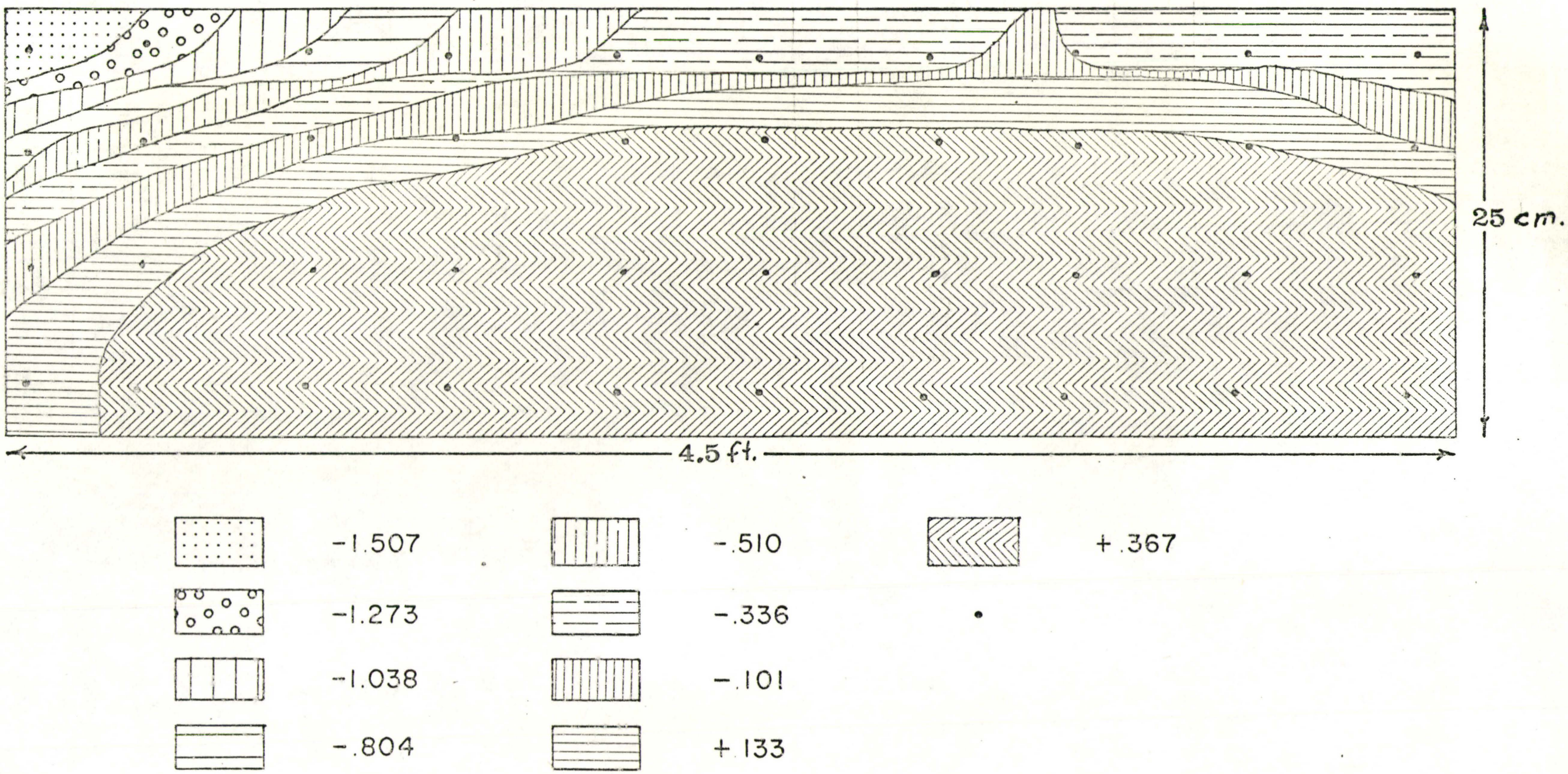
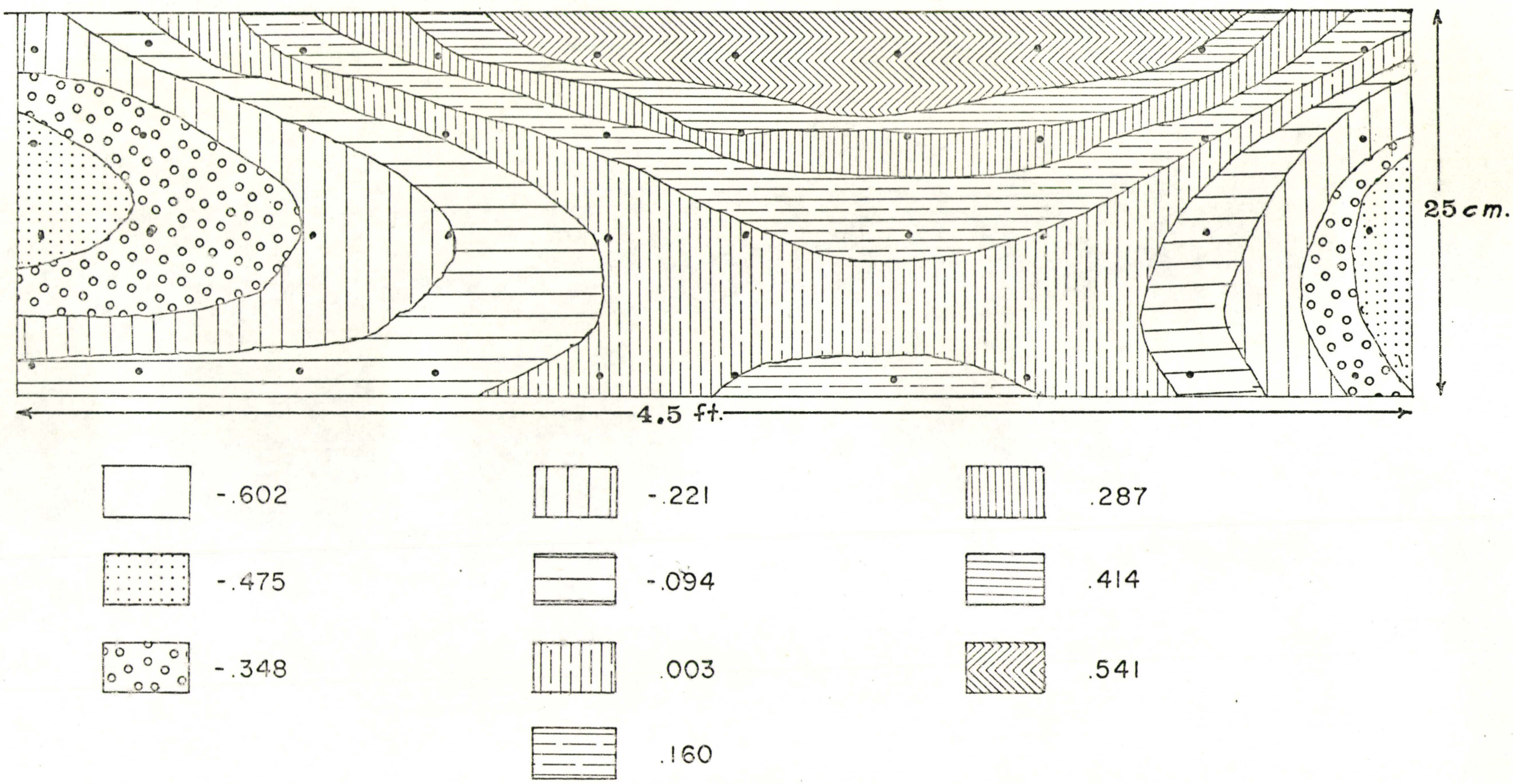


FIGURE 22. The trend of the 2nd canonical root (.9327) using all the variates of the LATERAL TRENCH.



The above canonical root (figure 23) explains variations of the variates gravel, calcium and alkalinity whereas the second canonical root (.9259-15% probability that the trend is due to chance) explains variations of gravel, sand, clay, calcium and alkalinity (Figure 24). Its associated equations are as follows:

$$U = -.720A - .312B - .121C - .338D - .083E - .008F - .053G - .080H - .141I - .031J + .033K + .296L - .360M.$$

and $V = .2930X + .9561Y - .0001X^2 - .0046XY - .0058Y^2$

The other variates do not contribute to the trend.

Two subsequent computer runs were made for each polygon: one using the contributing variates and the other using the non-contributing variates. The result for the Lateral Trench using the dominant variates produced a canonical root of .9417 (15% probability that this resulted from chance). Its associated canonical variates were:

$$U = -.012A + .115B - .628L + .769M$$

and $V = -.2035X + .9732Y + .0016X^2 + .0038XY - .1020Y^2 - .0001X^2Y + .0007XY^2 + .0034Y^3.$

The second canonical root (.8951-15% probability of chance) had the following canonical variates:

$$U = .257A + .601B + .553L - .517M.$$

and $V = .3691X + .9284Y - .0030X^2 - .0373XY - .0212Y^2 + .0003X^2Y + .0012XY^2 - .0001Y^3.$

FIGURE 23. The trend of the 1st canonical root (.9792) using all the variates of Polygon 1.

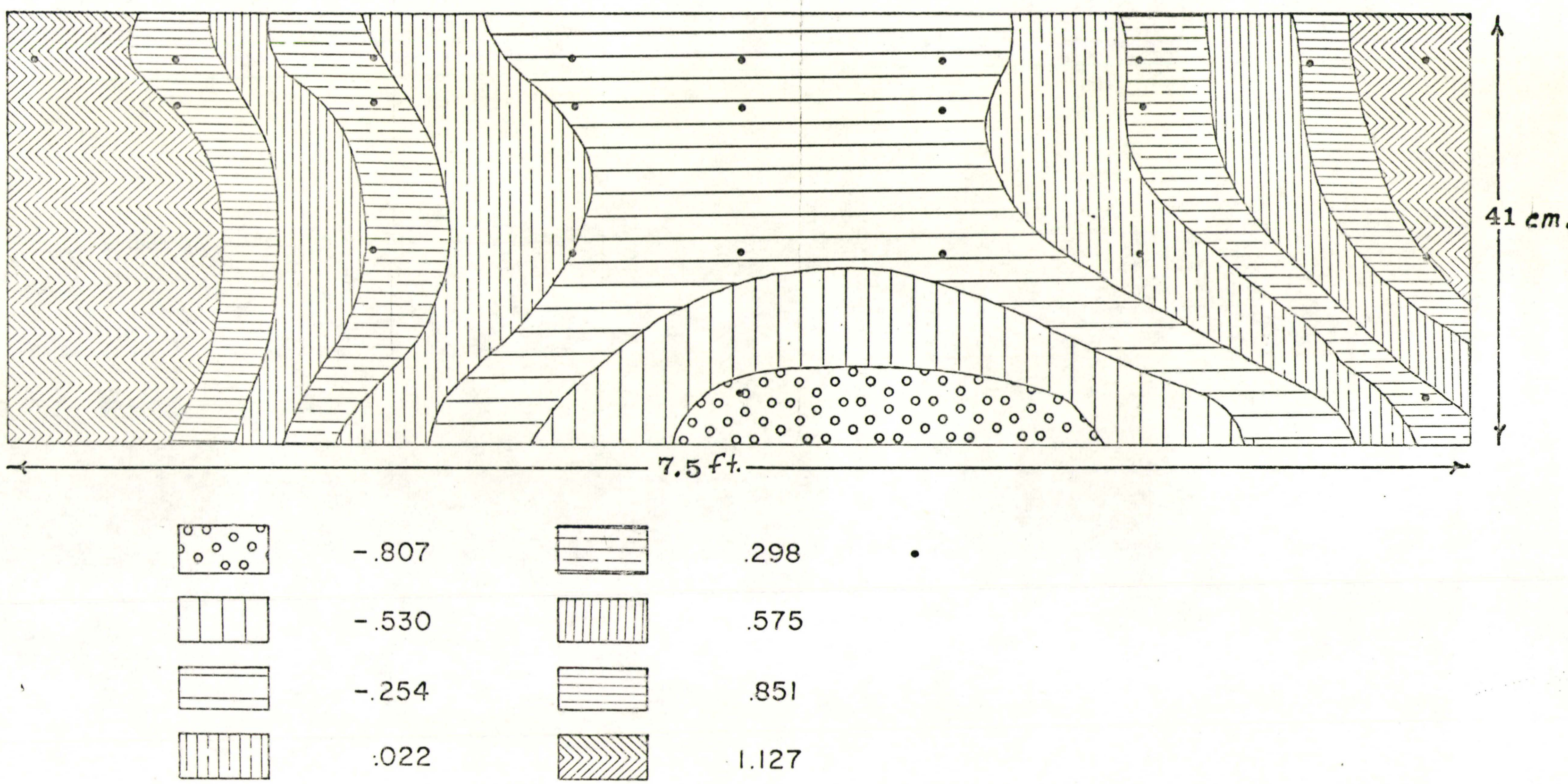
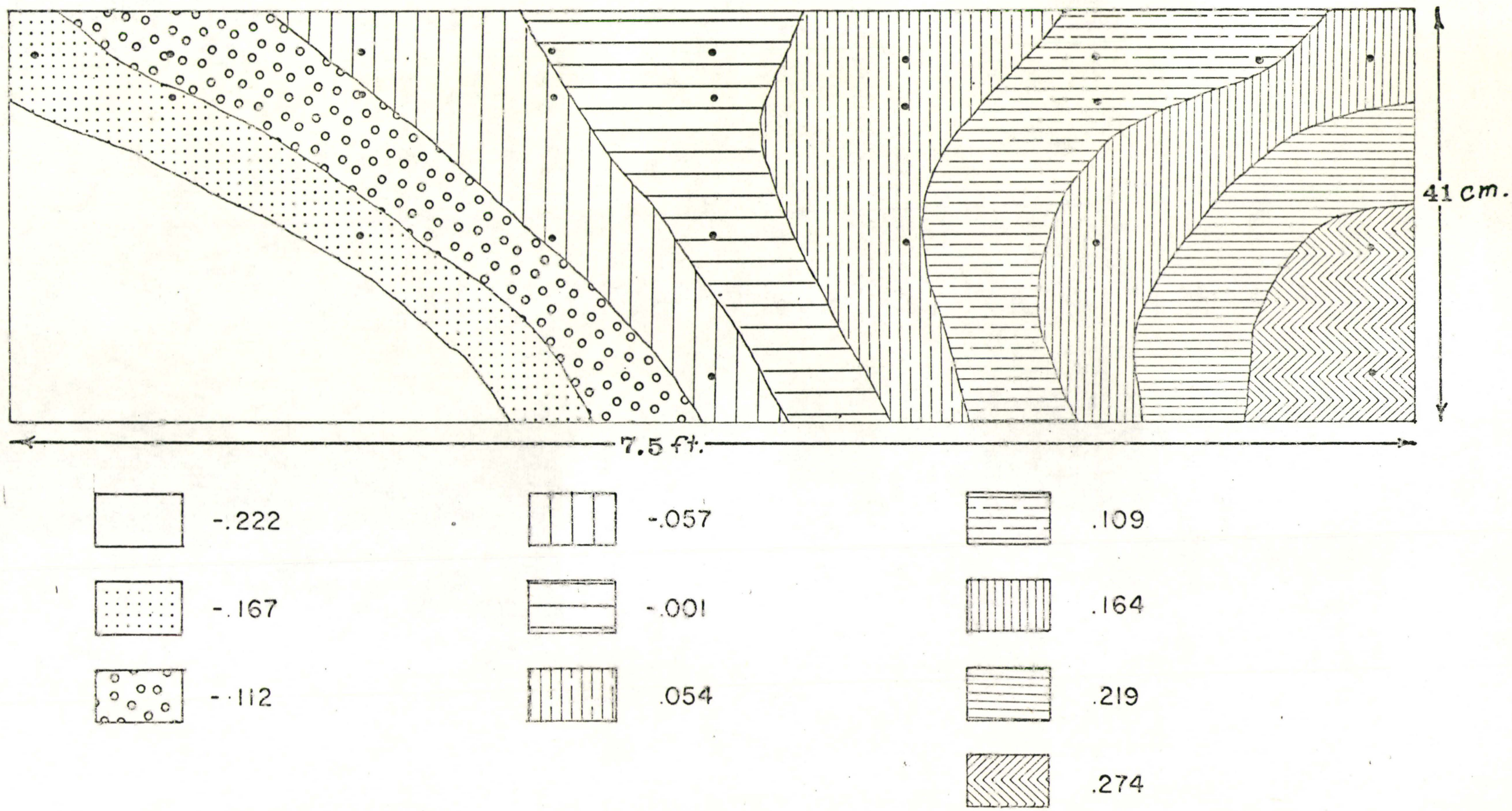


FIGURE 24. The trend of the 2nd canonical root (.9259) using all the variates of Polygon 1.



The first canonical root (figure 25) explains variations of sand, calcium, and alkalinity whereas the second canonical root (figure 26) explains variations of the same variates. Thus gravel is of minor importance in the dominant variates. Using the non-contributing variates for the Lateral Trench, the first canonical root was .9395 (15% probability that this trend was due to chance). Its associated variates were:

$$U = -.053C + .251D + .332E - .221F + .002G + .429H - .739I - .156J - .144K.$$

$$\text{and } V = -.2523X + .9649Y + .0048X^2 - .0011XY - .0722Y^2 + .001X^2Y - .0003XY^2 + .0015Y^3$$

The second canonical root (.8708-20% probability due to chance) had the following associated canonical variates:

$$U = -.051C + .160D + .110E + .300F - .059G + .585H + .718I - .044J - .084K$$

$$\text{and } V = .6553X - .7509Y - .0056X^2 - .0190XY + .0804Y^2 + .0002X^2Y - .0002XY^2 - .0011Y^3.$$

The first canonical root (figure 27) explains the variations of pH and liquid limit while the second canonical root (figure 28) explains variations of liquid limit and organic matter.

The result of the run using the dominant variates for Polygon 1 gave a canonical root of .9462 (10% probability

FIGURE 25. The trend of the 1st canonical root (.9417) using the dominant variates for the Lateral Trench

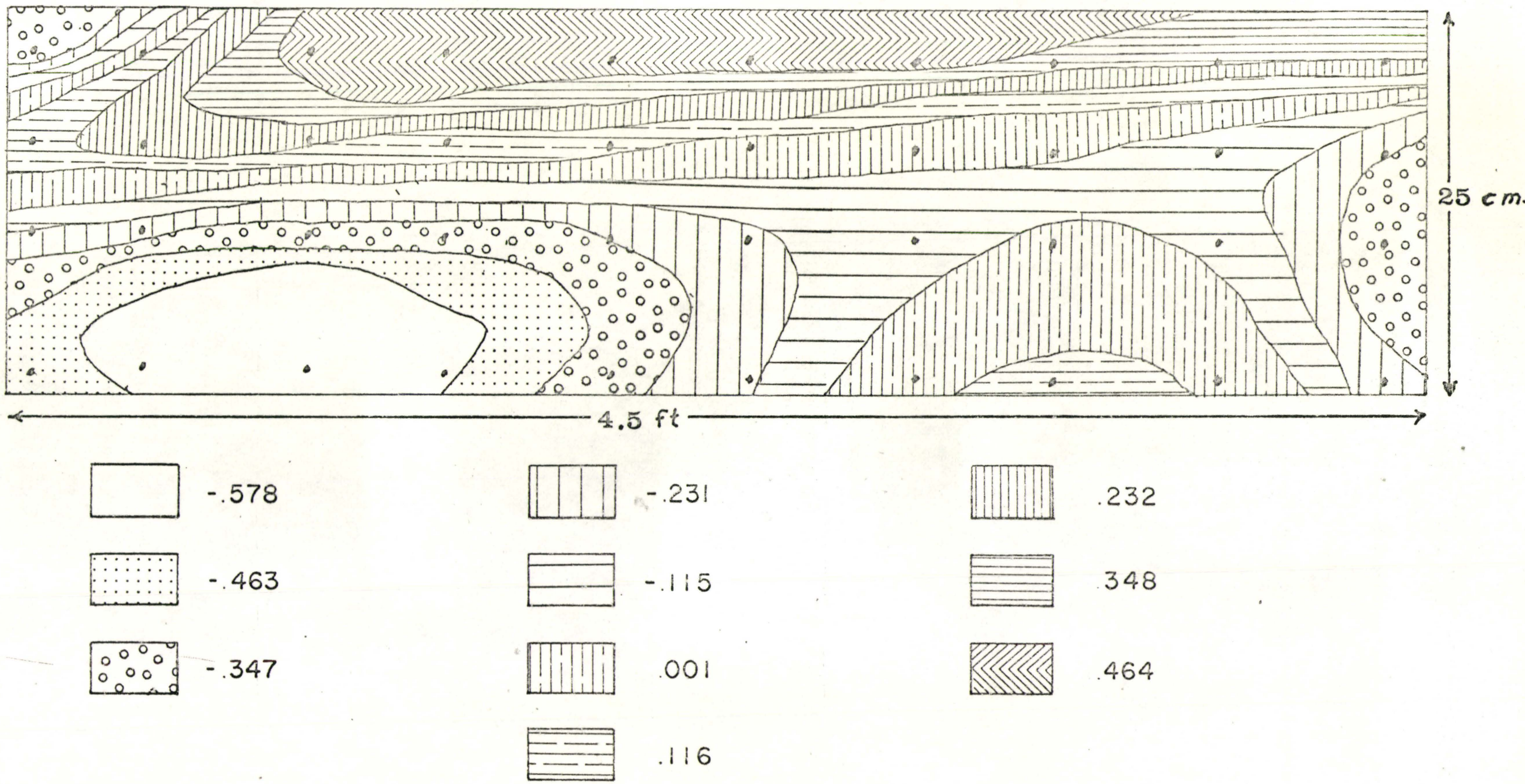


FIGURE 26. The trend of the 2nd canonical root (.8951) using the dominant variates for the Lateral Trench.

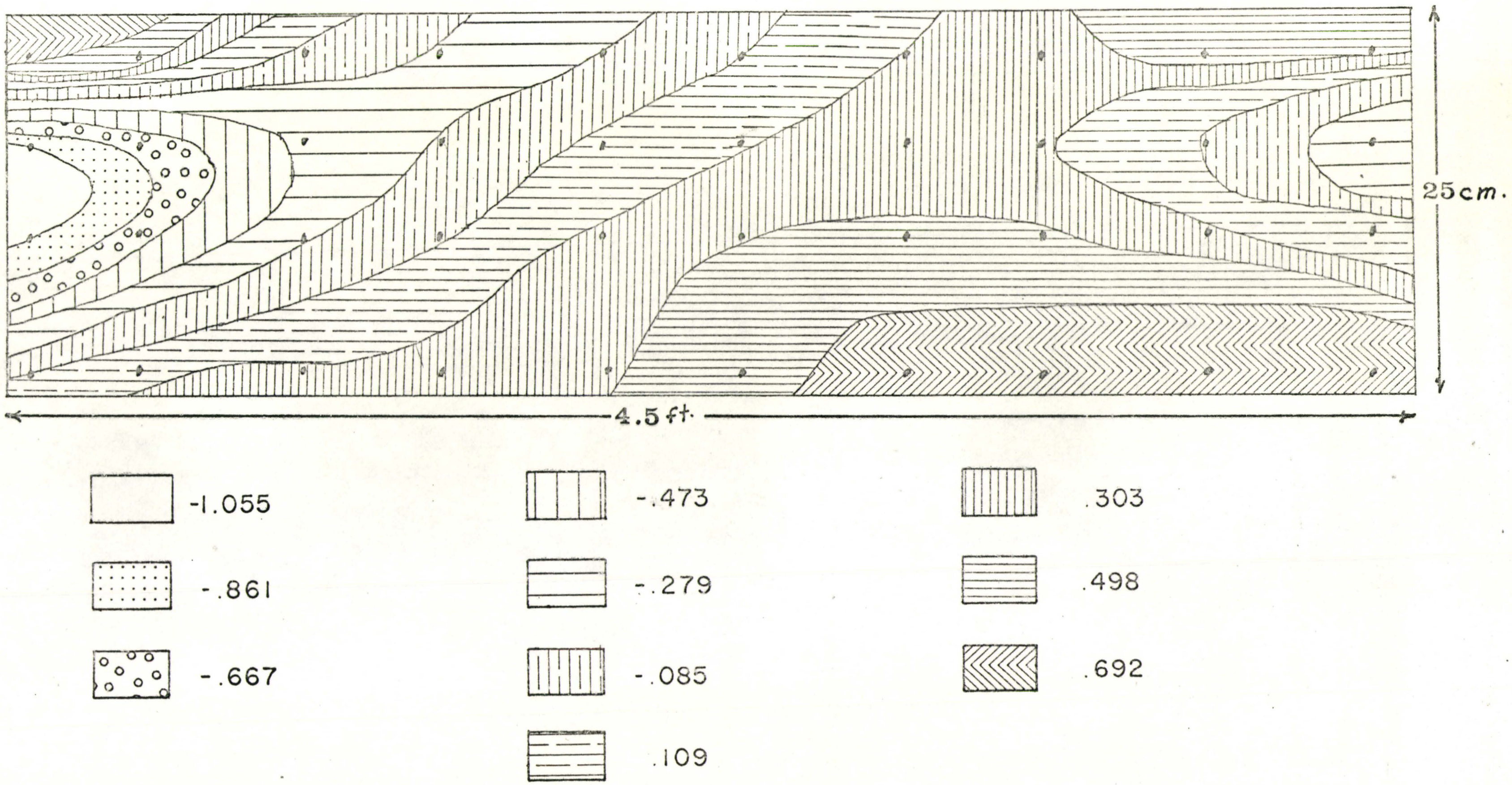


FIGURE 27. THE TREND OF THE FIRST CANONICAL ROOT (.9395) USING THE NON-CONTRIBUTING VARIATES OF THE LATERAL TRENCH.

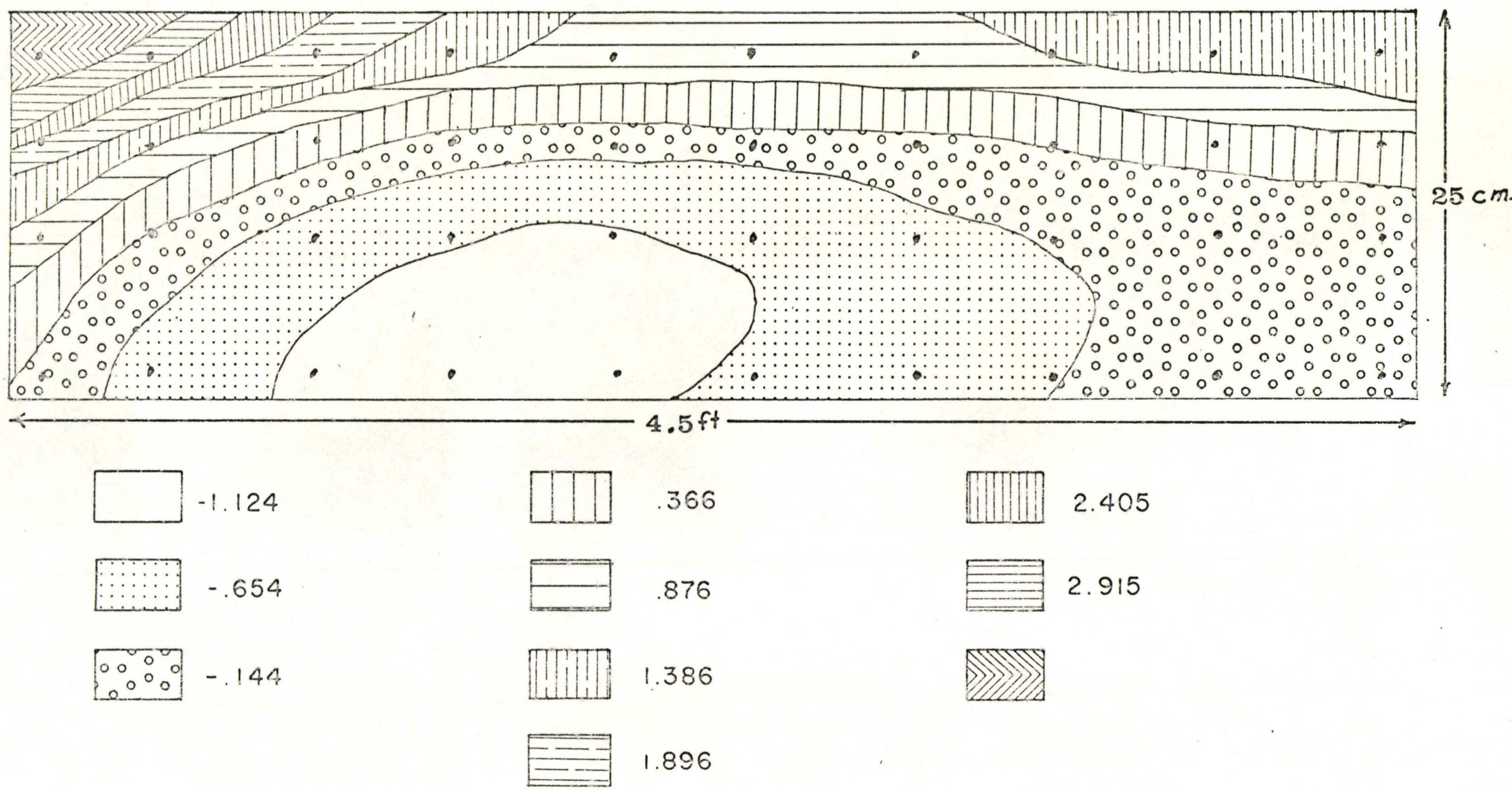
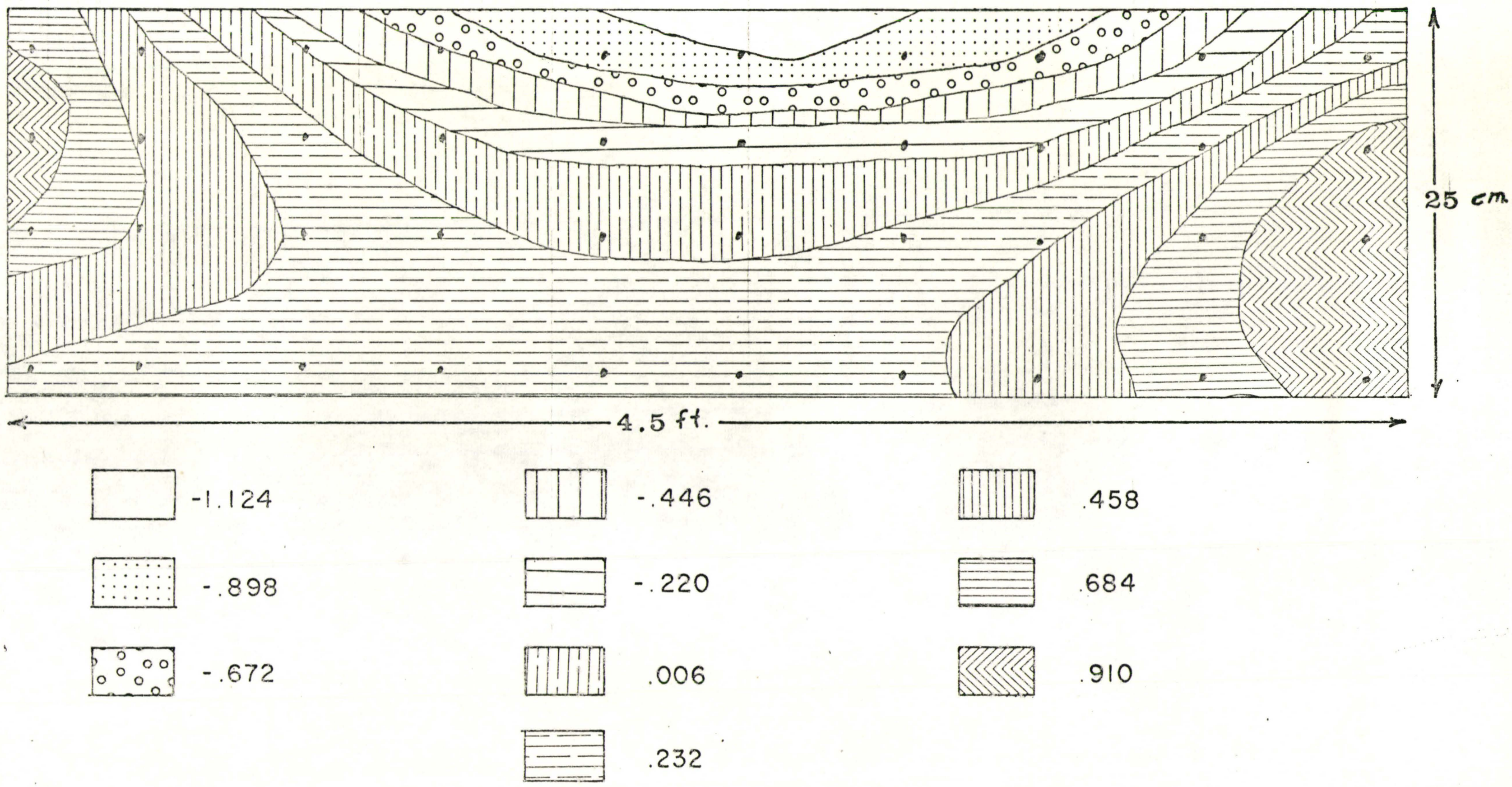


FIGURE 28. The trend of the second canonical root (.8708) using the non-contributing variates of the Lateral Trench.



that the trend was due to chance). Its corresponding canonical variates were:

$$U = -.282A + .519B - .330D - .628L + .385M$$

and $$V = .0184X - .9995Y + .0001X^2 + .0045XY + .0247Y^2 - .001XY^2 - .0001Y^3$$

Its second canonical root was .8457 (20% probability that the trend was due to chance) with the associated canonical variates:

$$U = -.139A + .008B + .259D - .456L + .840M.$$

and $$V = .3315X + .9433Y - .0011X^2 - .0107XY - .0108Y^2 + .0001XY^2$$

The first canonical root (figure 29) explained variations of sand clay, calcium and alkalinity while the second canonical root explained variations of calcium and alkalinity (figure 30). The trend of the non-contributing variates for Polygon 1 produced a canonical root of .9659 (10% probability that this was a result of chance). Its corresponding canonical variates were:

$$U = -.161C + .256E - .162F - .038G + .503H + .706I - .098J - .338K$$

and $$V = -.2715X - .9623Y + .0012X^2 + .0077XY + .0171Y^2 - .001XY^2 - .0001Y^3$$

The second canonical root for the non-contributing variates

FIGURE 29. The trend of the first canonical root (.9462) using the dominant variates for Polygon 1.

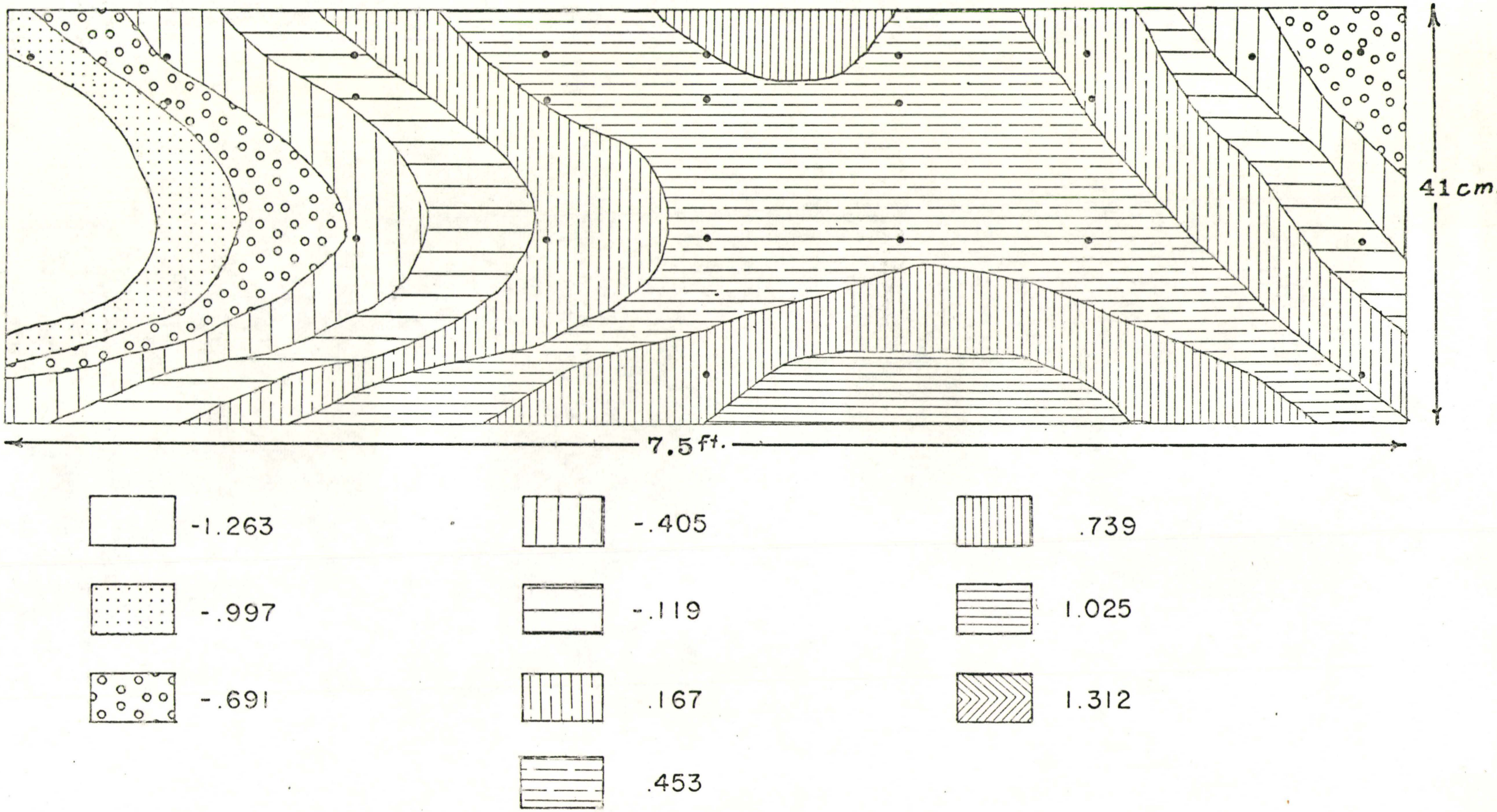
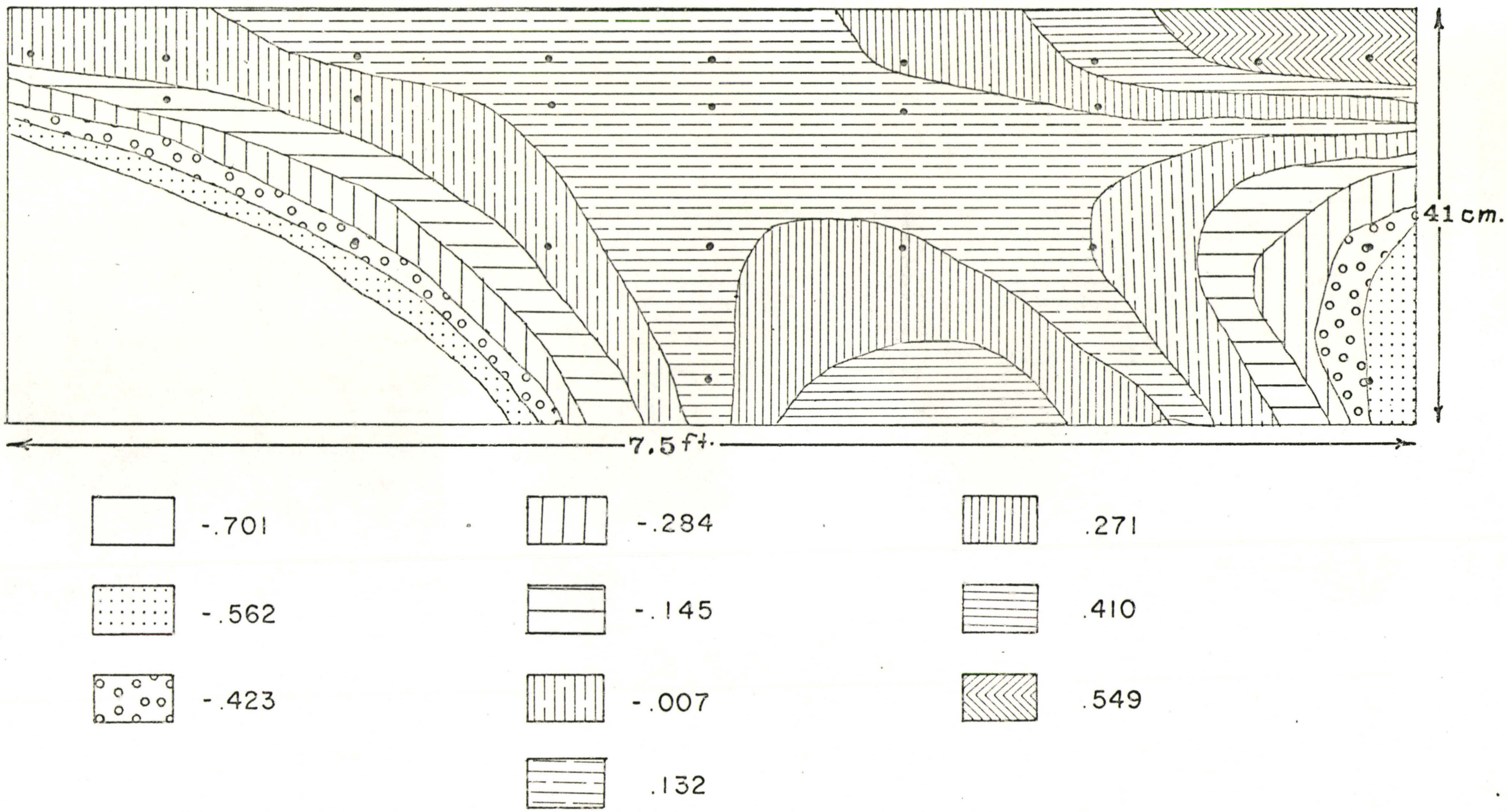


FIGURE 30. The trend of the second canonical root (.8457) using the dominant variates for Polygon 1.



was .9598 (10% probability due to chance) with the associated canonical variates:

$$U = -.049C + .333E + .026F - .455G + .818H + .073I - .062J - .039K$$

and
$$V = -.3517X - .9351Y + .0001X^2 + .0026XY + .0439Y^2 - .0001XY^2 - .0006Y^3.$$

The first canonical root explained variations of liquid limit, pH, and electrical conductivity (figure 31), whereas the second canonical root explained variations of moisture, bulk density and liquid limit (figure 32).

The resulting trend using all the variates of the Lateral Trench illustrated a typical cross-section of a polygon as related to texture (gravels on the border and surface-figure 21). The trend using the contributing variates for the Lateral Trench was much more complex showing a low area in the lower left-hand section (figure 25). A "saddle" shape appeared in the right-hand sector which compared well with the second canonical root using all the variates (figure 22). Using the non-contributing variates for the Lateral Trench, a low area was illustrated in the same section as that for the dominant variates (figure 27). However its overall pattern more closely approximated the run using all the variates than did the run using the dominant variates. The saddle shape of the second trend using all the variates (figure 22) was more

FIGURE 31. The trend of the first canonical root (.9659) using the non-contributing variates of Polygon 1.

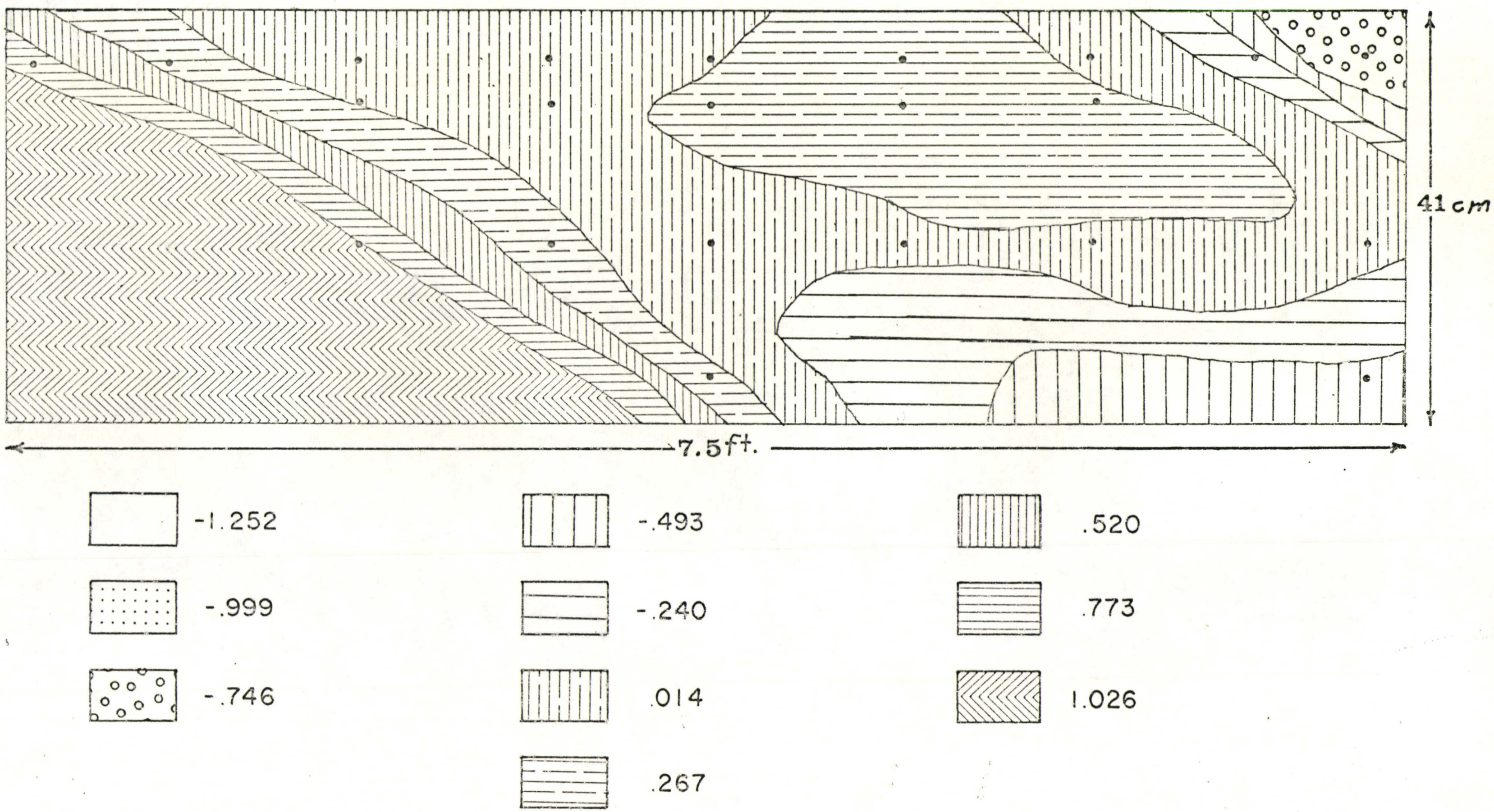
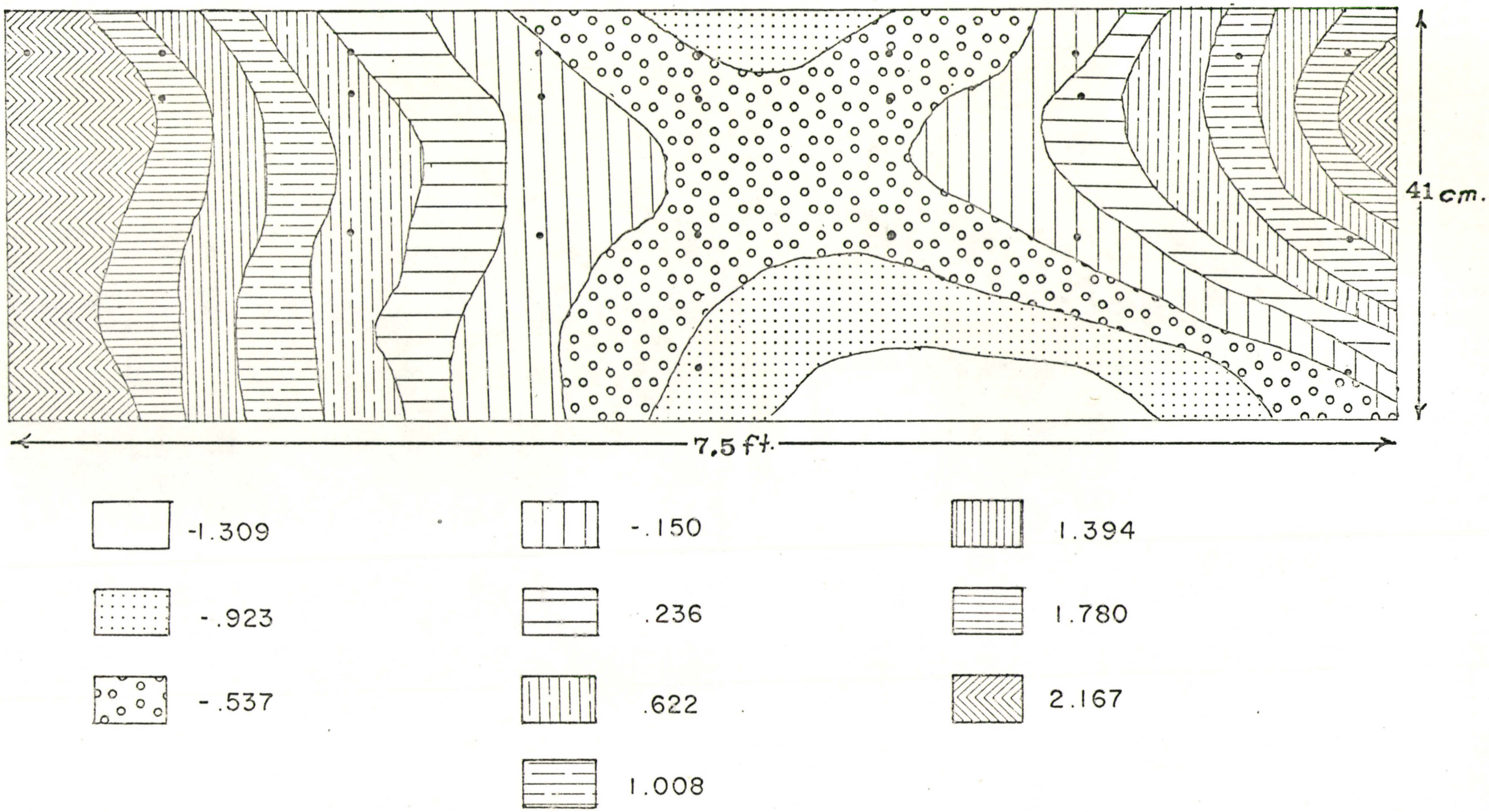


FIGURE 32. THE TREND OF THE SECOND CANONICAL ROOT (.9598) USING THE NONCONTRIBUTING VARIATES OF POLYGON 1.



closely repeated by the second trend using the non-contributing variates (figure 28) than by the second trend using the contributing variates (figure 26). This would seem to imply that gravel, sand, pH, liquid limit, organic matter, calcium, and alkalinity have some relevance in the resulting trend of the Lateral Trench.

As in the case of the Lateral Trench, the resulting trend of all the variates for Polygon 1 approximated the cross-section of a "typical" polygon (figure 23). The pattern was duplicated in the first canonical root of the trend of the contributing variates (figure 29).but, there was no similarity in the resulting trend of the first canonical root using the non-contributing variates (figure 31). In analyzing the trend surfaces of the second canonical roots, there is some similarity in the left-hand sectors of the trends for all the variates and the contributing variates (figures 24 and 30). The trend of the second canonical root using the non-contributing variates illustrated a "saddle". There were some similarities between this trend and the trends of the second canonical roots above, again located in the left-hand sector (figure 32). It would thus appear that the non-contributing variates, unlike those of the Lateral Trench, have no influence on the resulting trends. It is concluded that gravel, sand, clay, calcium and alkalinity are the only contributing variates for Polygon 1.

Conclusions of the Trend Surface Analysis

Unfortunately, the apparent difference in the activity of the two polygons was not conclusively proved using this type of analysis. However, the differences in the importance of the variates organic matter and pH may be explained by the greater inactivity of the Lateral Trench. If the Lateral Trench were active, its instability would likely hinder the development of plant species, and also the vertical differentiation of pH. Organic matter was not detected in Polygon 1 so that no statistical comparison could be made using this variate. The pH would therefore be the only variate on which to base an explanation of the differing characters of the two polygons. Meaningful results could not be drawn from this one variate alone.

This study is by no means complete but it seems to have indicated several dominant variates common to the two polygons analyzed. Since the parent material of these two features is limestone debris in the form of beach gravels it would influence the high values of calcium and alkalinity as compared to areas of igneous or metamorphic rocks. As a result, these two variates should be removed if this method of analyzing polygons is to be applied elsewhere. It would appear that texture (gravel, sand, silt and clay) is the dominant aspect of the resulting trends and as such should be given more weight in future analyses.

CHAPTER VI

CONCLUSIONS

1) Soils

The soils of Southwest Devon Island show little profile development both in the coastal lowlands and the plateau areas. Profile development or, more correctly, textural differentiation on the South Plateau is restricted to increased clay content and decreased gravel content with depth. However these features are present only in some of the soils of the South Plateau. These soils derive their characteristics directly from the parent rock and display no real profile development. Therefore the soils of the South Plateau are Lithosolic in origin.

The soils of Caswell Tower show profile development similar to the soil units of South Plateau. Very little organic matter was present in these or the South Plateau soils. There is some increase of clay with depth as well as some colour changes. However it is thought that these differences in colour are a result of differences in moisture content rather than being indicative of variations in the intensity of weathering.

The soils of the coastal lowlands show more evidence of pedogenic alteration and in some cases have 2 to 3 inches of complete in situ organic cover. However most of these soils illustrate only minor or no profile development. In some of these soils, colour changes at the permafrost table indicate that gleying is present in the lower thawed layers and in the permanently frozen material. No mottles are present in the gleyed layers which would indicate seasonal or periodical aeration or waterlogging. Increase of clays with depth is also a feature of some of the soil profiles of the coastal lowlands. Only partial decomposition of organic matter was present in these soils, this fibrosity being a further indication of the incipient nature of the pedogenic processes.

Drainage samples collected from some of these soils also reflect this incipient degree of soil development. The higher values of the measured cations (Ca^{++}, Mg^{++}, Cl^{-}, NO_3^{-}) and the lower pH found in the permafrost drainage samples may result from a past pedologic influence which could possibly be ascribed to the post-glacial climatic optimum. In this regard it could be assumed that depth to permafrost was greater and temperatures were possibly higher than at present. Thus the weathering capabilities under such a regime would be higher with greater mobilization of divalent cations which would have accumulated at a depth now permanently frozen.

2) <u>Chemical Alteration in the Area</u>

The degree of chemical alteration found in these soils is extremely low. Results indicate that only Ca^{++} is mobilized to any significant degree in the soil (see Drainage Samples from a Meadow Tundra Soil in Chapter II). The Ca^{++} ion is then transported by either surface or subsurface drainage waters to streams. The stream waters show no increase in the Ca^{++} ion concentration downstream indicating that no further Ca^{++} mobilization is occurring within the streams themselves.

There is some external supply of ions from the sea in the form of air-born sea spray. It is concluded in Chapter II that this process is responsible for the dominant supply of chloride ions to the study area since precipitation samples contain Cl^- concentrations which are slightly greater than the drainage samples. The bedrock analyses (Chapter I) show no chloride ion content except that located in the chlorite clay minerals. However it has been shown in Chapter II that no observable weathering of these clay minerals is present.

The source of the moisture in the drainage seeps at the base of the South Plateau scarp is either meltwater from perennial snowbanks or a mixture of precipitation and permafrost meltwater originating within the talus or or on the South Plateau.

3) Polygonal and Patterned Ground

It has been shown in Chapter IV that patterned ground features, traditionally geomorphic phenomena, may be analyzed and described as if they were pedogenic features. As the slight slope ($<4^{o}$) on which these have formed decreases, their size increases and their length-width ratios decrease.

Skewness and kurtosis values of the grain size distribution from one polygon have shown that the samples obtained and analyzed from the polygonal centre are well-sorted with a near-normal distribution whereas the samples from the margins display a non-normal distribution. This may result from frost processes which tend to sort the material moving the coarse material (gravels) to the surface and margins and thus produce a well-sorted polygon centre.

Use of tracer dye showed that the flow of water in the polygonal patterned ground was greater in the margins than in the central sections of these features as a result of the low permeability of the silt and clay centres. This may explain the presence of organic matter found on the surface of the polygonal margins.

The canonical trend surface analysis has determined that texture is the dominant pedomorphic feature in explaining the cross-sectional shape of polygonal features. For further investigations it is concluded that this variate (gravel, sand, silt and clay) is the main one to be considered for analysis.

4) The Terrain Map

The pedomorphic units illustrated in the terrain map of the area (Figure 9, Chapter III) are defined by surface texture, degree of wetting and organic cover. The soils of the coastal lowland originated from a large variety of geomorphic processes and as such are characterized by an extremely complex assemblage of surface conditions whereas the soils located on the plateaux are relatively uniform having been derived by frost processes from local bedrock. Organic cover is almost completely absent on the plateau surface resulting in the dominance of mineral soils associated with sorted forms of patterned ground whereas the coastal lowland displays some organic cover particularly in the Meadow Tundra soil. Within the coastal lowlands, continuous permafrost and numerous depressions resulted in a predominance of poor drainage, even on gravel beach surfaces at low levels. Thus it may be possible, if not desirable, to equate these soils with the generally poorly-drained tundra soils further south and term them cryaquentic soils.

APPENDIX

```
         6400 END OF RECORD

C      CANONICAL TREND SURFACE PROGRAM
C     DEPARTMENT OF GEOGRAPHY
C    REVISED FROM P. J. LEE PROGRAM FOR IBM 7040
C      SUBROUTINES REQUIRED EMERVC, MATINV
C
      REAL IPOLY
      DIMENSION Q(903),R11(27,27),R22(15,15),R12(27,15),
     1PRO ( 27,15 ) , PRO1 ( 15,15 ) , SUMSQ (42) , SUM
     2(42) , A( 9,9 )
      DIMENSION SIG(300),E(42),DOT(10),P 4 2 ),D(42),NTRA
     1(15),NTYPE(15),POLY(50,50),B(300),C(300),FMT(20),
     2DM(300,17),TITLE(20),VARIAT(45),IPOLY(50,50),
     3RESIDU(300),TERM(27),MAPING(300,2)
      COMMON VEC(15,15),PRO2(15,15)
      EQUIVALENCE (POLY,IPOLY)
      DATA TERM/4H  X,4H  Y,4H  X2,4H XY,4H Y2,4H X3,4H
     1X2Y,4H XY2,4H  Y3,4H  X4,4H X3Y,4HX2Y2,4H XY3,4H
     2Y4,4H  X5,4H X4Y,4HX3Y2,4HX2Y3,4H XY4,4H  Y5,4H
     3X6,4H X5Y,4HX4Y2,4HX3Y3,4HX2Y2,4H XY5,4H  Y6/
      DATA DOT/2H 0,2H 2,2H 3,2H 4,2H 5,2H 6,2H 7,2H 8,2H 9/
      DATA SAMPLE,BLANK/2H *,2H  /
      READ(5,2) TITLE
    2 FORMAT(20A4)
      READ(5,1) N,M,NTRA,NORDER,FEET
    1 FORMAT(I3,2I2,I1,F8.0)
      S=N
      WRITE(6,3) TITLE
    3 FORMAT(1H1,20X,20A4///)
      IF(MTRA.EQ.0) GOTO 13
      READ(5,201) (NTRA(I),NTYPE(I),I=1,MTRA)
  201 FORMAT(26(I2,I1))
   13 MU=M*3
      READ(5,6) (VARIAT(I),I=1,MU)
    6 FORMAT(18A4)
      READ (5,2) FMT
      WRITE(6,999)FMT
  999 FORMAT (IHO,20A4)
      XMAX=-100000.0
      XMIN=100000.0
```

```
      YMAX=-100000.0
      YMIN=100000.0
      M90=M+27
      IM90=(27+M+1)*(27+M)/2
      DO 20 I=1,M90
      SUM(I)=0.0
   20 SUMSQ(I)=0.0
      DO 21 I=1,IM90,1
   21 Q(I)=0.0
      DO 131 ISAMPLE=1,N
      READ(5,FMT) X,Y,(D(J),J=1,M)
      IF(MTRA.EQ.0) GOTO 11
      DO 15 ITRA=1,MTRA
      JTRA=NTRA(ITRA)
      KTYPE=NTYPE(ITRA)
      IF(KTYPE.EQ.1.OR.KTYPE.EQ.2.OR.KTYPE.EQ.3.OR.KTYPE.
     1EQ.4.OR.KTYPE.EQ.5.OR.KTYPE.EQ.6) GOTO 202
   19 WRITE(6,12)
   12 FORMAT(1H0,30H WRONG CODE FOR TRANSFORMATION)
      STOP
  202 GOTO(9,10,301,302,303,304),KTYPE
    9 D(JTRA)=ASIN(SQRT(D(JTRA)))
      GOTO 15
   10 D(JTRA)=ALOG10(D(JTRA))
      GOTO 15
  301 D(JTRA)=ALOG10(D(JTRA)+1.0)
      GOTO 15
  302 D(JTRA)=ALOG(D(JTRA))
      GOTO 15
  303 D(JTRA)=ALOG(D(JTRA)+1.0)
  304 D(JTRA)=SQRT(D(JTRA))
   15 CONTINUE
   11 DO 16 J=1,M
   16 DM(ISAMPL,J)=D(J)
      DM(ISAMPL,M+1)=X
      DM(ISAMPL,M+2)=Y
      XMAX=AMAX1(X,XMAX)
      YMAX=AMAX1(Y,YMAX)
      XM1N=AMIN1(X,XMIN)
      YMIN=AMIN1(Y,YMIN)
      DO 130 I=1,1,M
      SUM(I)=SUM(I)+D(I)
  130 SUMSQ(I)=SUMSQ(I)+D(I)*D(I)
  131 CONTINUE
      DO 126 I=1,M
```

```
    SUMSQ(I)=SQRT((S*SUMSQ(1)-(SUM(I))**2)/(S*(S-1.0)))
126 SUM(I)=SUM(I)/S
    WRITE(6,96)
 96 FORMAT(1H1,30X,5H MEAN,5X,19H STANDARD DEVIATION/)
    IV1=0
    DO 93 I=1,M
    IV=IV1+1
    IV1=1V+2
 93 WRITE(6,95) ((VARIAT(J),J=IV,IV1),SUM(I),SUMSQ(I))
 95 FORMAT(1H0,10X,3A4,5X,F10.3,7X,F12.3)
    WRITE(6,106)
106 FORMAT(///)
    DO 127 J=1,N
    DO 127 I=1,M
127 DM(J,I)=(DM(J,I)-SUM(I))/SUMSQ(I)
    DO 129 I=1,M90
129 SUM(1)=0.0
    DO 8 IS=1,N
    DO 128 J=1,M
128 D(J)=DM(IS,J)
    X=DM(IS,M+1)
    Y=DM(IS,M+2)
    L=M
    A(I,1)=1.0
    DO 17 I=1,6
    DO 18 J=1,1
    A(J,I+1)=A(J,1)*X
    L=L+1
 18 D(L)=A(J,I+1)
    A(I+1,I+1)=A(I,I)*Y
    L=1+1
 17 D(L)=A(I+1,I+1)
    DO 8 I=1,M90
 22 SUM(I)=SUM(I)+D(I)
    DO 8 J=1,M90
    L=(J-1)*J/2+1
    Q(L)=Q(L)+D(J)*D(I)
  8 CONTINUE
    DO 25 I=1,M90
    DO 25 I=1,M90
    K=(J-1)*J/2+1
 25 Q(K)=(S*Q(K)-SUM(I)*SUM(J))/(S*(S-1.0))
    J3=0
    WRITE(6,102) N
```

```
102 FORMAT(1HO,10X,19H COVARIANCE MATRIX,10X,21H THE
   1SAMPLE SIZE IS I5//)
    DO 103 J=1,M
    K=0
    DO 104 I= 1, J
    KK=J*( J-1) /2+1
    K=K+1
104 E(K) = Q(KK)
    J2=J3+1
    J3=J2+2
    WRITE(6,105) ((VARIAT(J1),J1=J2,J3) , (E(K1),
   1K1=1,K))
105 FORMAT(1HO,5X,3A4,15F7.3)
103 CONTINUE
    ROOT = 0.000
    ITERM=0
    WRITE ( 6,113 )
113 FORMAT(1H1,10X,53H RECORD OF SUCCESSIVE EVALUATION
   1TREN SURFACE D EGREE///)
125 DO 27 NPOWER=1,NORDER
    IPOWER=NPOWER
    ITERM=IPOWER+ITERM+1
    IF(M.GT.ITERM) GOTO 37
    NL=ITERM
    NR=M
    DO 32 I=1,NR
    DO 32 J=1,NL
    K=(J+M-1)*(J+M)/2+1
 32 R12(J,1)=Q(k)
 33 DO 35 I=1,NR
    DO 35 J=1,NR
    L=J*(J-1)/2+1
    R22(I,J)=Q(L)
 35 R22(J,I)=R22(I,J)
    CALL MATINV(R22,NR,15,IERR)
    IF(IERR.EQ.0) GOTO 29
 39 WRITE(6,34)
 34 FORMAT(IHO,45H GEOLOGICAL VARIATE MATRIX CANNOT
   1BE INVERTED)
    STOP
 29 DO 31 I=1,NL
    DO 31 J=I,NL
    K=(J+M-1)*(J+M)/2+1+M
    R11(I,J)=Q(K)
 31 R11(J,I)=R11(I,J)
```

```
      CALL MATINV(R11,NL,27,IERR)
      IF(IERR.EQ.0) GOTO 36
   43 WRITE(6,30)
   30 FORMAT(1H0,42H X-Y COORDINATES MATERIX CANNOT BE
     1INVERTED)
      STOP
   37 NL=M
      NR=ITERM
   42 DO 44 I=1,NR
      DO 44 J=1,NR
      K=(J+M-1)*(J+M)/2+1+M
      R22(I,J)=Q(K)
   44 R22(J,I)=R22(I,J)
      CALL MATINV(R22,NR,15,IERR)
      IF(IERR.EQ.I) GOTO 43
   56 DO 45 I=1,NL
      DO 45 J=1,NR
      K=(J+M-1)*(J+M)/2+1
   45 R12(I,J)=Q(K)
      DO 40 I=1,NL
      DO 40 J=1,NL
      K=J*(J-1)/2+1
      R11(,J)=Q(K)
   40 R11(J,I)=R11(I,J)
      CALL MATINV(R11,NL,27,IERR)
      IF(IERR.EQ.1) GOTO 39
   36 DO 46 I=1,NL
      DO 46 J=1,NR
      PRO(I,J)=0.0
      DO 46 K=1,NL
   46 PRO(I,J)=PRO(I,J)+R11(I,K)*R12(K,J)
      DO 47 I=1,NR
      DO 47 J=1,NR
      PRO1(I,J)=0.0
      DO 47 K=1,NL
   47 PRO1(I,J)=PRO1(I,J)+R12(K,I)*PRO(K,J)
      DO 48 I=1,NR
      DO 48 J=1,NR
      PRO2(I,J)=0.0
      DO 48 K=1,NR
   48 PRO2(I,J)=PRO2(I,J)+R22(I,K)*PRO1(K,J)
      DO 49 I=1,NR
      DO 49 J=1,NR
      VEC(I,J)=0.0
      IF(I.EQ.J) VEC(I,J)=1.000
   49 CONTINUE
```

```
      CALL EBERVC(NR,1,200,0.01,0.001,1000.0,15,1)
      TEMP=-100.0
      DO 50 J=1,NR
      IF(TEMP.GT.PRO2(J,J)) GOTO 50
      TEMP=PRO2(J,J)
      JJ=J
   50 CONTINUE
      CANON=SQRT(PRO2(JJ,JJ))
      DIF=CANON-ROOT
      ROOT=CANON
      WRITE(6,52) IPOWER,ROOT
   52 FORMAT( 1H ,10X,24H THE DEGREE IS EQUAL TO I2,
     15X,23H THE CANONICAL ROOT IS F10.4)
      IF(DIF.LT.0.05.OR.ROOT.GE.0.95000) GOTO 51
   27 CONTINUE
   51 WRITE(6,53) IPOWER,ROOT
   53 FORMAT(1H0,10X,57H THE DEGREE OF THE MOST PREDICT
     1ABLE SURFACE IS EQUAL TO I2,3X,48H THE CORRESPOUN
     2DING CANONICAL ROOT IS EQUAL TO F7.4//)
      NR1=NR-1
      DO 171 I=1,NR1
      JP=I +1
      DO 171 J=JP,NR
      IF(PRO2(I,I).GE.PRO2(J,J)) GOTO 171
      TEMP=PRO2(I,I)
      PRO2(I,I)=PRO2(J,J)
      PRO2(J,J)=TERP
      DO 174 K=1,NR
      TEMP=VEC(K,J)
      VEC(K,J)=VEC(K,I)
  174 VEC(K,I)=TEMP
  171 CONTINUE
      TOTALX=XMAX-XMIN
      TOTALY=YMAX-YMIN
      INDEX=TOTALT/TOTALX*50.0
      DELTA=TOTALX/50.0
      TX=50.0/TOTALX
      TY=FLOAT(INDEX)/TOTALY
      DO 172 JJ=1,NR
      INDEX1=1
      PRO2(JJ,JJ)=SQRT(PRO2(JJ,JJ))
      WRITE(6,173) PRO2(JJ,JJ)
  173 FORMAT(1H1,10X,37H TREND SURFACE FOR THE CANONICAL
     1ROOT,2X,F8.4//)
      WRITE(6,114)
```

```
114 FORMAT(1H0,10X,34H THE EQUATION OF THE TREND
   1SURFACE///)
    DO 54 I=1,NL
    E(I)=0.0
    DO 54 J=1,NR
 54 E(I)=E(I)+PRO(I,J)*VEC(J,JJ)
    RR=0.0
    DO 55 I=1,NL
    E(I)=E(I)/PRO2(JJ,JJ)
 55 RR=RR+E(I)*E(I)
    DO 57 I=1,NL
 57 E(I)=E(I)/SQRT(RR)
    J3=0
    IF(M.GT.ITERM) GOTO 59
    DO 60 J=1,M
    J2=J3+1
    J3=J2+2
 60 WRITE(6,58) (VARIAT(J1),J1=J2,J3),VEC(J,JJ)
 58 FORMAT(1H ,5X,3A4,3X,F6.3)
    GOTO 112
 59 DO 132 J=1,M
    J2=J3+1
    J3=J2+2
132 WRITE(6,58) (VARIAT(J1),J1=J2,J3),E(J)
112 DO 64 I=1,ITERM,10
    IPRINT=I+9
    LIMIT=ITERM
    IF(ITERM.GT.IPRINT) LIMIT=IPRINT
    WRITE(6,115)
115 FORMAT(//)
    WRITE(6,62) (TERM(J),J=I,LIMIT)
 62 FORMAT(1H0,10(6X,A4))
    IF(M.GT.ITERM) GOTO 65
 61 WRITE(6,63) (E(IK),IK=I,LIMIT)
 63 FORMAT(1H0,10F10.4//)
    GOTO 64
 65 WRITE(6,63) (VEC(J,JJ),J=I,LIMIT)
 64 CONTINUE
    WRITE(6,97)
 97 FORMAT(1H0,40H  NOTE X4Y2=X**4*Y**2,X3=X**3,AND
   1SO ON)
    BSUM=0.0
    CSUM=0.0
    BSS=0.0
    CSS=0.0
    BCR=0.0
    DO 72 NSAMPL=1,N
    L=0
```

```
      A(1,1)=1.0
      DO 73 I=1,POWER
      DO 74 J=1,I
      A(J,I+1)=A(J,I)*DM(NSAMPL,M+1)
      L=L+1
   74 P(L)=A(J,I+1)
      A(I+1,I+1)=A(I,I)*DM(NSAMPL,M+2)
      L=L+1
   73 P(L)=A(I+1,I+1)
  108 B(NSAMPL)=0.0
      C(NSAMPL)=0.0
      IF(M.GT.ITERM) GOTO 75
      DO 76 J=1,ITERM
   76 B(NSAMPL)=B(NSAMPL)+E(J)*P(J)
      DO 77 I=1,M
   77 C(NSAMPL)=C(NSAMPL)+VEC(I,JJ)*DM(NSAMPL,I)
      GOTO 81
   75 DO 78 J=1,ITERM
   78 B(NSAMPL)=B(NSAMPL)+VEC(J,JJ)*P(J)
      DO 79 I=1,M
   79 C(NSAMPL)=C(NSAMPL)+E(I)*DM(NSAMPL,1)
   81 BSUM=BSUM+B(NSAMPL)
      BSS=BSS+B(NSAMPL)**2
      CSUM=CSUM+C(NSAMPL)
      CSS=CSS+C(NSAMPL)**2
   72 BCR=BCR+B(NSAMPL)*C(NSAMPL)
      DENON=S*BSS-BSUM**2
      ALPHA=(BSS*CSUM-BSUM*BCR)/DENON
      BETA=(S*BCR-BSUM*CSUM)/DENON
      DO 133 I=1,N
      B(I)=ALPHA+BETA*B(I)
  133 RESIDU(I)=C(I)-B(I)
      S2=0.0
      DO 116 I=1,N
  116 S2=S2+RESIDU(I)
      S2=-1.0*S2/S
      DO 117 I=1,N
  117 RESIDU(I)=RESIDU(I)+S2
      WRITE(6,118) S2
  118 FORMAT(IHO,10X,55H THE CONSTANT OF THE TREND SUR
     1FACE EQUATION IS EQUAL TO,F10.4)
      WRITE(6,80)
   80 FORMAT(1H1,13H X-COORDINATE,5X,13H Y-COORDINATE,
     15X,15H OBSERVED VALUE,5X,17H CALCULATED VALUE,
     25X,9H RESIDUAL///)
      WRITE(6,82) ((DM(I,M+1),DM(I,M+2),B(I),RESIDU(I),
     1RESIDU(I),I=1,N)
   82 FORMAT(1H ,F10.4,8X,F10.4,8X,F10.4,12X,F10.4,8X,F
     110.4)
```

```
      DO 66 LENGTH=1,INDEX
      Y=YMAX-DELTA*(FLOAT(LENGTH)-1.0)
      DO 66 LWIDTH=1,50
      X=XMIN+DELTA*(FLOAT(LWIDTH)-1.0)
      L=0
      A(1,1)=1.0
      DO 67 I=1,IPOWER
      DO 68 J=1,I
      A(J,I+1)=A(J,I)*X
      L=L+1
   68 P(L)=A(J,I+1)
      A(I+1,I+I)=A(I,I)*Y
      L=L+1
   67 P(L)=A(I+1,I+1)
  107 POLY(LENGTH, LWIDTH)=52
      IF(M.GT.ITERM) GOTO 69
      DO 70 J=1,ITERM
   70 POLY(LENGTH,LWIDTH)=POLY(LENGTH,LWIDTH)+(J)*P
     1(J)
      GOTO 66
   69 DO 71 J=1,ITERM
   71 POLY(LENGTH,LWIDTH)=POLY(LENGTH,LWIDTH)+VEC(J,JJ)
     1*P(J)
   66 POLY(LENGHT,LWIDTH)=ALPHA+BETA*POLY(LENGTH,LWIDTH)
      PMAX=-100000.0
      PMIN=100000.0
      DO 83 I=1,N
      PMAX=AMAXI(PMAX,B(I))
      PMIN=AMINI(PMIN,B(I))
   83 CONTINUE
      DIFF=PMAX-PMIN
   86 GRAD=DIFF/10.0
      DO 88 LENGTH=1,INDEX
      DO 88 LWIDTH=1,50
      DO 121 I=1,10
      IGRAD=I
      DISC=GRAD*(FLOAT(I)-1.0)+PMIN
      IF(DISC.GE.POLY(LENGTH,LWIDTH)) GOTO 123
  121 CONTINUE
      IGRAD=10
  123 IPOLY(LENGTH,LWIDTH)=DOT(IGRAD)
   88 CONTINUE
      DO 134 I=1,N
      DTEMPX=(DM(I,M+1)-XMIN)*TX
      DTEMPY=(YMAX-DM(I,M+2))*TY
      MAPING(I,1)=DTEMPX
      MAPING(I,2)=DTEMPY
      IF(MAPING(I,1).EQ.0) MAPING(I,1)=1
```

```
      IF(MAPING(I,2).EQ.0) MAPING(I,2)=1
  134 CONTINUE
      DO 137 I=1,INDEX
      DO 137 J=1,50
      DO 138 K=1,N
      IF(MAPING(K,1).EQ.J.AND.MAPING(K,2).EQ.I) GOTO 139
  138 CONTINUE
      GOTO 137
  139 IPOLY(I,J)=SAMPLE
  137 CONTINUE
  150 SCALE=TOTALX*4.0/100.0*FEET
      MSCALE=SCALE
      WRITE(6,90) MSCALE
   90 FORMAT(1H1,35X,5H ----,I8,5H FEET,5X,18H * SAMPLE
     1LOCALITY///)
  153 WRITE(6,91)
   91 FORMAT(1H ,13X,105H ******************************
     1**************************************************
     2***************************)
      WRITE(6,92) ((IPOLY(I,J),J=1,50),I=1,INDEX)
   92 FORMAT(1H ,13X,2H *,101X,2H */14X,2H,2H *,50A2,1X,
     12H *)
      WRITE(6,124)
  124 FORMAT(1H ,13X,2H *,101X,2H *)
      WRITE(6,91)
      WRITE(6,122)
  122 FORMAT(1H0,10X,7H LEGEND/)
      DO 109 I=1,10
      DISC=GRAD*(FLOAT(I)-1.0)+PMIN
  109 WRITE(6,110) (DOT(I),DISC)
  110 FORMAT(1H0,11X,A2,2H =,F8.3)
      IF(INDEX1.EQ.2) GOTO 172
      PMAX=-100000.0
      PMIN=100000.0
      DO 151 I=1,N
      PMAX=AMAX1(PMAX,RESIDU(I))
      PMIN=AMIN1(PMIN,RESIDU(I))
  151 CONTINUE
      GRAD=(PMAX-PMIN)/10.0
      DO 161 I=1,N
      DO 159 J=1,10
      JDOT=J
      DISC=CGRAD*(FLOAT(FLOAT(J)-1.0)+PMIN
      IF(DISC.GE.RESIDU(I)) GOTO 160
  159 CONTINUE
      JDOT=9
  160 SIG(I)=DOT(JDOT)
  161 CONTINUE
```

```
      DO 152 I=1,INDEX
      DO 152 J=1,50
      DO 157 K=1,N
      IF(MARING(K,1).EQ.J.AND.MAPING(K,2).EQ.I) GOTO 156
      IPOLY(I,J)=BLANK
  157 CONTINUE
      GOTO 152
  156 IPOLY(I,J)=SIG(K)
  152 CONTINUE
      INDEX1=2
      WRITE(6,158)
  158 FORMAT(1H1,10X,17H THE RESIDUAL MAP//)
      GOTO 153
  172 CONTINUE
  100 STOP
      END
$IBFTC EBERVC
      SUBROUTINE EBERVC(N,IN,NBMAX,EPS,EPSI,EF,NN,IND)
      COMMON AV(15,15),A(15,15)
      DO 16 II=1,IN
      EPS=EPS/EF
      EPS1=EPS1/EF
      NB=0
   18 DR=0.0
      DI=0.0
      DO 17 I=2,N
      IJ=I-1
      DO 17 J=1,IJ
      C=A(I,J)+A(J,I)
      D=A(I,I)-A(J,J)
      IF(EPS.LE.ABS(C)) GOTO 23
   21 CC=1.0
      SS=0.0
      GOTO 22
   23 CC=D/C
      SIG=SIGN(1.0,CC)
      COT=CC+SIG*SQRT(1.0+CC*CC)
      SS=SIG/SQRT(1.0=COT*COT)
      CC=SS*COT
      DR=DR+1.0
   22 E=A(I,J)-A(J,I)
      IF(EPS.GT.ABS(E)) GOTO 31
      CO=CC*CC-SS*SS
      SI=2.0*SS*CC
      H=0.0
      G=0.0
      HJ=0.0
      DO 40 K=1,N
      IF(K.EQ.I) GOTO 40
      IF(K.EQ.J) GOTO 40
```

```
      H=H+A(I,K)*A(J,K)-A(K,I)*A(K,J)
      S1=A(I,K)*A(I,K)+A(K,J)*A(K,J)
      S2=A(J,K)*A(J,K)+A(K,I)*A(K,I)
      G=G+S1+S2
      HJ=HJ+S1-S2
   40 CONTINUE
      D=D*CO+C*SI
      H=2.0*H*CO-HJ*SI
      F=(2.0*E*D-H)/(4.0*(E*E+D*D)+2.0*G)
      IF(EPSI.GT.ABS(F)) GOTO 31
      CH=1.0/SQRT(1.0-F*F)
      SH=F*CH
      DI=DI+1.0
      GOTO 36
   31 CH=1.0
      SH=0.0
   36 C1=CH*CC-SH*SS
      C2=CH*CC+SH*SS
      S1=CH*SS+SH*CC
      S2=SH*CC-CH*SS
      IF((ABS(S1)+ABS(S2)).EQ.0.0) GOTO 17
      DO 52 L=1,N
      A1=A(L,I)
      A2=A(L,J)
      A(L,I)=C2*A1-S2*A2
      A(L,J)=C1*A2-S1*A1
      IF(IND.LT.0) GOTO 52
      A1=AV(L,I)
      A2=AV(L,J)
      AV(L,I)=C2*A1-S2*A2
      AV(L,J)=CI*A2-S1*A1
   52 CONTINUE
      DO 53 L=1,N
      A1=A(I,L)
      A2=A(J,L)
      A(I,L)=C1*A1+S1*A2
      A(J,L)=C2*A2+S2*A1
      IF(IND.GT.0) GOTO 53
      A1=AV(I,L)
      A2=AV(J,L)
      AV(I,L)=CI*A1+S1*A2
      AV(J,L)=C2*A2+S2*A1
   53 CONTINUE
   17 CONTINUE
      IF((DR+DI).LT.0.5) GOTO 16
      NB=NB+1
      IF(NB.NE.NBMAX) GOTO 18
   16 CONTINUE
```

```
      EPS=EPS*EF**IN
      EPS1=EPS1*EF**IN
      IF(IND.LE.0) GOTO 70
      DO 80 I=1,N
      SUM=0.0
      DO 81 J=1,N
   81 SUM=SUM+AV(J,I)**2
      SUM=SQRT(SUM)
      DO 82 J=1,N
   82 AV(J,I)=AV(J,I)/SUM
   80 CONTINUE
      RETURN
   70 DO 90 I=1,N
      SUM=0.0
      DO 91 J=1,N
   91 SUM=SUM+AV(I,J)**2
      SUM=SQRT(SUM)
      DO 92 J=1,N
   92 AV(I,J)=AV(I,J)/SUM
   90 CONTINUE
      RETURN
      END
$IBFIC MATINV
      SUBROUTINE MATINV(A,N,NN,IERR)
C     ADAPTED FROM MULTIVARIATE PROCEDURES ROR THE
C     BEHAVIOURAL
C     SCIENCES BY COOLEY AND LOHNES, P.198.
C
C
      DIMENSION A (NN,NN),PIVOT(27)
      DIMENSION IPIVOT(27),INDEX(27,2)
      EQUIVALENCE (IROW,JROW)JCOLUM),(AMAX,I,SWAP)
      IERR=0
      DETERM=1.0
      DO 20 J=1,N
   20 IPIVOT(J)=0
      DO 550 I=1,N
      AMAX=0.0
      DO 105 J=1,N
      IF(IPIVOT(J)-1) 60,105,60
   60 DO 100 K=1,N
      IF(IPIVOT(K)-1) 80,100,740
   80 IF(ABS(AMAX)-ABS(A(J,K)) 85,100,100
   85 IROW=J
      ICOLUM=K
      AMAX=A(J,K)
  100 CONTINUE
  105 CONTINUE
```

```
      IPIVOT(ICOLUM)=IPIVOT(ICOLUM)+1
      IF(IROW-ICOLUM) 140,260,140
140   DETERM=-DETERM
      DO 200 L=1,N
      SWAP=A(IROW,L)
      A(IROW,L)=A(ICOLUM,L)
200   A(ICOLUM,L)=SWAP
260   INDEX(I,1)=IROW
      INDEX(I,2)=ICOLUM
      PIVOT(I)=A(ICOLUM,ICOLUM)
      DETERM=DETERM*PIVOT(I)
      IF(PIVOT(I).GT.-0.0005.AND.PIVOT(I).LT.0.0005) GOTO 760
      A(ICOLUM,ICOLUM)=1.000
      DO 350 L=1,N
350   A(ICOLUM,L)=A(ICOLUM,L)/PIVOT(I)
      DO 550 L1=1,N
      IF(L1-ICOLUM) 400,550,400
400   T=A(L1,ICOLUM)
      A(L1,ICOLUM)=0.0
      DO 450 L=1,N
450   A(L1,L)=A(L1,L)-A(ICOLUM,L)*T
550   CONTINUE
      DO 710 I=1,N
      L=N+1-I
      IF(INDEX(L,1)-INDEX(L,2)) 630, 710,630
630   JROW=INDEX(L,1)
      JCOLUM=INDEX(L,2)
      DO 705 K=1,N
      SWAP=A(K,JROW)
      A(K,JROW)=A(K,JCOLUM)
      A(K,JCOLUM)=SWAP
705   CONTINUE
710   CONTINUE
740   RETURN
760   IERR=1
      RETURN
      END
          640 END RECORD
```

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FIGURE 18 A). SAMPLE LOCATIONS AND A SKETCH OF THE TEXTURE OF THE VERTICAL TRENCH.

FIGURE 18 B). PENETRABILITY (kg/cc.) IN THE VERTICAL TRENCH.