

THE GENESIS OF SOME ALPINE SOILS

IN BRITISH COLUMBIA

by

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B.S.A., University of British Columbia, 1968

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in the Department

of

Soil Science

We accept this thesis as conforming to the
required standard

THE UNIVERSITY OF BRITISH COLUMBIA

October, 1969

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Date 30th October, 1969

ABSTRACT

The classification of Canadian alpine soils has been hampered due to the lack of knowledge about their genesis and morphology.

The objectives of this study were to determine the morphology of some alpine soils; determine their genesis through the investigation of physical, chemical and mineralogical properties; classify the soils and indicate what factors should be considered in making alterations to the present system of soil classification.

Five soils were analysed and three of these were found to have been influenced by volcanic ash. No one process was found to be characteristic of alpine soils. The analyses indicated clays, amorphous iron, aluminum, silicon and organic matter were being eluviated. At four sites organic matter was accumulating to form an acidic Chernozem-like Ah horizon. The mineralogical investigations indicated more advanced stages of weathering of minerals than expected in an alpine environment, with the concomittant formation of pedogenic secondary minerals.

In an attempt to classify the soils it was found that only three out of the five soils studied could be classified. Two soils were classified as a members of the Brunisolic Order, the third was placed into the Podzolic

Order. The two soils which could not be classified were excluded as no provision at any categorical level of classification is made for soils with non-turfy Alpine Dystric Brunisol Ah horizons, overlying Podzolic Bf horizons.

Considerations that should be given attention in relation to the present system of classification of Canadian soils are:

- (a) The presence of volcanic ash in soils has a morphological and physico-chemical influence on changes taking place in the soil.
- (b) Alpine soils are not limited to one morphology but can express any number of characteristics depending on environmental factors.

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ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Dr. L.M. Lavkulich of the Department of Soil Science for his assistance, guidance and encouragement throughout the project.

Sincere appreciation is also extended to Mr. L. Farstad, Head of British Columbia Soil Survey Section, Canada Department of Agriculture for his interest in the project and for making available the facilities at his disposal.

Thanks are due to Mrs. Karen Eady and Mr. Dennis Demarchi for their help in the identification of the vegetative species and to Mr. Bruce Kloosterman for his help with the statistical analyses.

To his wife Valerie the author extends his gratitude and appreciation for her understanding and cheerful encouragement during the course of this study.

INTRODUCTION

In Canada alpine soils are confined to the Canadian Cordillera which comprises some 90 percent of the Province of British Columbia. To date, very few research studies have been reported on Canadian alpine soils. It is important that more work be carried out on these soils for a better understanding of their development and for a better appreciation of the alpine environment and the ecological role of soils in these environments. Additional work is required for the construction of a classification scheme for these soils, which is acceptable to the National Soil Survey Committee of Canada.

The objectives of this study were:

1. To determine the morphology of some alpine soils;
2. To carry out investigations in physical, chemical and mineralogical properties in endeavour to determine the genesis of some alpine soils;
3. To classify the soils and to indicate factors that should be considered in making alterations in the present classification of Canadian soils.

LITERATURE REVIEW

"A system of classification . . . reflects a model as of a specific time, which in turn is an aggregate of knowledge and theory of that time." (Cline, 1961). The truth of this statement is reflected in the classification of alpine soils in the classification system of the National Soil Survey Committee (1968). Some mention has been made of Canadian alpine soils in the past (Farstad and Leahey, 1953; Rowles, Farstad and Laird, 1956; Farstad and Rowles, 1960; Farstad, Laird and Keser, 1964; and N.S.S.C., 1963, 1965, 1968) and research work has been reported, though mostly of an ecological nature (Archer, 1963; Brooke, 1966; Krajina, 1965; and Peterson, 1964). One study was recently completed by van Ryswyk (1969) on some alpine soils in British Columbia. Elsewhere research on alpine soils has been reported in Australia (Costin; Hollsworth and Woof, 1952), Great Britain (Romans, Stevens and Robertson, 1966), Japan (Kumada, Sato, Ohsumi and Ohta, 1967) and the United States (Nimlos and McConnell, 1965) to cite a few. Pedologic studies have also been reported on the closely related soils of the Arctic (Tedrow and Brown, 1967) and Antarctic (McCraw, 1967).

Johnson and Cline (1965) noted that alpine soils were defined with an "exceedingly strong bias towards

geographic distribution and landscape positions, little or no relevance being given to the kind of genetic profile." Retzer (1956) recognized process though his divisions were largely a separation of drainage classes. Nimlos and McConnell (1962 and 1965) and Johnson and Cline (1965) recognized the presence of a greater number of soil types in American alpine soils. In Europe Kubiena's classification of alpine soils (1953) recognizes a number of genetic soil types within two major drainage classes, the well and poorly drained. Costin et al. (1952), in Australia, consider the alpine humus soils as being the climatic climax soil of alpine areas though not related to soils of the polar regions. Tedrow and his co-workers, (1958) in the Arctic regions appear to be beyond the criticism of Johnson and Cline (1965) when they report their findings and indicate that the podzolic process takes place on stable well drained sites and weakens northward, resulting in the successive development of Podzols, Minimal Podzols, Arctic Browns, Arctic Browns shallow phase, and finally, minimal soil formation corresponding to the Russian polar deserts. Tundra soils were reported to be the poorly drained members of the drainage catena. Certain of the alpine soils may be related to the soils of the Arctic.

Most of the writers are in agreement as to the importance of physical weathering in the genesis of the alpine soils, however, the processes of chemical weathering

are least understood and have led to the greatest amount of discussion among researchers. One of the problems associated with these soils appears to be the establishment of the origin and uniformity of parent material (Costin et al., 1952; Nimlos and McConnell, 1962 and Retzer, 1956). Another problem concerns the recognition of the dominant pedogenic process or processes taking place, cases being put forward for gleization, calcification and podzolization (Drew and Tedrow, 1958; Johnson and Cline, 1965; Krajina, 1965 and Kubiena, 1953).

Recent studies have reviewed the ecological relationships between soils, vegetation and climate (Bamberg and Major, 1968; Bliss, 1956, 1963, 1966; Johnson and Billings, 1962 and Wardle, 1968).

Recent studies (Young, 1969 and van Ryswyck, 1969) have reviewed the literature on alpine soils while Hamelin and Cook (1967) and Embleton and King (1968) illustrated and explained many of the glacial and periglacial landforms and processes encountered in alpine regions.

Alpine soils are utilized in watershed protection, in game management, in recreation planning and in some countries are the basis of the cattle industry (Starr and Cawlfeld, 1963; U.S. Department of Interior, 1965; Vilenskii, 1957; and Western Land Grant Universities and Colleges, 1944). Insufficient attention has been directed to alpine soils in British Columbia. This is especially apparent at the present time when all resources are being scrutinized.

DESCRIPTION OF THE SAMPLE AREAS

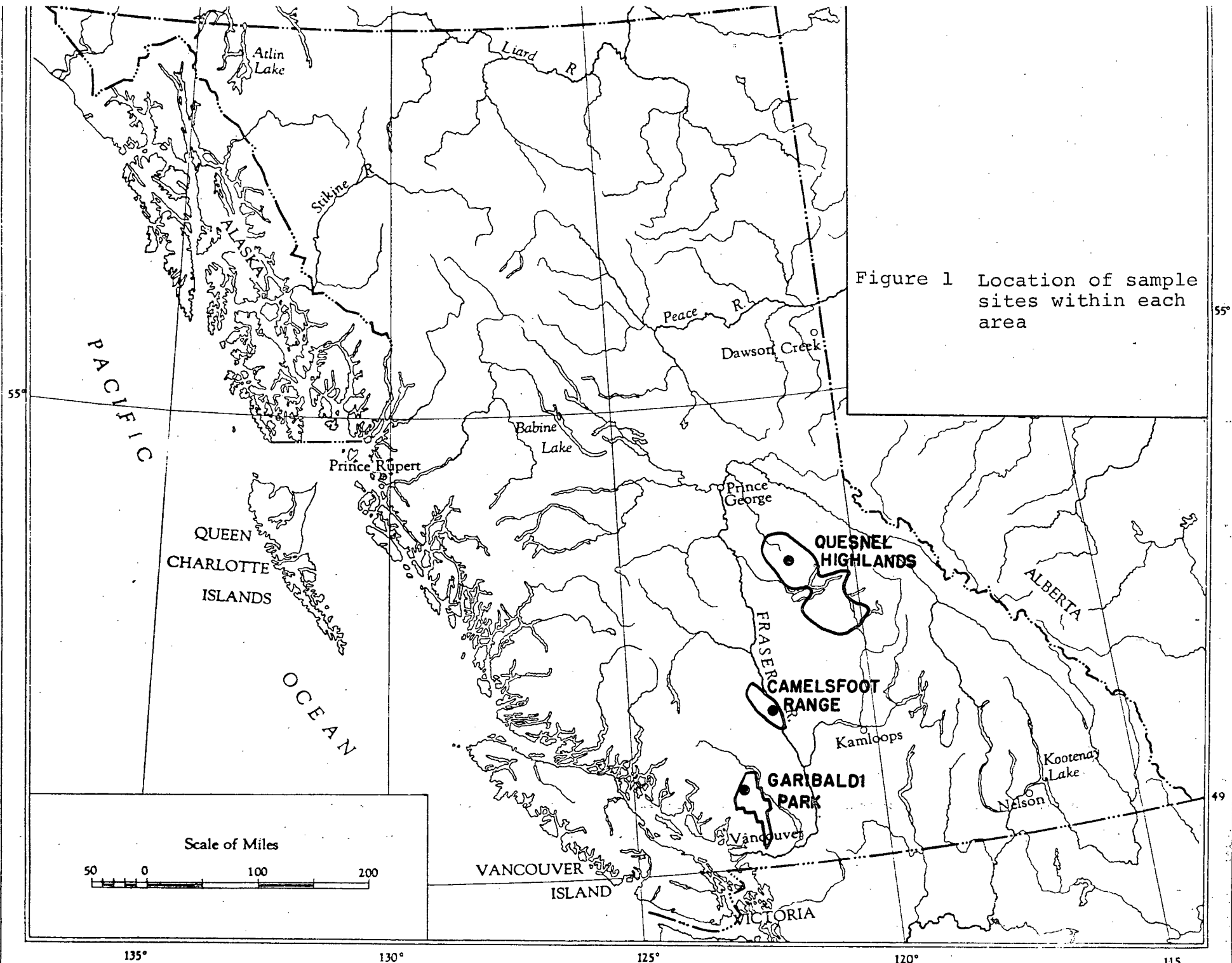
Three areas were selected where soils were known to occur in an alpine environment. These were the Camelsfoot Range, the Quesnel Highland and Garibaldi Park.

Geology

The Camelsfoot Range: The Camelsfoot Range occupies a graben associated with faults along the eastern edge of the Coast Range and bounding the Fraser River Cretaceous belt, elevation ranges between 1,370 and 2,280 m (Holland, 1964).

Underlying the Camelsfoot Range are moderately dipping sandstones, graywackes and conglomerates of the Jackass Mountain group. Fossil records indicated the Jackass Mountain Group was of mid Lower Cretaceous age and, with the sedimentary record, the mode of origin has been suggested as being partly marine, partly nearshore (fresh-water or marine) and partly subaerial (Duffell and McTaggart, 1952 and Trettin, 1961).

Aerial photographs indicated little glacial activity compared with adjacent areas. Trettin (1961) noted that glacial erosion was slight and till was rare. He suggested that ice movement was not rapid due to major ice divide occurring fifty miles to the north.



Volcanic ash was observed in the area, which coincided with the distribution pattern given by Nasmith, Mathews and Rouse (1967) of a 2440 ± 140 years B.P. ash with a source in the region of the upper Lillooet River, sixty miles to the southwest.

The Quesnel Highland: The Quesnel Highland upland areas are remnants of a highly dissected plateau which rises from 1,520 m in the west to over 1,980 m in the east and with peaks up to 2,542 m.

Closely folded schistose, sedimentary rocks of Proterozoic and Cambrian age underlie most of the area (Holland, 1961). In the sample area the gray and black dominantly argillaceous rocks of the Midas formation are found with vein quartz inclusions associated with faults (Holland, 1954).

During the Pleistocene, ice covered most of the high areas to a depth of 2,130 m while cirques and features associated with valley glaciers developed during the later stages of glaciation (Sutherland Brown, 1963). Volcanic cinder cones and vents occurred at the south end of the Quesnel Highland (Holland, 1964).

The geology of the area has been reported in some detail by Campbell (1961), Holland (1954 and 1964) and Sutherland Brown (1957 and 1963).

Garibaldi Park: The ridge north of Cheakamus Lake forms part of a pendant, extending 8 miles to the southwest of the Twin Islands group (Roddick, 1965). Roddick reported that the Twin Island group occurred as rather small pendants engulfed in plutonic rocks. At the sampling sites plutonic rock underlies the pedon and made up most of the greater than 2 mm fraction material. Mathews (1957, 1958) described the geology and petrology of the volcanic rocks in the Garibaldi Park area and indicated the difficulties in classifying the rocks and range in composition of extrusions and intrusions due to magma differentiation and gravitative selection.

Mathews (1951, 1958) has described the glaciation and history of alpine glaciation in the Mount Garibaldi map area. Most of his description can equally apply to the sample area which was immediately to the northeast. The snout of the Overlord glacier occurred at less than one and a half miles to the east of the sample area.

A cinder cone was found less than 13 km to the southwest, about which Mathews (1958) described ". . . lapilli, ash and bomb fragments ejected during Strombolian eruptions at the Cinder Cone."

Climate

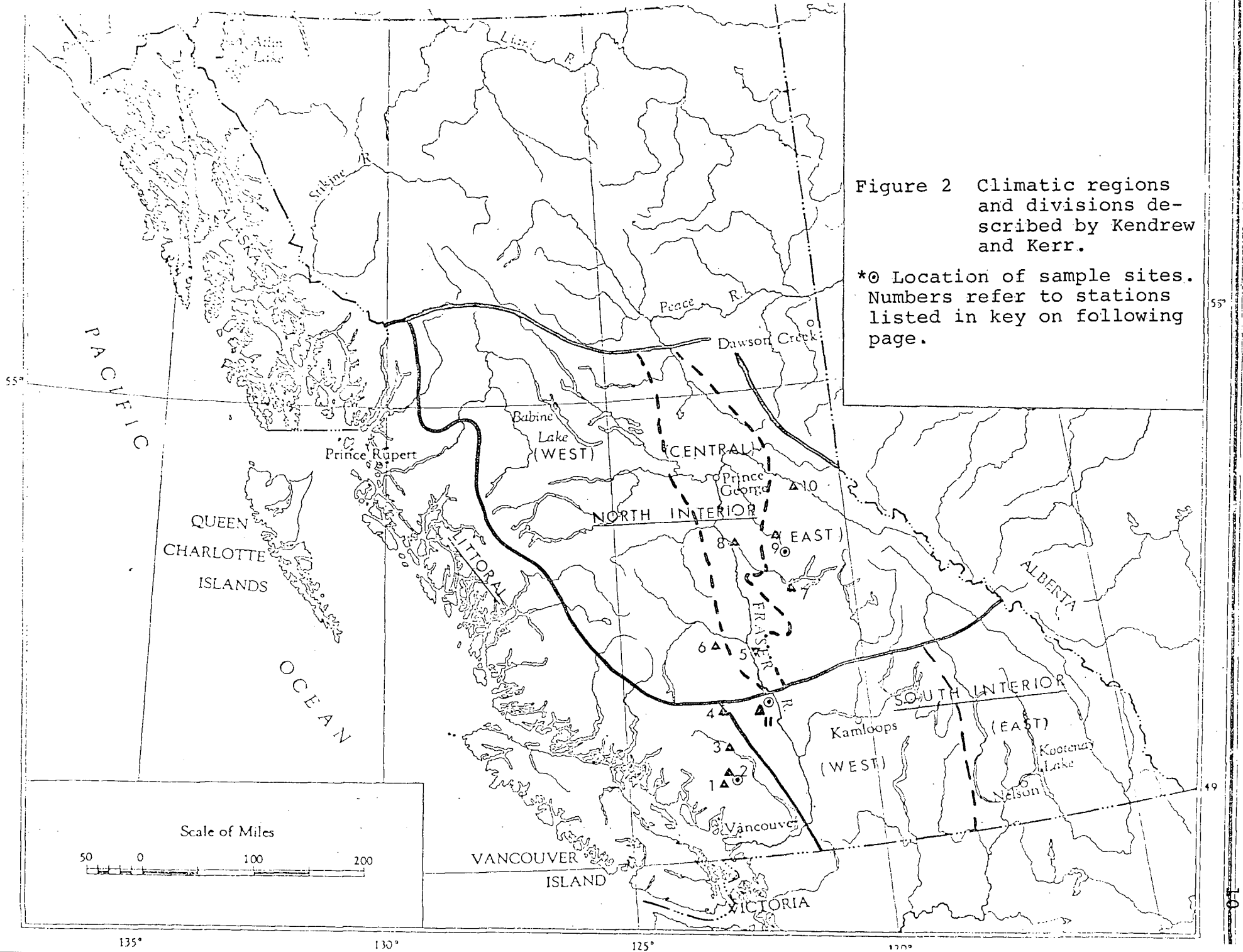
Though more than 75 percent of the Province of British Columbia lies at an elevation of greater than 910 m (Brink

and Farstad, 1949) almost all of the long term meteorological stations are situated below that contour. Some indication of the climatic environment of the sites can be obtained from short term data appearing in miscellaneous publications and by interpretation of the long term data from stations closest to the sites. In making interpretations the characteristics of mountain climates outlined by Brink (1949) should be taken into account.

Table I gives the long term climatic records of stations adjacent to study areas (Canada Department of Transport, 1967).

The Camelsfoot Range: The Camelsfoot Range lies close to the northern edge of the western division of the South Interior 'climatic region' described by Kendrew and Kerr (1955) as mild continental. The uplands are described as being cold in winter and cool in summer, they have more precipitation than the valleys and are not as cloudy.

At lower elevations air movement tends to be channelled by valleys. At higher elevations, as in the alpine, air movement is not influenced to the same degree by landform. In the area at the head of the generally south-facing valleys a streamlining effect was observed in the ground vegetation pattern. This was interpreted as being due to a 'venturi effect' brought about by winds blowing up the valleys and becoming constricted at the approach to the



valley head. A frost action origin was discounted as the streamlining was only observed at valley heads. No information has been recorded for this area, however, considering minimal topographic influence of the major air streams the data for the 'Old Glory' station east of Princeton at 2,350 m, and in the same climatic region, may be useful. The most frequent wind directions were NW and SW in fall and winter, NW and SE in spring and NW, SW and SE in summer; calms are very rare (Kendrew and Kerr 1955).

The Camelsfoot Range lies in the rain shadow of the Coast Mountains. The precipitation pattern follows that for the region with the greatest amount falling in winter and the spring receiving the least. No season is especially dry. Almost all of the winter precipitation comes as snow, as weather stations in the area record a mean monthly temperature of less than 0°C for a period of five months per year. There were indications, volcanic

*Key to stations located on Figure 2 whose climatic records are tabulated in Table I.

- | | |
|----------------------|--------------------|
| 1. Garibaldi | 7. Horsefly Lake |
| 2. Alta Lake | 8. Quesnel Airport |
| 3. Pemberton Meadows | 9. Barkerville |
| 4. Bralorne | 10. Dome Creek |
| 5. Dog Creek Airport | 11. Moha |
| 6. Big Creek | |

TABLE I — Climatic records of stations adjacent to study areas

Station	Lat N		Long W		Elev m	Precipitation Mean Annual - cm			Temperature °C									Year's Record	
									Mean			Absolute		No. Months					
									Annual	Jan	July	Max	Min	above* 10	below ⁺ 0	fluct [†] 0			
						Rain-fall	Snow-fall	Total											
o	'	o	'														Temp	Precip	
Camelsfoot	51	00	122	11	2124														
Big Creek	51	44	123	00	945	19.6	124.5	32.1	2.4	-10.4	13.5	39	-47	3	5	5	25+	25+	
Bralorne	50	51	122	55	1066	39.8	259.1	65.7	4.4	- 7.5	14.9	38	-36	4	4	4	10+	25+	
Dog Creek A.	51	38	122	15	1027	21.7	161.5	37.8	3.8	- 9.0	16.0	34	-41	5	5	3	10	10+	
Moha	50	53	122	16	549	23.1	95.3	32.7	M	M	M	M	M	M	M	-	-	25+	
Yanks Peak	52	53	121	26	1783														
Barkerville	53	20	121	35	1274	57.5	574.3	114.9	1.5	- 9.2	12.4	36	-47	2	5	5	25+	25+	
Dome Creek	53	45	121	05	670	49.7	261.1	75.8	4.3	- 9.2	16.2	42	-49	5	5		10+	10+	
Horsefly Lake	52	23	121	17	788	50.3	200.9	70.4	4.2	- 8.9	15.1	33	-44	4	5	3	10	10-	
Quesnel A.	53	02	121	31	544	34.9	190.5	53.9	4.8	- 9.5	16.6	41	-47	5	5	5	25+	10+	
Fitzsimmons	50	02	122	53	1950														
Alta Lake	50	07	122	59	648	81.7	635.0	145.2	5.7	- 4.3	14.9	34	-31	4	3	5	10	10	
Pemberton Meadows	50	27	122	56	222	67.6	264.7	94.1	7.3	- 5.1	20.9	38	-40	5	3	3	25+	25+	
Garibaldi	49	59	123	08	365	115.0	394.5	154.5	M	M	M	M	M	M	M	-	-	25+	

*Months with mean monthly temperatures above 10°C

⁺Months with mean monthly temperatures below 0°C[†]Months with mean maximum temperatures above 0°C and mean minimum temperatures below 0°C^MData missing

ash accumulations in the lee of the ridge crest and lack of a stabilizing vegetative cover, that the alpine area where the soils were sampled remained essentially snow free all winter.

Assuming a lapse rate of 2°C per 310 m of elevation the Camelsfoot Range alpine area has a mean annual temperature between -4.4 and -1.6°C . Lapse rate constants are useful for generalizations, however temperature inversions and annual variations must be considered. The lack of snow in the area at the time of sampling suggested that the spring and summer temperatures were higher than either of the other two sampling areas, where snow still occurred in patches at the time of sampling.

Smith (1964) indicated that mean annual soil temperatures were generally 1.1°C higher than mean annual air temperatures and in cold climates the difference tended to increase due to the insulation of snow. If the assumption that the sample area was snow free in winter was correct, soil temperatures below freezing would occur for a considerable portion of the year; a minimum of five months is suggested from the long term annual air temperature data available from adjacent stations. If Longley's (1967) hypothesis, that heat is released by condensing water vapour on frozen soil particles, is correct and with the greater insolation effect experienced at high altitudes, the soils of the sample area would be expected to warm up

rapidly in the spring and early summer.

With most precipitation coming in the winter months little if any becomes effective soil water in windblown areas. Windblown areas would represent more arid conditions than snow receiving areas. Similar observations have been recorded by Bamberg and Major (1968), Nimlos and McConnell (1962) and Wardle (1968).

The Quesnel Highland: The Quesnel Highland is continental as described by Kendrew and Kerr and lies in the eastern division of the north interior climatic region. "The chief characteristic is the long cold winter liable to intense cold when continental air sweeps out of the north and storms over the rampart of the rockies" (Kendrew and Kerr, 1955).

The lack of stations above the valley floors in this region makes wind direction difficult to predict. Kendrew and Kerr (1955) make the uncertain prediction that southerly winds were most frequent in winter and northerly winds in summer. The symmetrical though stunted trees of the sample area and lack of flagged and cushion krummholz indicated deep snow cover and low wind intensities, especially in the winter months.

Precipitation is spread over the whole year with summer and fall receiving the most. Barkerville close to the sample area at 1,275 m elevation receives 102 cm per



Figure 3 Landscape in vicinity of Yanks Peak

In the Quesnel Highland the symmetrical though stunted trees of the sample area and lack of flagged or cushion krummholz indicated deep snow cover and low wind intensities.

year with a mean annual snowfall of 462 cm, most of which falls in the months September to May. Similar precipitation figures and snow depths, and possibly slightly higher, were expected in the sample area.

Winter is longer and colder in this region than in the south due, in part, to the longer winter nights and incursions of polar air from the NW. Winter temperature inversions occur in this region and can be seen on examining the long term data for Quesnel and Barkerville. Kendrew and Kerr (1955) explained this as being due to gravitation of surface cooled air to the valley bottoms and possibly to shallow layers of continental arctic air moving in from the NE and failing to rise to higher elevations.

The great depths of snow in the alpine area (evidence previously mentioned) would result in a higher mean annual soil temperature than mean annual air temperature (Smith, 1964) with the soil rarely freezing below the snow cover.

Melting snow would maintain soil water at close to field capacity into late summer; in certain positions and aspects in the area snow patches have been observed which endured into the succeeding winter.

Garibaldi Park: Garibaldi Park lies at the south end of the Littoral 'climatic region' described by Kendrew and Kerr (1955). "The outstanding feature is the mildness and humidity of the winter for the latitude increasing to

enormous depth in the mountains . . . the mountains, even their lower slopes down almost to sea-level, are under many feet of snow from November to March."

The Garibaldi Park alpine sample area lies in an area whose wind strengths are not especially high for an ocean coast facing the westerlies, and whose wind direction has a strong topographic influence (Kendrew and Kerr, 1955). Cushion and flagged krummholz at the sample sites indicated considerable wind action especially in winter months.

The Littoral region received the greatest amount of precipitation of any region in the province. Fall and winter received the most precipitation while summer received the least. Mathews (1951) recorded some short term data at Garibaldi Lake and using drainage basin data for the Cheakamus River basin estimated the total precipitation to be about 254 cm per year. Brooke (1966) and Peterson (1964) indicated maximum precipitation for the area occurred between 915 and 1,220 m. Some of the fall and most of the winter precipitation came as snow which accumulated to depths of over 760 cm. Brooke's (1966) tabulation of snow depth data indicated an approximate snow depth average of 300 cm at elevations between 915 and 1,220 m.

In the sample area snow depth was variable due to redistribution by wind. Some drifts endured from one season

to the next and these were being exploited for year-round winter sports. The area received sufficient snow and was cool enough to support glaciers, the firn line in the region of Garibaldi Lake was at an elevation only 30.5 m higher than that of the sample sites (Mathews, 1951).

Brooke (1966) observed that annual temperature ranges for all windward stations were remarkably uniform and altitude was a stronger climatic control than latitude for coastal windward stations. Leeward upland stations exhibited more continental characteristics than their windward counterparts. Brooke also indicated that a transition from a coastal to an interior climate occurred between Alta Lake and Pemberton Meadows. Temperature inversions were not apparent from the data for the littoral region, though Walker (1961) described the manner and occurrence of summer and winter inversions which do occur occasionally. Local inversions and frost pockets, however, are likely a relatively common occurrence where air drainage is restricted. Assuming a lapse rate of 2°C per 310 m elevation change, the sample area has a mean annual temperature of between -3.9°C and -1.1°C .

Variable depths of snow in the alpine area would result in fluctuating soil temperatures from area to area. Permafrost within 76 cm of the surface to a depth of at least 1,220 cm occurs on a sheltered exposure on the western part of The Cinder Cone (Mathews, 1951).



Figure 4 The Cheakamus Glacier from Fitzsimmons Range

The area received sufficient snow and was cool enough to support glaciers.

Soil water supply will vary throughout the alpine area according to the snow drift pattern and duration of snow cover.

Vegetation

The vegetative cover was different at each of the three sample areas. A brief description of the vegetation at each site was recorded.

The Camelsfoot Range: The vegetative cover in the vicinity of the sample site came closest to the climatic climax vegetation described by Krajina (1965) as being indicative of the alpine zone. The plant indicators present at the site were *Cassiope mertensiana* and *Phyllodoce empetrifomis*. These species make up a portion of the climatic climax plant association cited by the same author.

The Quesnel Highland: The vegetative cover in the region of the sample sites consisted dominantly of sedges and perennial forbs with some reeds and grasses. Clumps of alpine fir were scattered throughout the area. Charcoal was found at the surface over most of the area indicating that the area may have had a greater amount of tree cover in the past. The present limited tree cover was most likely the result of the activity of miners in the area in the latter half of the last century. Weir (1964) notes the

presence, potential and limitations of the area for alpine range.

Garibaldi Park: The vegetative cover in the region of the sample sites was made up of sedges, reeds, grasses, mosses and forbs, and scattered alpine fir with a generally krummholz life form. The alpine vegetation and ecological relationships have been recently reported for the area by a number of workers (Archer, 1963; Brink, 1959, 1964; Brooke, 1966 and Peterson, 1964).

Soils

Reports and descriptions of alpine soils in the Province are very limited. However, Rowles et al., (1956) in describing the mountainous areas of the Province indicated that most of the unconsolidated mountain deposits were composed of Lithosols with some weak to moderately well developed soils approaching Podzols. Poorly drained areas were associated with Alpine Meadow soils.

Rankers, Rendzinas and Podzols are the characteristic zonal soils of Krajina's (1965) Alpine Zone, developed under the prevailing pedogenic processes of skeletal disintegration, weak podzolization and strong gleization.

In the southern part of the Province and in northern Washington State volcanic ash was reported as being a

common constituent of the surface horizons of alpine soils (van Ryswyk, 1969; and Starr and Cawlfeld, 1963). In British Columbia, van Ryswyk (1969) reported the occurrence of soils with Alpine Dystric Brunisol Ah horizons overlying Podzolic Bf horizons. These soils appeared to be similar to the Ptarmigan series in Montana described by Nimlos and McConnell (1962) though they did not indicate the presence of volcanic ash.

Young (1969) described the presence of Alpine Dystric Brunisols, Degraded Alpine Dystric Brunisols and organic soils in the Alpine region of Mount Wells, British Columbia.

Alpine soils have been examined in the course of ecological studies in the vicinity of Garibaldi Park (Archer, 1963; Brooke, 1966 and Peterson, 1964). These studies indicated the presence of soils classified as Alpine Rawmarks and Rankers (Regosols), Lithosols, and Anmoor-like (Gleysols). Volcanic ash was noted in some areas.

MATERIALS AND METHODS

Field Methods

A site or sites were selected at each of the sample areas. The soils were described following the nomenclature and procedures prescribed by the N.S.S.C. (1968) and sampled by maximum expression of morphological genetic horizons. Samples of vegetation were also taken at each site for subsequent identification.

Site and Soil Descriptions

Site 1 - CAMELSFOOT

- Location: Lat. 51° 00.9' N, Long. 122° 11.1' W. Camelsfoot Range and 3.7 miles W of Hogback Mountain (Yalakom River 920/1 E, 1:50,000 map sheet).
- Position: At 2,124 m elevation facing S and on a 6 percent slope.
- Geology: The bedrock and channers and flags in the pedon consist of conglomerate and sandstone of the Jackass Mountain group. In the vicinity of this site and to the leeward of the ridge crest a paleosol was found buried beneath 30 cm or more of volcanic ash. The ash consists of about 35 percent pellets up to 3 mm in diameter.
- Drainage: Well drained - Permeability: Moderate -
Runoff: medium.
- Vegetation: *Carex pyrenica*
Carex spp.
Cassiope mertensiana
Dryas octopetala
Lichen spp.
Lupinus lepidus var. *lobbii*
Moss sp.



Figure 5 Paleosol buried beneath 30 cm of volcanic ash, Camelsfoot

Phyllodoce empetriformis

Salaquilla sp.

Salix arctica

Salix nivalis

Other

Features: Temperature at 20 cm 7.5°C
 at 25 cm 7.5°C
 and at 43 cm 7.2°C

on August 8, 1968

Surface cobbles and stones - 20 - 30 percent.

Horizon	Depth cm	
L-F	0.6 - 0	Loose litter of fresh and partly decomposed vegetative parts.
Ah1	0 - 6.3	Very dark brown (10YR 2/2 m), very dark brown (10YR 2.5/2 d) loamy sand; moderate coarse to very fine subangular blocky breaking to fine granular; very friable; abundant fine and very fine roots; 35 percent angular gravels; clear wavy boundary; 5 to 7.5 cm thick; pH 4.6.
Ah2	6.3 - 12.5	Dark reddish brown (5YR 2.5/2 m), very dark grayish brown to dark brown (10YR 3/2.5 d) sandy loam; moderate coarse to very fine subangular blocky

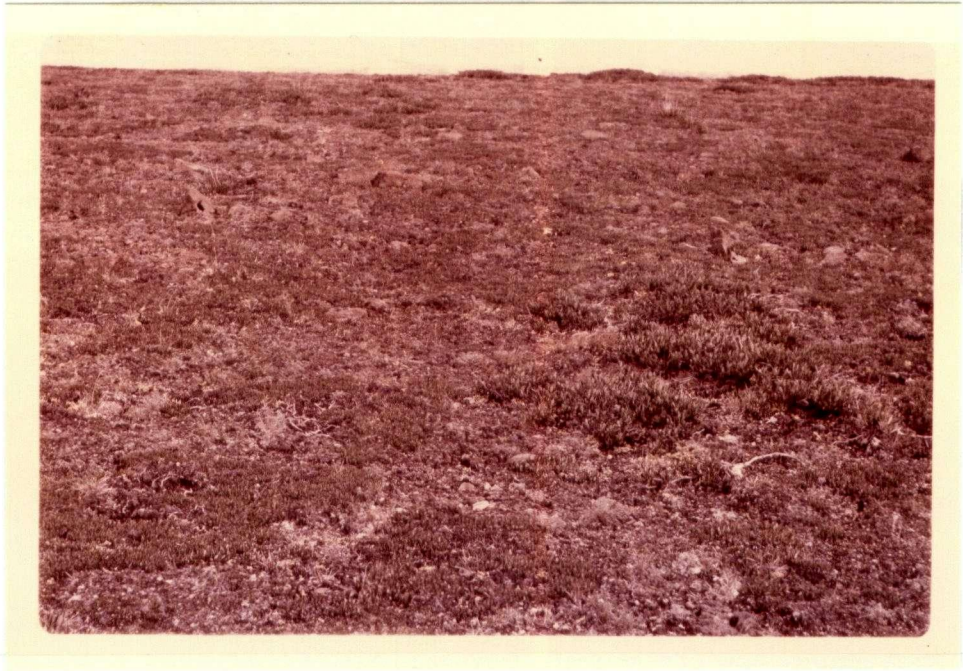


Figure 6 Vegetation and topography at site 1, Camelsfoot

- breaking to fine granular; very friable; few medium and fine to very fine roots; 45 percent angular gravels and channers; abrupt wavy boundary; 5 to 10 cm thick; pH 4.4.
- Bm 12.5 - 20 Dark yellowish brown (10YR 4/4 m), dark brown to dark yellowish brown (10YR 4/3.5 d) sandy loam; weak coarse subangular blocky breaking to weak very fine subangular blocky; very friable; very few fine and medium roots; 30 to 40 percent channers and flags; clear wavy boundary; 7.5 to 10 cm thick; pH 4.4.
- CB 20 - 43 Light olive brown to olive yellow (2.5Y 5.5/6 m), light yellowish brown (2.5Y 6/4 d) loam; weak coarse subangular blocky breaking to weak very fine subangular blocky; very friable; 40 to 80 percent channers and flags; abrupt wavy boundary; 20 to 25 cm thick; pH 4.6.
- C 43+ Shattered bedrock with many moderately thick and thin coatings of silt and clay.



Figure 7 Soil at site 1, Camelsfoot

Site 2 - YANKS PEAK

Location: Lat. 52° 53' N, Long. 121° 26' W. Two miles N of Yanks Peak on saddle between the headwaters of Little Snowshoe and Aster creeks (Quesnel Lake, 93A. 1:250,000 map sheet).

Position: At 1,783 m elevation facing NE on a 5 percent slope.

Geology: Bedrock and angular gravels in the pedon consist of black fine grained silty quartzite (metasiltstone) and black and dark-gray phyllite and slate, almost all highly folded, of the Midas formation. Some gravels identifiable with the Snowshoe formation were present as a result of glacial action.

Drainage: Well drained - Permeability: Moderate -
Runoff: medium.

Vegetation: *Anemone occidentalis*
Arenaria laterifolia
Festuca sp.
Hoplopappus sp.
Juncus parryi
Juncus spp.
Moss spp.
Muhlenbergia sp.
Pedicularis bracteosa

Ranunculus verecundus

Sibbaldia procumbens

Trollius laxus

Other

Features:

Temperature at 25 cm 10°C

and at 45 cm 10°C

on August 9, 1968

Occasionally charcoal was found in the surface horizons.

Horizon	Depth cm	
L-F	4 - 0	Litter of fresh and partly decomposed roots and vegetative parts.
Ah	0 - 15	Very dark gray (N 3/ m), dark gray (N 4/ d) very gravelly silt loam; weak fine subangular blocky to granular; friable; abundant fine and very fine roots; 50 percent gravel; clear wavy boundary; 15 to 20 cm thick; pH 4.00.
Bm	15 - 38	Very dark gray (N 3/ m), dark gray (10YR 4/1 d) very gravelly silt loam; moderate fine subangular blocky breaking to fine granular; friable; plentiful fine and very fine roots; 67 percent gravel, clear wavy boundary; 20 to 25 cm thick; pH 4.0.



Figure 8 Vegetation and topography at site 2, Yanks Peak

C 38+ Very dark gray (N 3/ m), very dark
 gray to dark gray (5Y 3.5/1 d) very
 gravelly loam, dispersed through
 shattered bedrock; very few fine and
 very fine roots; pH 4.2.



Figure 9 Soil at site 2, Yanks Peak

Site 3 - YANKS PEAK

- Location: Same general location and approximately 50 yards NE and downhill of site 2.
- Position: At 1,783 m elevation facing NE on a 10 percent slope.
- Geology: Bedrock and angular gravels in the pedon composed of fissile gray sericitic and argillaceous schists, mostly deformed by folding, and vein quartz. The lithology of the bedrock suggests it is a member of the Midas formation and the vein quartz is associated with the Imperial vein.
- Drainage: Well drained - Permeability: Moderate -
Runoff: Medium.
- Vegetation: *Caltha leptosepala*
Carex spp.
Hieracium spp.
Juncus spp.
Lacopodium alpinum
Moss spp.
Senecio triangularis
Sibbaldia procumbens
Valeriana sitchensis
Valerianella locusta
Veratrum viride



Figure 10 Vegetation and topography at site 3, Yanks Peak

Other Features: Temperature at 25 cm 7.8°C
and at 50 cm 7.8°C

on August 9, 1968.

Occasionally charcoal was found in the surface horizon.
This site at the time of sampling appeared to be a drier
site in terms of soil water than site 2.

Horizon	Depth cm	
L-F	2 - 0	Litter of fresh and partly decomposed roots and vegetative parts; pH 3.6.
Ae	0 - 7.5	Gray to grayish brown (10YR 5/1.5 m), light gray to light brownish gray (10YR 6/1.5 d) gravelly silt loam; moderate medium to fine subangular blocky; friable; abundant fine and very fine roots; 30 percent gravel; abrupt wavy boundary; 5 to 10 cm thick; pH 3.6.
Bf	7.5 - 18	Dark yellowish brown (10YR 4/4 m), yellowish brown to light yellowish brown (10YR 5.5/5 d) gravelly silt loam; moderate coarse platy breaking to moderate coarse to fine subangular blocky; friable; plentiful fine and very fine roots; 26 percent gravel; clear wavy boundary; 7.5 to 12.5 cm thick; pH 3.9.

- BC 18 - 50 Light olive brown (2.5Y 5/4 m),
grayish brown to light brownish
gray (2.5Y 5.5/2 d) gravelly silt
loam; moderate coarse to medium
angular blocky breaking to fine
subangular blocky; firm; few fine
roots; 30 percent gravel; gradual
wavy boundary; 30 to 38 cm thick;
pH 4.2.
- C 50+ Very dark gray (N 3/ m), gray to
olive gray (5Y 5/1.5 d) very
gravelly sandy loam; 58 percent
gravel sized schists; pH 4.4.



Figure 11 Soil at site 3, Yanks Peak

Site 4 - FITZSIMMONS

- Location: Lat. 50° 02' N Long. 122° 51' W, Fitzsimmons Ridge and 1/2 mile E of Singing Pass and 2 3/4 miles NE of Overlord Mountain (Pemberton, 92J, 1:250,000 map sheet)
- Position: At 1,950 m elevation facing SSW on a 19 percent slope.
- Geology: The bedrock and angular to subangular gravels in the pedon consist of phaneritic fine to medium grained gabbros and quartz diorites. A cindercone occurs 7 miles to the SW and there is evidence of extensive volcanic activity in the map area.
- Drainage: Moderately well drained - Permeability: Moderate - Runoff: Medium.
- Vegetation: *Antenaria* sp.
Antenaria umbrinella
Arenaria sp.
Carex phaeocephala
Carex spectabilis
Carex sp.
Juncus parryi
Phleum alpinum
Potentilla villosa
Silene parryi
Sibbaldia procumbens
Valeria sitchensis



Figure 12 Vegetation and topography at site 4,
Fitzsimmons

Other

Features: Temperature at 50 cm 10°C, on October 3, 1968
 Surface stone and rock 30 to 40 percent.

Horizon	Depth cm	
L-F	0.6 - 0	Litter of fresh and partly decomposed vegetative remains.
Ah	0 - 12.5	Dark brown to brown (10YR 4/3 m), dark grayish brown to grayish brown (10YR 4.5/2 d) gravelly loam; strong medium to fine subangular blocky breaking to fine granular; friable; abundant fine and very fine roots; 26 percent angular gravel and stones; clear wavy boundary; 10 to 14 cm thick; pH 4.0.
Bfh	12.5 - 30	Dark yellowish brown (10YR 3.5/4 m), brown to dark yellowish brown (10YR 4/3.5 d) gravelly sandy loam; strong coarse to fine subangular blocky; friable; abundant fine and very fine roots; 31 percent angular gravel and stones; clear wavy boundary; 17 to 20 cm thick; pH 4.4.
BC	30 - 44	Dark yellowish brown (10YR 4/4 m), light olive brown (2.5Y 5/4 d)

gravelly sandy loam; strong coarse to fine subangular blocky; friable; plentiful fine and very fine roots; 46 percent angular gravel and stones; abrupt wavy boundary; 12 to 16 cm thick; pH 4.5.

C	44+	Grayish brown to olive brown (2.5Y 4.5/3 m), pale olive (5Y 6/3.5 d) very gravelly sandy loam; common, medium, prominent, brownish yellow and yellowish brown (10YR 6/8 and 5/8 m) mottles; coarse angular pseudo blocky; firm, very few fine roots; 63 percent angular gravel; pH 4.6.
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Figure 13 Soil at site 4, Fitzsimmons

Site 5 - FITZSIMMONS

- Location: Same as general location and on opposite side of small knoll from site 4.
- Position: At 1,950 m elevation facing NNE and on a 6 to 8 percent slope.
- Geology: The bedrock and angular to subangular gravels in the pedon consist of phaneritic fine to medium grained quartz diorites gneisses and granitics.
- Drainage: Well drained - Permeability: Moderate -
Runoff: Medium.
- Vegetation: *Abies lasiocarpa*
Anemone occidentalis
Antinaria umbrinella
Arenaria sp.
Carex nigricans
Carex sp.
Cladonia sp.
Erigeron sp.
Juncus parryi
Lecidea granulosa
Luetkea pectinata
Lycopodium sitchense
Poa arctica
Polytrichum piliferum
Sibbaldia procumbens
Solorina crocea



Figure 14 - Vegetation and topography at site 5,
Fitzsimmons

Site 5 is located at the base of the snowbank,
which is lowest in the picture.

Other
Features:

Temperature at 25 cm 8°C
and at 50 cm 8°C, on October
3, 1968.

Surface stone and rock 30 to 40 percent.

Horizon	Depth cm	
L-F	0.6 - 0	Litter of fresh and partly decomposed vegetative remains.
Ah	0 - 10	Dark brown (7.5YR 3.5/2 m), dark grayish brown to brown (10YR 4/2.5 d) gravelly loam; moderate coarse to fine subangular blocky; very friable; abundant fine and very fine roots; 33 percent angular gravel; abrupt wavy boundary; 8 to 12 cm thick; pH 4.0.
Bfh	10 - 21.5	Brown to dark brown (7.5YR 4/3 m), yellowish brown (10YR 5/5 d) gravelly sandy loam; moderate coarse to fine angular blocky and moderate fine subangular blocky; friable; plentiful fine and very fine roots; 40 percent angular gravel; clear wavy boundary; 8 to 12 cm thick; pH 4.6.

- BC 21.5 - 36 Light olive brown (2.5Y 5/4 m),
pale olive (5Y 6/3 d) very gravelly
sandy loam; moderate coarse to fine
angular blocky and subangular blocky;
friable; few fine and very fine roots;
60 percent angular gravel; abrupt
wavy boundary; 10 to 16 cm thick;
pH 4.8.
- C 36+ Olive (5Y 4.5/3 m) pale olive
(5Y 6/3 d) very gravelly sandy loam;
coarse angular pseudo blocky; moist
hard; very few fine roots; 57 percent
angular gravel; pH 4.9.



Figure 15 Soil at site 5, Fitzsimmons

Laboratory Methods

Preparation of Field Samples

The bulk soil samples were subsampled on arrival at the laboratory, for pH and field water determinations, the remainder were air dried at room temperature. The samples were weighed and ground between sheets of brown paper with a wooden roller to pass a 2 mm sieve and stored in quart 'sealer' jars. The greater than 2 mm size fraction was weighed and tabulated as a percentage of the previously weighed unsieved sample and retained for specific gravity determinations.

All physical, and chemical analyses were carried out in duplicate, unless otherwise indicated.

Physical Analyses

Bulk Density, Field Water Content and Hygroscopic Water:

Appropriate sized samples were oven dried at 105°C for 24 hours and bulk density (core), field water and hygroscopic water contents were calculated (Black, 1965).

Particle Size Analysis: Particle size analysis of the less than 2 mm fraction, fine earth, was carried out; following removal of organic matter by hydrogen peroxide (Black, 1965) and free iron oxides by sodium dithionite-citrate

procedure (Mehra and Jackson, 1960); by the pipette method (Black, 1965) and using the apparatus described by Clark and Green (1961). The fine clay fraction was determined gravimetrically on a measured aliquot taken from a portion of the total clay after centrifugation (Baver, 1956 and Jackson, 1956). Removal of carbonates was not considered necessary as all samples were relatively acidic.

Soil Water Retention: Soil water retention was measured at matric tensions of fifteen, one, one third, and one tenth bars using the procedure outlined by Richards (1965) and U.S. Salinity Laboratory Staff (1954), with two exceptions. A period of four to five days was allowed for the samples to reach equilibrium and to maintain a more even water vapour gradient inside the extractors, three sponge rubber strips were glued vertically to the sides with the bottom of the strips immersed in water, while the equipment was in operation.

Specific Gravity of the Gravels: Specific gravity determinations were made using a torsion balance and water at 20°C as the displacement liquid (Berry and Mason, 1959). Determinations were made on six gravel sized particles per site.

Mineralogical Analyses

Mineral Identification by X-ray Diffraction: Particle size separation was carried out following the procedure of Kittrick and Hope (1963) the following fractions being separated, medium and fine clay (less than 0.2 μ), coarse clay (0.2-2 μ), silt (2-50 μ) and very fine sand (50-100 μ). The medium and fine and coarse clay fractions were further treated to make the following parallel oriented slides, Mg saturated, Mg saturated glycol solvated, K saturated, K saturated and heated to 300°C and K saturated and heated to 500°C, following the procedure outlined by Jackson (1956).

Identification of the parallel oriented clay minerals and randomly oriented silts and very fine sands was made by obtaining X-ray diffraction patterns by means of a Philips X-ray diffractometer equipped with a proportional counter and pulse height analyser using nickel filtered CuK_{α} radiation generated at 40 kilovolts and 20 milliamperes.

Petrographic Analyses: A polarizing microscope with X200 magnification was used to examine the very fine sand fraction, which was mounted on a glass slide under a cover-slip with an index of refraction oil of 1.640. Over 200 counts were carried out on each slide.

Differential Thermal Analyses: A Dupont 900 thermal analyser and a differential scanning calorimeter cell with a temperature range from ambient to 600°C was used to characterize the thermal characteristics of less than 2 μ clay with organic matter and free iron oxides unremoved in a controlled atmosphere of nitrogen.

Chemical Analyses

Measurement of pH: pH was measured in 0.01 M calcium chloride in a 1:2 soil to solution ratio (Schofield and Taylor, 1955) and in a 1:1 soil to water ratio (Atkinson et al., 1958) using a Beckman Zeromatic pH meter.

Total Carbon: Total carbon was determined using a 'Leco Gasometric Carbon Analyzer' comprising of a high frequency induction furnace and a semi-automatic carbon determinator (Black, 1965 and Leco, 1959). The pH values measured above indicated that the amount of carbonates present would be negligible.

Determination of Total Nitrogen: Nitrogen was determined by the macro-Kjeldahl method (Atkinson et al., 1958).

Total Sulphur: Sulphur was determined using a 'Leco Combustion Sulfur Analysis Apparatus' comprising of a high frequency induction furnace and a sulphur titrator (Leco, 1959).

Exchangeable Cations and Exchange Capacity: Exchangeable cations were determined as outlined by Atkinson et al., (1958) using 1.0 N ammonium acetate at pH 7.0 as the extracting solution. Exchangeable calcium, magnesium, potassium and sodium were determined with a Techtron atomic absorption spectrophotometer Type AA-5.

Cation exchange capacity was determined by direct distillation of absorbed NH_3 into boric acid and titrated with standard sulphuric acid using bromphenol blue indicator (Atkinson et al., 1958). The cation exchange capacity was also determined after soil samples were equilibrated by shaking with 0.01 N CaCl_2 for five days according to the method described by Clark (1965). The difference between the two exchange capacities was tabulated as the pH dependent cation exchange capacity.

Dithionite - and Oxalate - extractable Iron, Aluminum, Silicon and Manganese: Unground less than 2 mm samples were extracted following the dithionite-citrate-bicarbonate procedure of Mehra and Jackson (1960).

Samples ground to 100 mesh were extracted following the acid ammonium oxalate procedure of McKeague and Day (1966).

Iron, aluminum, silicon and manganese were determined on the extracts with a 'Perkin Elmer 404' atomic absorption spectrophotometer.

Pyrophosphate-dithionite-extractable Iron, Aluminum and

Carbon: Pyrophosphate-dithionite-extractable iron aluminum and carbon were extracted following the procedure outlined by Franzmeier, Hajek and Simonson (1965). Iron and aluminum were determined with a Perkin Elmer 404 atomic absorption spectrophotometer. Carbon was determined, by a method developed by Lavkulich et al. (1970. Can. J. Soil Sci. In press) with a Leco Gasometric Carbon Analyzer.

Extraction of Amorphous Materials from the Fine Earth and Clay Fractions and Determination of Selected Constituents:

Separation of the clay fraction and the extraction of amorphous oxides, hydroxides and alumino-silicates was carried out as described by Yuan (1968) with the following modifications:

- a) Extraction of amorphous materials was carried out on both the fine earth and clay fractions.
- b) The supernatant solutions and washing solutions from organic matter destruction were retained.
- c) Clay suspensions were used in all cases for quantitative measurement of clay used for extraction.

The extracts were analyzed for silicon, iron, aluminum and manganese with a Perkin Elmer 404 atomic absorption spectrophotometer.

Statistical Analyses

Statistical Analyses: Correlation coefficients were determined at the University of British Columbia computing centre using an IBM 360/67 computer and the UBC TRIP sub-routine program.

The correlation coefficients used in the text are given in Appendix I.

RESULTS AND DISCUSSION

Physical Analyses

The results of selected physical analyses are shown in Table II and illustrated in Figures 16, 17, 18, 19, 20 and 21. All the data are expressed on an oven dry basis where applicable.

Bulk Density: Owing to the friable nature of the peds and the amount of gravel in the pedons, clods and undisturbed cores were difficult to obtain. Bulk densities were determined on cores from two horizons of sites 1, 2 and 3, from one horizon at site 4 and on none from site 5. Where bulk densities were determined on two horizons per profile, they increased with depth.

Field Water Content: In comparing field water content and water content at various tensions, it must be kept in mind that field water content is determined on a complete soil while the water content at the various tensions was determined on the less than 2 mm separates. The true water contents would have been lower if the complete soil had been used.

Field water contents were influenced by the character and content of organic matter present in the

TABLE II — Selected physical analyses of the soils under study*

Horizon	Depth cm	% Particle size Analysis on <2mm fraction				Wt.% >2mm	Text. Class	Bulk Density	% Field Water	% Hygr. Water
		Sand	Silt	Clay	Fine Clay+					
Site 1 Camelsfoot										
Ah1	0 - 6.3	74.2	22.3	3.5	0.62	34.6	LS	1.15	21.9	5.2
Ah2	6.3-12.5	69.3	25.6	5.1	1.54	45.1	SL	-	27.1	3.6
Bm	12.5-20	54.3	36.3	9.4	3.61	29.2	SL	-	21.4	4.2
CB	20 -43	50.9	40.6	8.5	2.77	41.4	L	1.48	13.9	2.6
Site 2 Yanks Peak										
L-F	4 - 0								80.2	8.4
Ah	0 -15	27.7	56.9	15.4	3.74	50.0	GrSiL	1.29	22.4	3.0
Bm	15 -38	34.2	50.0	14.8	4.97	67.0	GrSiL	-	24.4	1.6
C	38+	38.3	47.0	14.7	3.20	69.1	GrL	1.43	23.1	0.9
Site 3 Yanks Peak										
L-F	2 - 0								128.1	7.2
Ae	0 - 7.5	29.1	56.0	14.9	3.17	30.6	SiL	1.35	39.4	1.9
Bf	7.5-18	31.6	54.3	14.1	3.14	26.4	SiL	-	43.6	3.3
BC	18 -50	33.4	50.7	15.9	4.07	29.8	SiL	1.66	19.6	1.0
C	50+	57.8	35.1	7.1	1.80	58.3	GrSL	-	14.6	0.8
Site 4 Fitzsimmons										
Ah	0 -12.5	44.5	44.6	10.9	2.33	26.6	L	0.91	52.6	3.6
Bfh	12.5-30	56.0	35.9	8.1	2.01	31.0	SL	-	41.4	5.1
BC	30 -44	54.9	37.3	7.8	1.74	46.0	SL	-	26.6	2.9
C	44+	53.5	36.4	10.1	1.72	62.7	GrSL	-	10.0	1.6
Site 5 Fitzsimmons										
Ah	0 -10	43.6	46.2	10.2	2.48	33.4	L	-	71.4	5.4
Bfh	10 -21.5	66.5	24.0	9.5	6.81	41.1	SL	-	42.1	4.8
BC	21.5-36	54.6	36.5	8.9	3.66	59.6	GrSL	-	16.1	2.0
C	36+	56.3	34.2	9.5	2.46	57.3	GrSL	-	13.9	1.0

* All percentages by weight

⁺ % of total clay

Figure 16 Water content distribution with depth for the soils under study

—x—x— Field water content

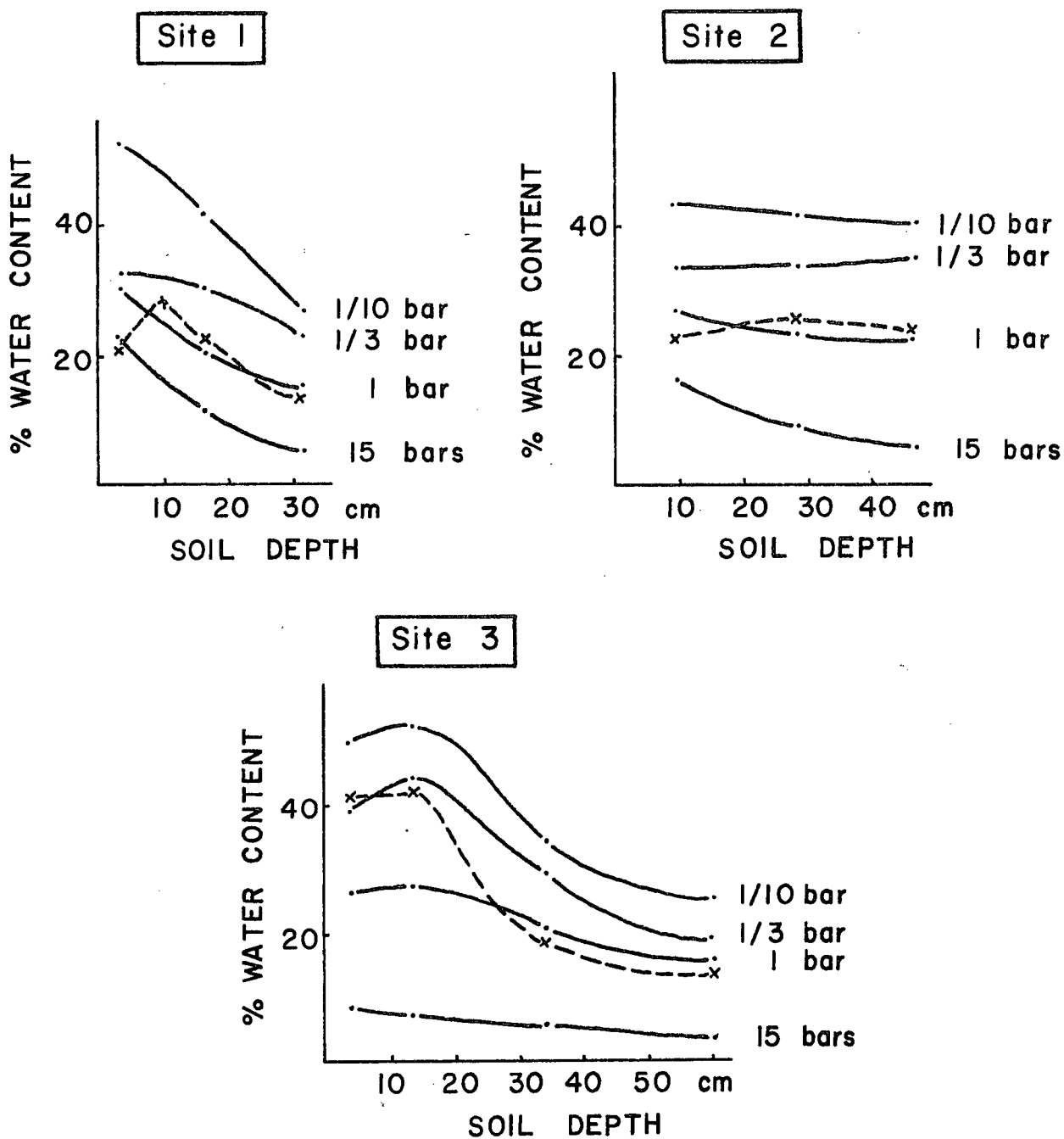
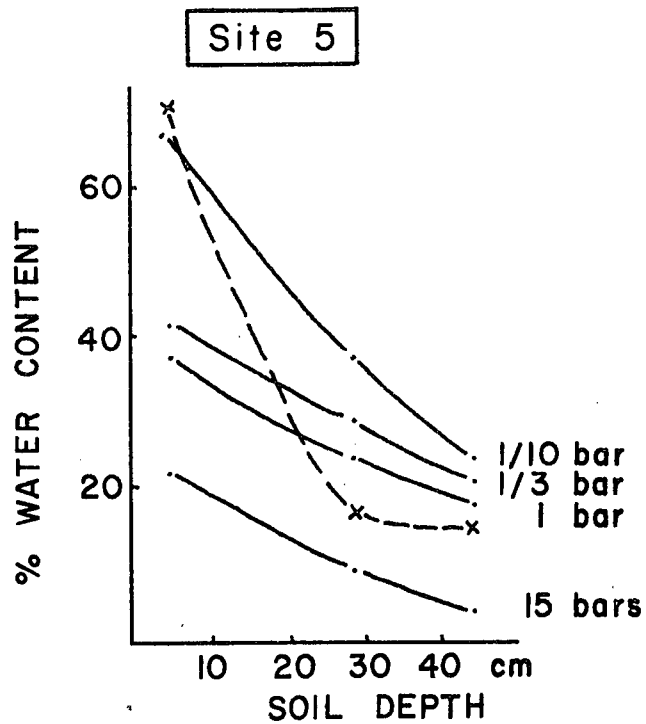
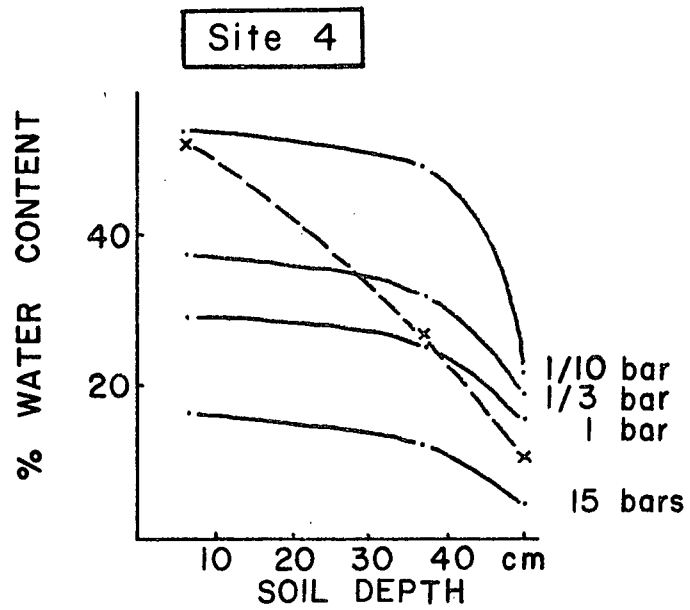


Figure 16 (continued)

—x—x—x Field water content.



soil. A correlation between field water content and total carbon was found significant at the one percent level. Other correlations were also indicated but these merely reflected the relationship to organic matter content.

Sites 1, 2 and 3 were sampled in early August. No information was available as to the pre-sampling weather conditions, though it is known that both sample areas were shrouded in clouds for several days prior to sampling.

The surface horizon at site 1 was at a water content equivalent to that at 15 bars tension. The remainder of the pedon had a water content almost equivalent to that at 1 bar tension. Sites 2 and 3 had water contents equivalent to that between 1/3 and 1 bar tensions.

Sites 4 and 5 were sampled in early October which was the beginning of the wet season. Again no weather information was available immediately prior to sampling, though it was known it had been rainy and cloudy for several weeks prior to sampling in the valley at Alta Lake.

The Ah horizon of both sites 4 and 5 had field moisture contents in the region equivalent to 1/10 bar water content. Both sites had a decreased field water content in their C horizons, which were both at water contents equivalent to that between 1 and 15 bars.

The field water content at site 1 reflected the desiccating conditions at the surface of the site. Site

2 reflected uniform conditions throughout the pedon with a slight desiccating effect at the surface. Site 3 reflected the slightly less exposed position of the site and indicated a possible recent recharge of water at the surface. Sites 4 and 5 reflected the recent wet weather, with a decrease with depth of field water content.

Hygroscopic Water Content: Hygroscopic water is held at a tension between 31 and 10,000 bars and varies with the colloid content of the soil. It is largely non-liquid and moves in vapour form (Buckman and Brady, 1968).

A correlation significant at the one percent level was found between hygroscopic water content and total carbon content, cation exchange capacity and amorphous oxides in the clay fraction. The most significant correlation was with cation exchange capacity. Baver (1956) showed that hygroscopicity increased with the total exchange capacity of the colloids and also showed that the water content of various clay systems was inversely proportional to the volume occupied by the exchangeable cations. The high correlation with the cation exchange capacity was influenced by the organic matter content of the soil as many of the exchange sites would originate on the colloidal organic complexes. The correlation coefficients showed a correlation between Na and K and the hygroscopicity but not between Ca and Mg the two dominant, in most cases, exchangeable cations.

Hygroscopic moisture generally tended to decrease with depth, increasing only in the illuvial horizons of sites 1, 3 and 4.

Soil Water Retention: The water retention values obtained at 0.1, 0.33, 1.0 and 15.0 bars tension are plotted in Figures 17, 18, 19, 20 and 21. The water retention values for all horizons decreased with increasing tension.

The decrease in water retention with depth at sites 1, 4 and 5 coincided with the decrease in organic matter content. The clay and amorphous material distribution within the pedons did not appear to have markedly influenced the water retention characteristics exhibited by the water retention curves for these sites.

The surface mineral horizons of sites 1, 4 and 5 contained the greatest amounts of organic matter (See Table VIII) of any of the mineral horizons. These horizons showed the most rapid drop in water retention between 0.1 and 0.33 bars. The surface mineral horizons of sites 1, 4 and 5 also contained 31, 10 and 35 percent volcanic ash respectively in the very fine sand fraction (See Table VIII). Sites 1 and 5 which contained the most ash exhibited the sharpest drop in water content with initial increases in water tension in the surface mineral horizon and in addition had the highest water contents, greater than 20 percent, at the 15 bar water tension. The same characteristics were not exhibited at site 4.

Figure 17 WATER RETENTION CURVE
FOR $\leq 2\text{mm}$. SIZE FRACTION
SITE 1 CAMELSFOOT

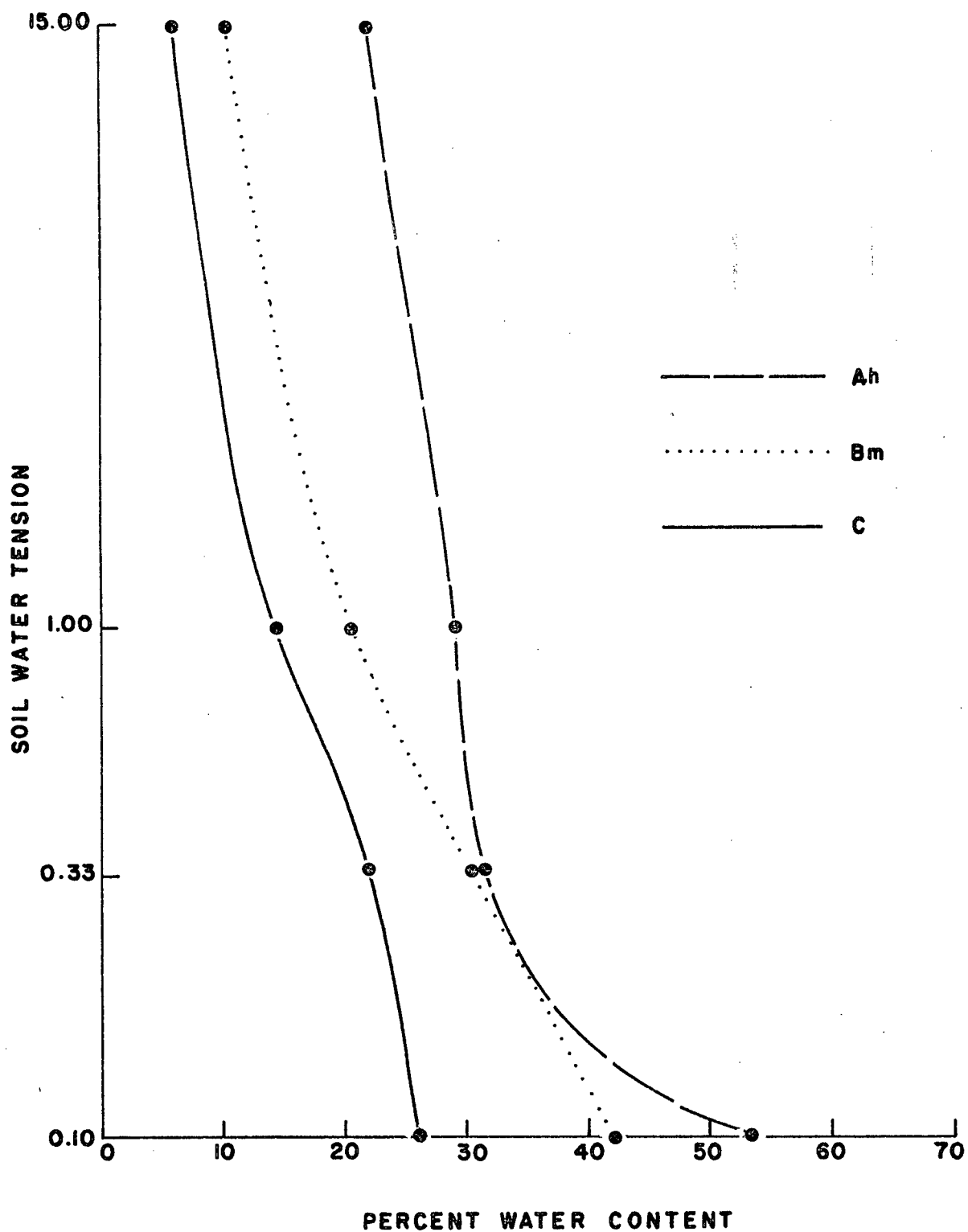


Figure 18 WATER RETENTION CURVE
FOR <2mm. SIZE FRACTION
SITE 2 YANKS PEAK

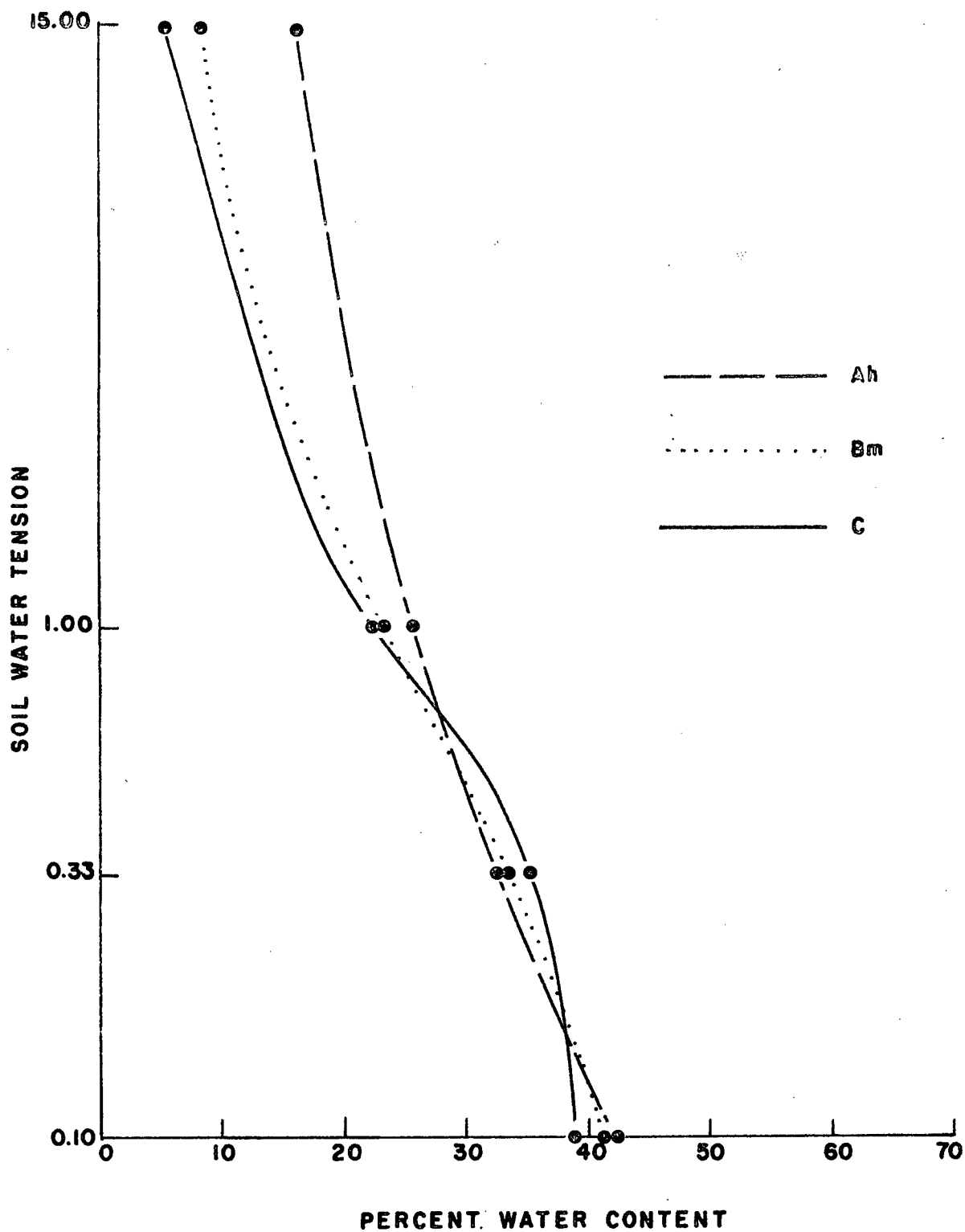


Figure 19

**WATER RETENTION CURVE
FOR <2mm. SIZE FRACTION
SITE 3 YANKS PEAK**

66

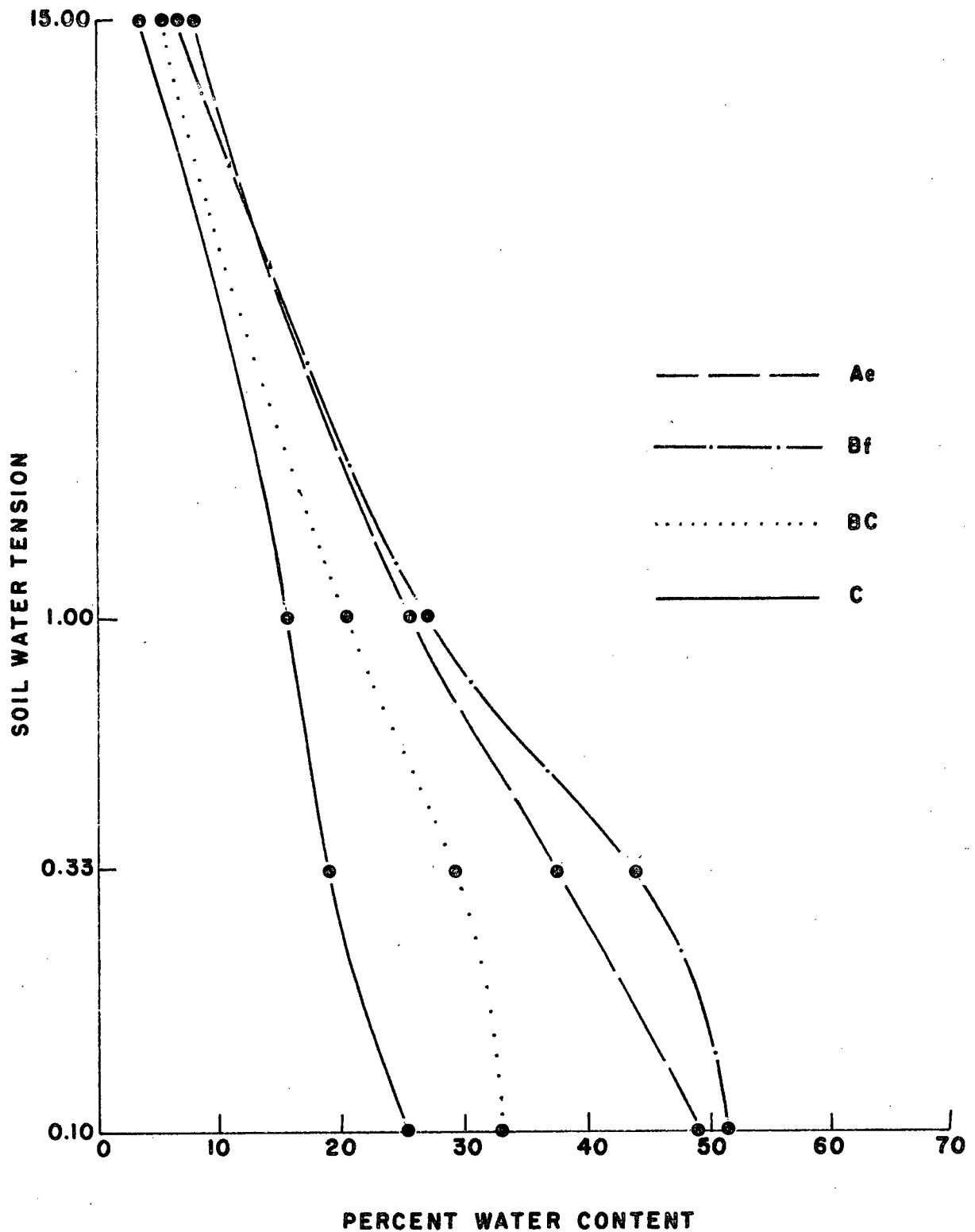


Figure 20

**WATER RETENTION CURVE
FOR ≤ 2 mm. SIZE FRACTION
SITE 4 FITZSIMMONS**

67

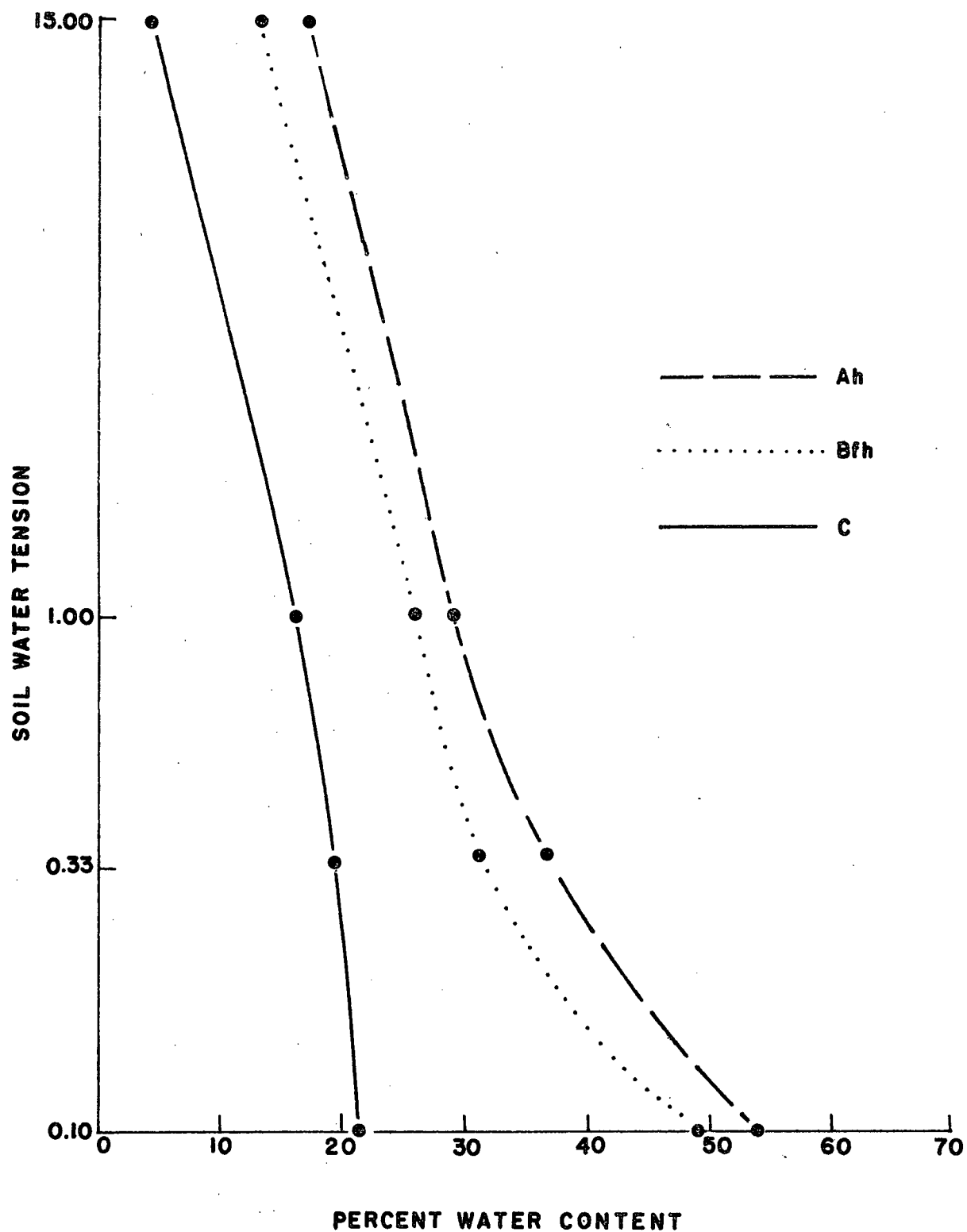
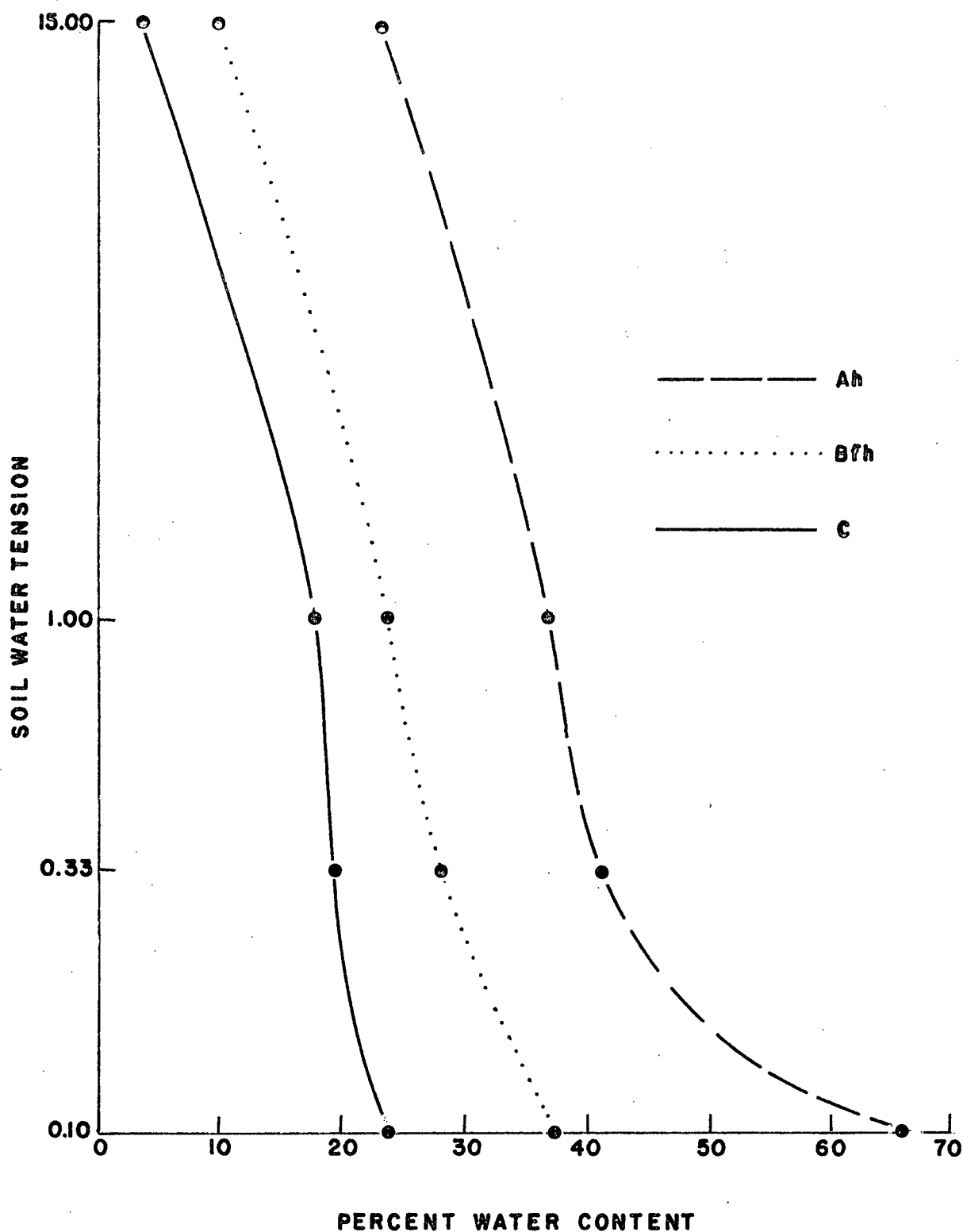


Figure 21 WATER RETENTION CURVE
FOR <2mm. SIZE FRACTION
SITE 5 FITZSIMMONS



The similar water retention, at lower water tensions of all mineral horizons at site 2 may be explained as being due to the more nearly uniform distribution of fine earth separates, organic matter and clay associated amorphous material (See Tables II, IX and X).

The greater water retention of the Bf horizon, of site 3, over the Ae horizon coincided with the greater amount of clay associated amorphous material in the Bf horizon.

Organic matter content appeared to have exhibited the greatest influence on the water retention properties between horizons at each site. Some characteristics of certain horizons were influenced by the volcanic ash content. Volcanic ash water retention relationships are suggested in the literature (Soil Survey Staff, 1967 and Ministry of Agriculture and Forestry, 1964). Water retention was influenced to some degree by the amount of amorphous material of both mineral and organic origin in the soil, however this was not strongly evident in the data nor did it appear warranted of investigation.

It was recognised that the water retentivity of the whole soil would be less than that determined on the fine earth fraction. The water retentivity of the whole soil was calculated (Richards, 1965) however the values obtained were unsatisfactory.

Particle Size Analyses: The particle size distribution of a soil is an expression of the proportions of the various sizes of particles which it contains. The proportions are represented by the relative weights of the size classes (Day, 1965). Particle size classes are based on the U.S.D.A. scheme of size limits (Soil Survey Staff, 1951). The fine clay is expressed as the less than 0.2 micron fraction. The textural class was determined using the analyses data of the < 2 mm fraction (N.S.S.C., 1968).

Textures of the horizons ranged from loamy sand to silt loam. Silt loam textures occurred at the Yanks Peak sites reflecting the schistose and argillaceous nature of the bedrock. The loamy sand and sandy loam textures at sites 1, 4 and 5 reflected the nature of the bedrock of sandstone and conglomerate at site 1 and granitics at sites 4 and 5.

Site 1 showed a decrease in sand and an increase in silt with depth, while the clay fraction increased with depth, to the Bm horizon and started to decrease in the CB horizon. The fine clay distribution paralleled that of the total clay.

The data indicated that silt, clay, and fine clay have been eluviated. Silt and clay coatings observed on the shattered bedrock at the bottom of the soil supported the interpretation that eluviation has taken place.

On repeating the particle size analysis without removing the free iron oxides the data showed a similar distribution for the sand and silt sized fraction. However the amount of clay in both clay fractions decreased with depth indicating that iron and aluminum oxides have acted as cementing agents bonding the clay into larger separates. For this reason a horizon with sufficient clay accumulation to qualify as a Bt horizon was not recognised as such but as a Bm in the field. It was noted that there were silt coatings on the coarser fractions.

Sites 2 and 3 showed an increase in sand and a decrease in silt with depth. At site 2 the total clay showed a slight decrease with depth while the fine clay showed a slight increase in the Bm horizon. At site 3 the total clay showed a slight increase in the BC horizon and the fine clay distribution paralleled that of the total clay.

The sand and silt distribution at sites 2 and 3, indicated that weathering of part of the sand fraction to silt had taken place, the amount of weathering having decreased with depth. The total clay distribution at site 2 suggested that clay had been formed at the expense of the silt fraction and this had taken place most actively at the surface. The distribution of the fine clay indicated that some eluviation of this fraction had taken place.

At site 3 both the coarse and fine clay had been subjected to eluviation, the greatest accumulation occurring in the BC horizon.

The sand and silt distribution at site 4 was relatively uniform in the Bfh, BC and C horizons. The Ah horizon contained relatively less sand and more silt than the underlying horizons. Clay decreased with depth to the BC horizon while the C horizon had a clay content almost equal to that of the Ah horizon. The fine clay fraction decreased throughout the sampling depth.

The differences between surface horizons and the underlying horizons in silt and sand content may be due to more intense weathering in the surface horizon or more likely are the result of stratification or lithologic change in the pedon. The total clay distribution indicated that in situ clay formation had taken place and that the intensity of formation decreased with depth. The amount of clay found in the C horizon was not considered illuvial. The decrease in fine clay with depth was a further indication that the accumulation of clay in the C horizon was not the result of eluviation.

The sand and silt distribution in the BC and C horizons at site 5 was relatively uniform. The silt and sand decreased and increased, respectively, in the Bfh horizon and increased and decreased, respectively, in the Ah horizon, relative to the amounts in the BC and C

horizons. The total clay distribution was essentially uniform throughout the pedon with a slightly greater amount of clay in the Ah horizon. The amount of fine clay increased with depth to the Bfh horizon and decreased in the BC and C horizons.

As in site 4, a lithologic or stratigraphic change was indicated by the distribution of silt and sand. Some eluviation of the fine clay had taken place as evidenced by the fine clay data.

The percentage of material greater than 2 mm increased with depth at sites 2, 4 and 5. At site 1 no depth relationship was evident and at site 3 the greater than 2 mm fraction increased with depth below the Ae horizon, which had relatively more gravel than the Bf horizon below.

The increase with depth of the greater than 2 mm fraction was interpreted partly as reflecting the intensity of weathering with depth but also as reflecting the action of the ice as it shattered the underlying bedrock and incorporated this in the thin layer of drift that it laid down.

Some stratification was evident (See Table II) in the surface horizons of sites 1 and 5. A more rigorous separation of the particle sizes may have increased the evidence supporting lithologic or stratigraphic changes in the pedons (Barshad, 1964).

Specific Gravity of the Gravels: The mean specific gravities of the gravels at sites 1, 2, 3, 4 and 5 was found to be 2.39, 2.31, 2.43, 2.56 and 2.65, respectively. The values covered the range expected for the constituent gravels encountered at each site.

Mineralogical Analyses

The results of the selected mineralogical analyses are shown in Tables III, IV, V, VI, VII and VIII.

Mineral Identification by X-ray Diffraction: The minerals in the study were identified using the criteria published in the literature (Jackson, 1956, 1964 and Whittig, 1965).

Site 1 Camelsfoot: Vermiculite was the dominant to major clay mineral in the silt, coarse clay and medium and fine clay fractions. Chlorite and 10 Å⁰ mica were detected in trace to minor amounts in all fractions. A minor amount of mixed layer vermiculite-chlorite was detected in the fine and medium clay fractions. Quartz and feldspar were major to dominant in the coarser size fractions diminishing in relative quantities with decrease in size of the separate, no feldspar and only a trace of quartz being detected in the medium and fine clay fraction.

No precise trends were identified from the mineral distribution patterns obtained. It was assumed that most

TABLE III -- Mineral distribution in four different size fractions of the soils at site 1, Camelsfoot, determined by X-ray diffraction procedures

Hori- zon	Depth cm	Chlorite	10 Å Mica	Kaol- inite	Mont- morill- onite	Vermi- culite	Mixed Layers	Quartz	Feld- spar	Amphi- bole	Olivine	Crystalline iron oxides
Medium and fine clay $<0.2\mu^*$												
Ah1	0 - 6.3	2	0	0	0	3	2	1-0	0	0	0	0
Bm	12.5-20	2	0	0	0	4	2	1-0	0	0	0	0
CB	20 -43	0	1	0	0	4	2	1-0	0	0	0	0
Coarse clay $2-0.2\mu^*$												
Ah1	0 - 6.3	1	0	0	0	4	0	1	1-2	0	0	0
Bm	12.5-20	1	1	0	0	2	0	1	1	0	0	0
C	20 -43	2	1	0	0	3	0	1	1	0	0	0
Silt $2-50\mu^+$												
Ah1	0 - 6.3	2	0	0	0	3	0	2	3	1	1	0
Bm	12.5-20	1	0	0	0	3	0	2	3-2	1	1	0
C	20 -43	1-2	0	0	0	3	0	2	3	1	1	0
Very fine sand $50-100\mu^+$												
Ah1	0 - 6.3	0	1	0	0	0	0	3	3	0	0	0
Bm	12.5-20	1	1	0	0	0	0	4	2	0	0	0
C	20 -43	1	1	0	0	0	0	4	2	0	0	0

* Expressed as relative quantities

0. None 1. Trace 0-10% 2. Minor 10-35% 3. Major 35-65% 4. Dominant 65-100%

+ Expressed as relative occurrence

0. Absent 1. Present 2. Minor 3. Major 4. Dominant ? Not positively identified

of the chlorite was inherited from the parent material. In the medium and fine clay fraction there was some indication that the vermiculite had been weathered to chlorite by way of mixed layer vermiculite-chlorite as described by Jackson (1965). Replacement of potassium in the $10 \text{ \AA}^{\text{O}}$ micas to form vermiculite was also indicated as having taken place. The reduction in the amounts of quartz and feldspar with grain size was an indication of their increased susceptibility to weathering with increase in surface area. The slightly reduced amount of vermiculite present in the medium and fine clay fraction of the surface horizon and the lack of $10 \text{ \AA}^{\text{O}}$ mica and dominance of vermiculite in the coarse clay fraction of the same horizon suggested the most intense weathering of the clay minerals was taking place in the surface horizon. No differential movement of one mineral relative to another was detected.

Site 2 Yanks Peak: All tabulated size fractions were characterized by the presence of $10 \text{ \AA}^{\text{O}}$ mica, trace amounts occurred in the very fine sand and medium and fine clay fractions, major and dominant quantities occurred in the silt and coarse clay fractions. Traces of kaolinite were detected in the silt and smaller size fractions. Montmorillonite, along with trace amounts of vermiculite, was detected in the coarse clay and medium and fine clay fractions in

TABLE IV -- Mineral distribution in four different size fractions of the soils at site 2, Yanks Peak, determined by X-ray diffraction procedures

Hori- zon	Depth cm	Chlorite	10 Å Mica	Kaol- inite	Mont- morill- onite	Vermi- culite	Mixed Layers	Quartz	Feld- spar	Amphi- bole	Olivine	Crystalline iron oxides
Medium and fine clay <0.2μ*												
Ah	0 -15	0	1	0	3	1	1	1	0	0	0	0
Bm	15 -38	0	1	0	3	1	0	1-2	0	0	0	0
C	38+	0	1-0	1-0	3	1-0	0	1-2	0	0	0	0
Coarse clay 2-0.2μ*												
Ah	0 -15	0	3-4	1-2	1-2	1	0	1	0	0	0	0
Bm	15 -38	0	3	1	1-0	0	0	2	0	0	0	0
C	38+	0	3	0	1-0	0	0	2	0	0	0	0
Silt 2-50μ ⁺												
Ah	0 -15	3	2	0	0	0	0	3	1	0	0	0
Bm	15 -38	2	3	1	0	0	0	2	1	0	0	0
C	38+	1	4	0	0	0	0	2	1	0	1	0
Very fine sand 50-100μ ⁺												
Ah	0 -15	0	1	0	0	0	0	4	1	0	1	1
Bm	15 -38	0	1	0	0	0	0	4	1	0	1	1
C	38+	0	1	0	0	0	0	4	1	0	1	1

* Expressed as relative quantities

0. None 1. Trace 0-10% 2. Minor 10-35% 3. Major 35-65% 4. Dominant 65-100%

⁺ Expressed as relative occurrence

0. Absent 1. Present 2. Minor 3. Major 4. Dominant ? Not positively identified

trace and major amounts, respectively. Chlorite was limited to the silt sized fraction and mixed layer montmorillonite-vermiculite to the medium and fine clay fraction of the surface horizon. Quartz followed a similar distribution pattern to site 1 with feldspar occurring in trace amounts and only in the very fine sand and silt fractions. Traces of olivine were detected in the silt and very fine sand fractions. Traces of crystalline iron oxides were also detected in the very fine sand fraction, however, they were not identified as to mineral species.

Most of the 10 \AA mica appeared to be inherited from the parent material and the montmorillonite was forming at its expense (Jackson, 1964, 1965 and Mackenzie, 1965). It also appeared that some of the montmorillonite was being further weathered resulting in the formation of kaolinite though there was some indication that part of the kaolinite may have been inherited. The distribution of clay minerals in the coarse clay fraction indicated that pedogenic alteration of the clay minerals was the most intense in the Ah horizon. The decrease in primary minerals with decrease in grain size again illustrated the relative susceptibility of minerals to weathering with increase in surface area.

Site 3 Yanks Peak: Traces of chlorite and mixed layer montmorillonite-vermiculite were detected in both clay

fractions of site 2, otherwise the distribution of minerals in the silt and clay sized fractions was essentially similar to site 2. The very fine sand fraction differed in that neither 10 \AA° mica nor olivine was detected.

The sequence of weathering at site 3 appeared to be essentially the same as at site 2. If the kaolinite was pedogenic and not inherited at both sites then this indicated site 3 was pedogenically at a more advanced weathering stage than site 2 where the presence of olivine was a further indication of its relatively more youthful stage of development than site 3 (Jackson, 1948). The presence of chlorite solely in the Ae horizon of both clay fractions and distribution of 10 \AA° mica suggests parent material may have influenced the clay mineral content of these two sites more than pedogenesis. The alternative interpretation was that processes taking place in these soils do not correspond with those generally taking place in podzols (Brydon, Kodama and Ross, 1968).

Site 4 Fitzsimmons: Chlorite was present in all size fractions and was the major mineral present in the silt and both clay fractions. The silt fraction also contained major amounts of 10 \AA° mica which decreased to minor amounts in both clay fractions along with trace to minor amounts of vermiculite. Traces of kaolinite, montmorillonite and mixed layer vermiculite-montmorillonite were only detected

TABLE V -- Mineral distribution in four different size fractions of the soils at site 3, Yanks Peak,
determined by X-ray diffraction procedures

Horizon	Depth cm	Chlorite	10 Å Mica	Kaol- inite	Mont- morill- onite	Vermi- culite	Mixed Layers	Quartz	Feld- spar	Amphi- bole	Olivine	Crystalline iron oxides
Medium and fine clay 0.2μ*												
Ae	0 - 7.5	1-0	1	1	3	0	1-0	1	0	0	0	0
Bf	7.5-18	0	4	1	2	1	1	1	0	0	0	0
BC	18 -50	0	4	1	1	1	1	1-2	0	0	0	0
C	50+	0	1	1	4	0	0	1-2	0	0	0	0
Coarse clay 2-0.2μ*												
Ae	0 - 7.5	1-0	3-4	1-0	2	0	1-0	1-2	0	0	0	0
Bf	7.5-18	0	3-4	1-0	1-0	0	0	1	0	0	0	0
BC	18 -50	0	3	1	1-0	2	0	2	0	0	0	0
C	50+	0	3	1-2	1	1	0	2	0	0	0	0
Silt 2-50μ ⁺												
Ae	0 - 7.5	2	4	0	0	0	0	3	1	0	0	0
Bf	7.5-18	2	4	0	0	0	0	3	0	0	0	0
BC	18 -50	1	3-2	0	0	0	0	3	0	0	0	0
C	50+	2-3	3	1	0	0	0	3	0	0	0	0
Very fine sand 50-100μ ⁺												
Ae	0 - 7.5	0	0	0	0	0	0	4	1	0	0	1
Bf	7.5-18	0	0	0	0	0	0	4	1	0	0	1
BC	18 -50	0	0	0	0	0	0	4	1	0	0	1
C	50+	0	0	0	0	0	0	4	1	0	0	1

* Expressed as relative quantities

+ 0. None 1. Trace 0-10% 2. Minor 10-35% 3. Major 35-65% 4. Dominant 65-100%

+ Expressed as relative occurrence

0. Absent 1. Present 2. Minor 3. Major 4. Dominant ? Not positively identified

in the medium and fine clay fraction. Quartz and feldspar were detected in decreasing amounts with depth, a trace of quartz and no feldspar being detected in the medium and fine clay. Traces of amphibole crystalline iron oxides and possibly epidote were detected in the very fine sand fraction.

Chlorite and 10 \AA° mica appeared to be inherited from the parent material. The appearance of vermiculite in the coarse clay fraction and the relative decrease in 10 \AA° mica indicated that vermiculate had formed at the latter's expense (Jackson, 1965). In the medium and fine clay fraction the process of weathering appeared to have gone several stages further. The interpretation was that the vermiculite was being weathered to montmorillonite via a transitory intermediate of mixed layer vermiculite-montmorillonite. The kaolinite in the medium and fine clay fraction was believed to be pedogenic and formed by the "alumination" and "silication" of montmorillonite (Jackson, 1964, 1965; Altschuler, Dwornik and Kramer, 1963). Kaolinite formation in soils of granitic origin has been previously described (Stephen, 1952) though in this case the soils because of their location and position on the landscape would not have been expected to have reached such an advanced pedogenic age. The influence of the weathering products of volcanic ash may have had some influence though Kanno (1962) indicated that kaolin formation had been observed in some old members

TABLE VI -- Mineral distribution in four different size fractions of the soils at site 4, Fitzsimmons
determined by X-ray diffraction procedures

Horizon	Depth cm	Chlorite	10 Å Mica	Kaol- inite	Mont- morill- onite	Vermi- culite	Mixed Layers	Quartz	Feld- spar	Amphi- bole	Epidote	Crystalline iron oxides
Medium and fine clay < 0.2μ*												
Ah	0 -12.5	1	1	1	1	3	1	1	0	0	0	0
Bfh	12.5-30	3	2	1-2	1-0	1-2	0	1	0	0	0	0
C	44+	3	2	1	1	1-0	1	1	0	0	0	0
Coarse clay 2-0.2μ*												
Ah	0 -12.5	3	2	0	0	1-2	0	1-2	0	0	0	0
Bfh	12.5-30	3	2-1	0	0	1-2	0	1-2	0	0	0	0
C	44+	3-4	2-3	0	0	1-2	0	2	1	0	0	0
Silt 2-50μ ⁺												
Ah	0 -12.5	3-4	3	0	0	0	0	2	2	0	0	0
Bfh	12.5-30	3	3	0	0	0	0	2	2	0	0	0
C	44+	3	3	0	0	0	0	2	2-1	0	0	0
Very fine sand 50-100μ ⁺												
Ah	0 -12.5	1	0	0	0	0	0	3	2	0	?	1
Bfh	12.5-30	0	0	0	0	0	0	3	2	0	?	1
C	44+	1	0	0	0	0	0	3	2-1	1	?	1

* Expressed as relative quantities

0. None 1. Trace 0-10% 2. Minor 10-35% 3. Major 35-65% 4. Dominant 65-100%

⁺ Expressed as relative occurrence

0. Absent 1. Present 2. Minor 3. Major 4. Dominant ? Not positively identified

of humic allophane soils with strongly acid reactions, he did not indicate the age of the old members.

Site 5 Fitzsimmons: No mixed layer minerals were detected at site 5 otherwise the primary and secondary mineral content and processes that had taken place in the pedon were essentially the same as at site 4. The degree of weathering interpreted as having taken place only in the medium and fine clay fraction of site 4 appeared to have also taken place in the coarse clay fraction of site 5. The relative increase in the primary minerals feldspar, amphibole and possibly the crystalline iron oxides in the finer sized fractions indicated that weathering had not been as intense at site 5 as at site 4 or that amorphous coating had afforded some protection against weathering. On considering both the primary and secondary mineral distribution at site 5 there was an inference that other than the weathering of the regolith accounted for the distribution of the clay minerals. This again pointed to the volcanic ash as having had an influence on the mineralogy of the secondary minerals in the pedon.

Petrographic Analyses: The mineralogy of the very fine sand fraction was determined in a semi-qualitative manner. The sand grains were placed in one of two groups and were then classified within each group. The constituents

TABLE VII — Mineral distribution in four different size fractions of the soils at site 5, Fitzsimmons, determined by X-ray diffraction procedures

Horizon	Depth cm	Chlorite	10 Å Mica	Kaol- inite	Mont- morill- onite	Vermi- culite	Mixed Layers	Quartz	Feld- spar	Amphi- bole	Epidote	Crystalline iron oxides
Medium and fine clay <0.2μ*												
Ah	0 -10	1	1	1	1	3-4	0	1-0	0	0	0	0
Bfh	10 -21.5	3	0	0	0	3	0	0	0	0	0	0
C	36+	3	1-2	2	1-2	1	0	1	0	0	0	0
Coarse clay 2-0.2μ*												
Ah	0 -10	1	2	2-3	1-0	2	0	2	1	0	0	0
Bfh	10 -21.5	1	2	2-3	1-0	3	0	1	1	0	0	0
C	36+	3-4	3	1	1-0	0	0	1	1-0	0	0	0
Silt 2-50μ ⁺												
Ah	0 -10	3	2-3	0	0	0	0	2	2-1	1	0	1
Bfh	10 -21.5	3	2	0	0	0	0	2-1	2-3	1	0	1
C	36+	3	2	0	0	0	0	2	2	0	0	1
Very fine sand 50-100μ ⁺												
Ah	0 -10	1	1	0	0	0	0	3	2-1	1	?	1
Bfh	10 -21.5	1	1	0	0	0	0	3	2	1	?	1
C	36+	1	1	0	0	0	0	3	2-1	1	?	1

*Expressed as relative quantities

0. None 1. Trace 0-10% 2. Minor 10-35% 3. Major 35-65% 4. Dominant 65-100%

⁺Expressed as relative occurrence

0. Absent 1. Present 2. Minor 3. Major 4. Dominant ? Not positively identified

of the volcanic ash group were further classed according to morphology or phenocryst composition in a manner similar to that described by Smith, Okazaki and Aarstad (1968). The constituents of the non-ash group were classified according to appearance as opaque, non-opaque*, ferromagnesian and weathered and/or coated minerals. The opaque minerals consisted largely of metallic oxides and sulphides. The non-opaque minerals consisted largely of quartz and feldspars. The ferromagnesian minerals consisted of dark silicate minerals mostly comprising amphibole, pyroxene, biotite, olivine and chlorite and the weathered and/or coated minerals comprised of minerals which were difficult to identify due to their state of weathering and/or the amount of coating material covering them.

The opaque minerals were present in the least amounts of the non-ash fraction at all sites.

At sites 2 and 3 the non-opaque minerals decreased in abundance with depth. At sites 3, 4 and 5 they constituted the major percentage of the minerals present. At sites 1 and 5 they decreased, then increased with depth. Site 4 exhibited an increased content in the C horizon in the amount of non-opaque minerals.

At site 1 the ferromagnesian minerals comprised about 50 percent of the non-ash fraction, the greatest percentage occurring in the Bm horizon. Sites 2 and 3 had

* Uncoated non-opaque.

TABLE VIII — Petrographic analyses of the very fine sand fraction

Hori- zon	Depth cm	% Non-ash fraction				Volcanic ash %	% Volcanic ash fraction							Total No. Counts	
		Opaque	Non- opaque	Ferro- magne- sian	Weathered coated minerals		Coarse vesi- cular	Fine vesi- cular	Phenocrysts*			Ferro- magne- sian			
									Platy	Tubular	Opaque		Non- opaque		
Site 1 Camelsfoot															
Ahl	0 - 6.3	1	32	49	18	31	11	49	14	12	4	3	8	239	
Bm	12.5-20	2	29	49	10	17	10	38	25	15	0	8	3	233	
CB	20 -43	1	33	49	17	0	0	0	0	0	0	0	0	235	
Site 2 Yanks Peak															
Ah	0 -15	0	60	2	38	2	0	40	20	40	0	0	0	221	
Bm	15 -38	1	28	3	66	2	25	0	0	50	0	25	0	211	
C	38+	0	10	2	88	0	0	0	0	0	0	0	0	169	
Site 3 Yanks Peak															
Ae	0 - 7.5	1	90	3	6	5	0	9	55	27	0	9	0	240	
Bf	7.5-18	1	87	5	7	0	0	0	0	0	0	0	0	242	
BC	18 -50	2	87	5	6	0	0	0	0	0	0	0	0	253	
C	50+	1	54	5	41	0	0	0	0	0	0	0	0	223	
Site 4 Fitzsimmons															
Ah	0 -12.5	0	49	14	37	10	15	30	25	15	0	10	5	202	
Bfh	12.5-30	1	49	19	29	1	50	50	0	0	0	0	0	216	
C	44+	1	55	27	17	0	0	0	0	0	0	0	0	206	
Site 5 Fitzsimmons															
Ah	0 -10	1	61	24	14	35	9	40	16	8	0	12	15	220	
Bfh	10 -21.5	0	42	21	31	6	0	8	0	92	0	0	0	211	
C	36+	1	54	25	20	0	0	0	0	0	0	0	0	216	

*Glass-encased phenocrysts

the lowest percent present with the Ae horizon of site 3 containing a lower percentage than the rest of the horizons. At site 4 they increased with depth and at site 5 constituted about 25 percent of the group. The Bfh horizon contained slightly less than the Ah and C horizons at site 5.

No two sites exhibited the same distribution of weathered and or coated minerals. At site 2 the percentages increased with depth. At site 4 they decreased with depth. At site 1 the percentages decreased in the Bm horizon and increased again in the C. At site 3 the distribution was uniform to the C where there was a large increase and at site 5 the distribution increased in the Bfh to decrease again in the C.

Volcanic ash was detected in the surface horizons of all the sites. Sites 1 and 5 both contained over 30 percent in their surface Ah horizon, while site 1 contained the most ash in the total pedon. The amount detected at sites 2 and 3 was 2 and 5 percent respectively, this was almost negligible; while site 4 contained 10 percent in the surface Ah horizon.

The mineralogy of the very fine sand fraction indicated that at least three of the sites, 1, 4 and 5, had been influenced by additions of volcanic ash to their surfaces.

At site 1 the percentage distribution of the non-ash fraction suggested that the parent material was stratified

or the soil had been subject to congeliturbation which seemed to be borne out by the depth at which volcanic ash was identified. However, surficially there was no evidence of congeliturbation features on the slopes, where the site was located.

There was an indication that site 2 is pedogenically younger than site 3 as pedogenesis has resulted in most of the, dithionite resistant, coating material being eluviated out of the solum of site 3; while site 2 has not been subjected to sufficient leaching to eluviate this material. Though not indicated in the table, almost all of the counts in the weathered coated column of these two sites were coated by an unidentified, apparently amorphous, black opaque material.

The percentage distribution of minerals at sites 4 and 5 suggest that there has been some stratification in the parent material. The present periglacial environment and abundance of glacial drift in the vicinity of the sites supports the case for some differential sorting having taken place in the parent material without any major lithological change having been involved.

The major differences between the volcanic ash at the two locations, the Camelsfoot Range and Garibaldi Park, was in the phenocrysts. The volcanic ash at sites 4 and 5 was made up of a greater percentage of non-opaque

and ferromagnesian glass encased phenocrysts than was the ash from site 1 which was composed of a percentage of opaque phenocrysts as well as non-opaque and ferromagnesian.

The minimal amount of ash that was detected at sites 2 and 3 suggested that the sites did not lie in the main path of ash deposition. The dominance of fine vesicular, platy and tubular shards suggested that these classes of shards are the least dense and were carried the greatest distances.

Differential Thermal Analysis: The differential thermal analysis curves were interpreted using the criteria in the literature (Chichester, Youngberg and Harward, 1969; Kirkman, Mitchell and Mackenzie, 1966; Mitchell, Farmer and McHardy, 1964 and Tan, 1969).

Broad exothermic peaks between 100°C and 200°C suggested the presence of amorphous material and possibly allophane in all horizons at all sites, though the peak heights usually decreased with depth. The peak heights did not correspond to the distribution of amorphous materials in the clay fraction, as determined by chemical analyses (See Table X), but corresponded more to distribution of organic matter.

The presence of goethite was suggested by an endothermic peak in the region of 290°C in the BC and C

horizons of site 3 and the C horizon of site 5. Crystalline iron oxides were detected by X-ray diffraction in the very fine sand fractions of sites 2, 3, 4 and 5.

Chemical Analyses

The results of selected chemical analyses are shown in Table IX.

pH: The pH values, measured in water, ranged from 4.27 in the Ae horizon of site 3 to 6.10 in the CB horizon of site 1. The majority of values were around pH 5.

The sites exhibiting the strongest B horizon development, sites 3, 4 and 5, also showed the lowest pH values in their surface horizons. While the remaining two sites exhibited slightly increased values in their surface horizons over the immediately underlying horizon. These two situations were interpreted as being the result of more intense leaching in the first case, and base cycling slightly over-riding the leaching effect in the latter.

The difference between pH values measured in water and in calcium chloride varied between 1.85 and 0.58 pH units. Sites 1, 2 and 3 showed differences of over 1 pH unit while sites 4 and 5 showed differences of less than 1 pH unit.

Surprisingly there was no significant correlation

TABLE IX — Selected chemical analyses of the study sites

Hori- zon	Depth cm	pH		Total C%	N%	S%	C/N	C.E.C.*	Base Satn.%	Exchangeable Cations				pH dependent C.E.C.
		H ₂ O	CaCl ₂							Ca	Mg	K	Na	
Site 1 - Camelsfoot														
Ah1	0 - 6.3	5.65	4.55	7.02	0.93	0.065	7.6	32.72	58.6	15.29	2.96	0.50	0.43	24.77
Ah2	6.3-12.5	5.35	4.38	4.47	0.52	-	8.6	26.15	25.4	4.29	1.85	0.16	0.34	-
Bm	12.5-20	5.55	4.40	3.18	0.36	0.028	8.8	25.31	12.3	2.35	0.50	0.09	0.17	22.15
CB	20 -43	6.10	4.58	0.59	0.07	0.003	8.4	16.81	19.9	2.90	0.14	0.12	0.18	13.91
Site 2 - Yanks Peak														
L-F	4 - 0	5.30	4.40	26.42	1.93	-	13.7	61.01	41.7	14.27	6.30	2.97	1.92	-
Ah	0 -15	5.12	4.07	4.07	0.56	0.046	7.3	23.25	24.2	3.68	1.31	0.36	0.28	14.21
Bm	15 -38	5.05	4.05	2.16	0.34	0.025	6.4	13.48	19.0	1.64	0.59	0.17	0.16	9.91
C	38+	5.17	4.15	1.18	0.23	0.019	5.1	7.01	25.5	0.85	0.47	0.12	0.28	5.63
Site 3 - Yanks Peak														
L-F	2 - 0	4.45	3.60	23.64	1.32	-	17.9	63.54	17.9	3.77	2.61	3.88	1.13	-
Ae	0 - 7.5	4.27	3.60	2.31	0.27	0.021	8.6	15.39	11.2	0.66	0.52	0.18	0.36	10.53
Bf	7.5-18	4.50	3.90	2.02	0.13	0.016	15.5	14.61	8.8	0.77	0.06	0.10	0.36	13.43
BC	18 -50	4.87	4.20	0.31	0.05	0.002	6.2	4.32	26.2	0.89	N.D.	0.12	0.12	0.52
C	50+	5.75	4.35	0.27	0.10	0.002	2.7	4.33	79.5	1.95	1.24	0.12	0.13	0.68
Site 4 - Fitzsimmons														
Ah	0 -12.5	4.90	4.03	6.94	0.62	0.053	11.2	19.66	17.5	1.63	0.74	0.39	0.67	15.81
Bfh	12.5-30	5.08	4.45	5.39	0.53	0.047	10.2	24.47	5.8	0.63	0.27	0.14	0.37	19.81
BC	30 -44	5.15	4.45	2.91	0.25	-	11.6	13.85	8.7	0.58	0.22	0.10	0.31	-
C	44+	5.35	4.60	0.79	0.01	0.009	11.3	7.43	19.3	0.61	0.42	0.10	0.30	6.03
Site 5 - Fitzsimmons														
Ah	0 -10	4.83	3.95	10.38	0.86	0.087	12.1	33.64	11.3	1.61	0.99	0.51	0.69	26.13
Bfh	10 -21.5	5.38	4.55	3.11	0.35	0.038	8.9	17.85	7.4	0.61	0.25	0.11	0.35	16.32
BC	21.5-36	5.33	4.75	1.19	0.13	-	9.2	6.85	20.2	0.72	0.26	0.10	0.30	-
C	36+	5.83	4.88	0.33	0.04	0.008	8.3	3.84	36.7	0.59	0.38	0.10	0.34	2.71

* Meq per 100 g

N.D. Not detectable

between pH and organic matter. Correlations were found to exist between the pH measured in calcium chloride and the dithionite, oxalate, and sodium hydroxide extractable soil aluminum and also the sodium hydroxide extractable aluminum from the clay fraction. Relationships between soil pH and aluminum have been noted in the literature (Clark, 1966; Heddleson, McLean and Holowaychuk, 1960 and Jones and Handreck, 1963).

Total Carbon, Nitrogen and C/N Ratio: The percentage of total carbon decreased with depth at all sites. This reflected root penetration more than it did organic matter eluviation. Site 3 which showed the least root density in the profile yielded the lowest carbon content on analysis in the laboratory.

The nitrogen content at all sites was greatest in the surface horizons and decreased with depth. The significant correlation at the one percent level between nitrogen and total carbon indicated that most of the nitrogen was in organic combination. The relatively low C/N ratios indicated that the organic matter at all sites was fairly well humified. However Crocker (1960) indicated that in pioneer communities there is a rapid build up of nitrogen. Possibly this situation is characteristic of alpine environments, making for narrow C/N ratios. The

degree of humification of the organic matter at the study sites was not measured but morphology of the profiles does not give the impression of a high degree of humification. Literature values ranged from about 9 for chernozems to 22 for podzols (Russell, 1961). Values obtained for alpine soils in Montana, Colorado and Washington State tended to be slightly higher (Nimlos and McConnell, 1964; Retzer, 1962 and Starr, 1963) than the values obtained from the study sites.

Total Sulphur: The total sulphur at all sites decreased with depth. The high correlation significant at the 1 percent level, with organic matter indicated that most of the sulphur was in organic combination. C:S and N:S ratios were in the region of 100:1 and 10:1, respectively, which was expected from values quoted in the literature (Alexander, 1961; Russell, 1961).

Exchangeable Cations and Base Saturation: The percent base saturation decreased with depth in the solum and started to increase again in the BC and C horizons at each site.

The exchangeable cations in order of dominance, Ca^{++} , Mg^{++} , Na^+ and K^+ , tended to decrease with depth in the pedon. A slight increase in one or more cations, mostly Na^+ was noted in the C horizon at all sites. In the organic horizon at site 3, K^+ dominated the exchange complex

indicating possible luxury consumption of K^+ by the vegetation.

The percent base saturation and distribution of cations in the pedon was influenced by and reflected the depth and intensity of weathering, the presence and availability of the elements in the regolith, the degree of leaching taking place in the pedon and the counter effect of base cycling by the vegetation.

Cation Exchange Capacity and pH Dependent Exchange Capacity:

The cation exchange capacity decreased with depth at all sites, except site 4 where there was an increase in the Bfh horizon before decreasing with depth. Organic surface material yielded values in the region of 60 meq/100 g, Ah horizons 20-30 meq/100 g and C horizons ranged from 16 to less than 4 meq/100 g.

The highest correlation, significant at the one percent level, was with total carbon. This correlation accounted for the decrease in cation exchange capacity with depth. The increase in cation exchange capacity in the Bfh horizon of site 4 may be related to the degree of decomposition of the organic matter in this horizon in relation to the horizon above. Organic matter appears to have made the greatest contribution to the exchange capacity in all these soils, as no correlations of any significance were made with soil texture. However, in the horizons

with lowest organic carbon contents the exchange capacities approached the values associated with the textural class (Buckman and Brady, 1969).

The pH dependent cation exchange capacity decreased with depth at all sites except at sites 3 and 4 where a slight increase in the Bf and Bfh horizons, was found before continuing to decrease the depth. The pH dependent cation exchange capacities of all horizons, except the C horizons of sites 2, 3, 4 and 5 and the BC horizon of site 3, were greater than 8 meq/100 g.

The pH dependent C.E.C. is the difference in exchange capacity between that measured close to or at the soil pH, in calcium chloride, and that measured under neutral conditions. The difference results from the release of exchange sites under neutral conditions which have been blocked by the aluminum at lower pH values (Clark, 1966; Black, 1968). Black (1968) also indicated that pH dependent exchange positions were principally in the organic matter. This relationship was indicated in the tabulated data.

It has been suggested (Clark, 1966) that a pH dependent C.E.C. of 8 meq/100 g be considered a lower limit for spodic horizons provided organic matter and free oxide requirements are met. The data obtained from the study indicated that this criteria may be complicated in very strongly to extremely acid soils containing relatively

large amounts of free aluminum or soils which have been influenced by volcanic ash and its weathering products.

Extracted Amorphous Materials from the Fine Earth and Clay Fractions: The values obtained in the extractions are shown in Table X. The iron aluminum and silicon are expressed as ferric oxide, alumina and silica.

The percentage of total amorphous material in the clay fraction tended to increase in the B horizons at all sites except site 2 which exhibited a decrease with depth. This indicated that the amorphous constituents were being illuviated, in either amorphous or ionic form, in the B horizons. At site 2 the indication was that eluviation within the pedon was not as marked a process as at the other sites.

The amorphous iron oxide and alumina tended to increase and silica to decrease in the clay fraction of the B horizons. Again site 2 was the exception where silica and alumina decreased with depth and ferric oxide increased. The results indicated that illuviation of iron and aluminum was taking place in the soil pedon. A possible interpretation for the distribution of silica is that it reflects some dissolution of crystalline clays by the extracting solution. The maximum amount of silicon having been brought into solution where the protective coating of amorphous iron and aluminum was thinnest. At

TABLE X — Composition of amorphous materials in the clay fraction ($<2\mu$) and in the soils of the study sites

Hori- zon	Depth cm	Fraction	Component %			Mole Ratio			% Amorphous Material in Clay	Dith	NaOH
			SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	SiO ₂	Al ₂ O ₃		NaOH	Dith
						R ₂ O ₃	Al ₂ O ₃	Fe ₂ O ₃		Fe	Si
Site 1 Camelsfoot											
Ahl	0 - 6.3	Soil	3.89	0.69	0.71	6.44	9.56	1.51		23.65	2.04
		Am.Clay	78.50	16.30	5.20	9.05	8.16	4.93	35.73	12.31	7.56
Bm	12.5-20	Soil	4.93	2.34	1.15	3.40	3.57	3.19		57.07	3.68
		Am.Clay	58.36	31.64	9.99	3.48	3.12	4.97	52.72	32.74	7.06
CB	20 -43	Soil	5.06	2.44	0.77	3.91	3.52	4.98		40.11	4.91
		Am.Clay	65.97	28.57	5.45	4.92	3.91	8.17	38.45	35.72	10.56
Site 2 Yanks Peak											
Ah	0 -15	Soil	4.30	0.43	1.04	6.37	17.14	0.65		60.13	4.61
		Am.Clay	73.83	8.93	17.24	6.24	14.10	0.81	21.53	49.99	4.62
Bm	15 -38	Soil	8.57	0.25	1.57	9.86	57.20	0.26		179.08	0.10
		Am.Clay	59.61	8.07	32.32	3.14	12.56	0.39	16.82	166.50	2.26
C	38+	Soil	15.22	0.27	1.63	16.76	93.70	0.27		569.20	0.40
		Am.Clay	37.86	6.47	55.66	1.28	9.90	0.18	15.99	339.26	0.94
Site 3 Yanks Peak											
Ae	0 - 7.5	Soil	2.14	0.26	0.21	10.58	13.85	2.00		14.02	3.64
		Am.Clay	78.75	13.38	7.87	8.81	10.00	2.66	10.79	19.90	1.80
Bf	7.5-18	Soil	1.68	0.74	2.07	1.29	3.84	0.56		722.90	1.17
		Am.Clay	40.95	13.35	45.70	1.48	5.19	0.46	18.10	695.88	1.62
BC	18 -50	Soil	2.24	0.63	1.92	1.88	5.97	0.52		256.62	1.40
		Am.Clay	44.42	16.75	38.82	1.74	4.49	0.68	15.47	290.81	1.62
C	50+	Soil	1.24	0.22	1.97	1.19	9.55	0.18		175.64	0.34
		Am.Clay	47.23	11.24	41.52	1.90	7.10	0.43	13.13	169.97	1.36

TABLE X (Continued) — Composition of amorphous materials in the clay fraction ($<2\mu$) and in the soils of the study sites

Hori- zon	Depth cm	Fraction	Component %			Mole Ratio			% Amorphous Material in Clay	Dith	NaOH
			SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	SiO ₂	Al ₂ O ₃		NaOH	Dith
						R ₂ O ₃	Al ₂ O ₃	Fe ₂ O ₃		Fe	Si
Site 4 Fitzsimmons											
Ah	0 -12.5	Soil	4.35	0.49	1.16	5.71	15.00	0.66		40.08	4.72
		Am.Clay	77.59	12.54	9.86	8.09	10.50	1.99	22.71	8.75	4.12
Bfh	12.5-30	Soil	2.95	2.02	1.32	2.28	2.48	2.39		42.23	1.00
		Am.Clay	40.15	42.96	16.88	1.64	1.58	3.98	29.03	36.23	3.44
C	44+	Soil	2.82	1.46	0.54	3.46	3.29	4.21		54.63	2.64
		Am.Clay	59.87	33.95	6.23	3.80	2.99	8.63	20.99	23.97	2.86
Site 5 Fitzsimmons											
Ah	0 -10	Soil	7.62	0.78	1.34	10.08	16.49	0.92		20.82	6.30
		Am.Clay	78.16	15.53	6.30	8.77	8.55	3.85	24.04	4.08	3.71
Bfh	10 -21.5	Soil	5.31	3.67	0.70	3.08	2.44	8.18		34.09	4.44
		Am.Clay	51.89	42.53	5.58	2.78	2.07	11.97	57.95	24.99	9.21
C	36+	Soil	2.50	1.25	0.51	3.50	3.42	3.84		17.81	2.08
		Am.Clay	60.83	33.84	5.32	3.98	3.05	9.92	23.30	16.67	4.06

site 2 the silica and alumina distribution was the inverse of the ferric oxide distribution, supporting this interpretation.

The silica to sesquioxide mole ratio values tended to decrease with depth and ranged from approximately 10 at the surface to 2 at the base of the pedon. The silica to alumina mole ratio values showed a similar distribution and range, with a slight decrease in value in the B horizons where aluminum had been illuviated.

The alumina to iron oxide ratio at sites 1, 4 and 5 increased with depth and the values ranged from 1 at the surface to 9 at the base of the pedon. At sites 2 and 3 the same ratio tended to decrease with depth, most values were less than 1 with the value of 2 in the Ae horizon at site 3. There was an indication that the volcanic ash content of these soils has had an influence on the distribution of amorphous material in the pedons.

The values obtained in making similar extractions on the fine earth fraction indicated similar though not as marked relationships. The high degree of correlation, significant at the one percent level, between the values obtained for the amorphous constituents of the fine earth fraction and the clay fraction indicated that the amorphous constituents were associated mostly with the clay fraction.

The ratios of dithionite extractable iron to sodium hydroxide extractable iron showed the greater efficiency of dithionite in extracting iron from the soil than sodium hydroxide. The efficiency of extraction tended to increase with depth and was generally greatest in the B horizons. At sites 2 and 3 the dithionite was about 10 times more efficient than at sites 1, 4 and 5 where it was up to 50 times more efficient than sodium hydroxide.

The ratios of sodium hydroxide extractable to dithionite extractable silicon indicated that sodium hydroxide could be up to 10 times as efficient in extracting silicon as dithionite though at some sites it was equally or less efficient.

Some amorphous constituents were lost in the peroxidation of organic matter prior to amorphous constituent determinations (Farmer and Mitchell, 1963; Follett, McHardy, Mitchell and Smith, 1965), these solutions were retained, analyzed and the results tabulated (Table XII).

Silicon, Iron and Aluminum Extracted by Two Methods and Calculated Molar Ratios: The amounts of silicon, iron and aluminum extracted were tabulated as oxides (Table XI).

The dithionite-citrate-bicarbonate solution extracted silicon in a relatively random manner, while iron oxide and aluminum tended to be extracted in the greatest quantities from the B horizons.

TABLE XI -- Silicon, iron and aluminum extracted by two methods and calculated molar ratios

Hori- zon	Depth cm	Dithionite Extraction						Oxalate Extraction						Ox./Dith. Fe
		SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	SiO ₂	SiO ₂	Al ₂ O ₃	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	SiO ₂	SiO ₂	Al ₂ O ₃	
		%	%	%	$\frac{\text{SiO}_2}{\text{Fe}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	$\frac{\text{Al}_2\text{O}_3}{\text{Fe}_2\text{O}_3}$	%	%	%	$\frac{\text{SiO}_2}{\text{Fe}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	$\frac{\text{Al}_2\text{O}_3}{\text{Fe}_2\text{O}_3}$	
Site 1 Camelsfoot														
Ah1	0 - 6.3	0.370	0.800	0.340	0.69	1.85	0.66	0.045	0.772	1.398	0.05	0.05	2.84	0.97
Bm	12.5-20	0.573	1.487	1.001	0.50	0.97	1.05	0.280	0.872	2.362	0.21	0.20	4.24	0.59
CB	20 -43	0.374	1.144	0.661	0.49	0.96	0.91	0.545	0.375	2.230	1.42	0.41	9.31	0.33
Site 2 Yanks Peak														
Ah	0 -15	0.642	1.616	0.283	0.71	3.84	0.27	0.045	0.942	0.302	0.08	2.53	0.50	0.58
Bm	15 -38	0.588	2.216	0.189	0.50	5.29	0.13	0.209	1.154	0.374	0.29	0.95	0.51	0.52
C	38	0.802	3.903	0.189	0.40	7.22	0.08	0.385	1.181	0.282	0.56	2.32	0.37	0.30
Site 3 Yanks Peak														
Ae	0 -7.5	0.263	0.472	0.151	0.91	2.96	0.50	0.036	0.360	0.295	0.13	0.21	1.28	0.76
Bf	7.5-18	0.439	4.089	0.416	0.20	1.79	0.16	0.026	2.892	0.607	0.02	0.07	0.33	0.71
BC	18 -50	0.381	3.088	0.340	0.23	1.90	0.17	0.460	0.835	0.238	0.92	3.29	0.45	0.27
C	50+	0.338	2.445	0.208	0.26	2.75	0.13	0.051	0.159	0.168	0.36	0.52	1.66	0.07
Site 4 Fitzsimmons														
Ah	0 -12.5	0.695	1.458	0.321	0.83	3.67	0.35	0.049	0.955	0.699	0.07	0.12	1.15	0.65
Bfh	12.5-30	0.471	1.458	1.795	0.34	0.45	1.93	0.017	1.561	1.349	0.01	0.02	1.35	1.07
C	44+	0.439	0.643	0.529	0.85	1.41	1.29	0.131	0.387	1.223	0.20	0.18	4.95	0.60
Site 5 Fitzsimmons														
Ah	0 -10	0.588	0.986	0.416	0.91	2.40	0.66	0.054	0.862	1.196	0.06	0.08	2.17	0.87
Bfh	10 -21.5	0.674	1.330	1.360	0.58	0.84	1.60	0.293	1.115	3.904	0.15	0.13	5.49	0.84
C	36+	0.620	0.615	0.416	1.35	2.53	1.06	0.009	0.386	0.964	0.02	0.02	3.90	0.63

The silica: sesquioxide ratios reflected the accumulations of iron and aluminum oxides in the B horizons with a slight decrease in the ratio indicated at that point, the ratio values ranged from 1.35 to 0.20 with the majority of values below 1.0. The silica : alumina ratio ranged from 7.22 to 0.84 with the lowest values generally occurring in the B horizons and reflecting the relative accumulations of alumina. The alumina : iron oxide values ranged from 0.08 to 1.93. Values of 0.50 and under were recorded at sites 2 and 3, both sites being relatively uninfluenced by volcanic ash, values close to or greater than 1.00 at sites 1, 4 and 5 which contained over 10 percent volcanic ash in their surface horizons.

Significant correlations (at the one percent level) were detected between dithionite-citrate-bicarbonate extractable aluminum and aluminum extracted by sodium hydroxide and oxalate. Similar correlations were detected between iron extractions, only the oxalate extractable iron correlation was significant at the two percent level.

The acid-ammonium-oxalate solution extracted relatively random amounts of silica as was extracted by dithionite though the quantities extracted were generally a half to a tenth as much. Only the CB horizon at site 1 yielded more oxalate extractable silica. Iron and aluminum oxides were extracted in the greatest amounts from the B horizons indicating their accumulation.

The silica : sesquioxide ratios ranged in value from 1.42 to 0.01 with most of the values well below 1.0. No relationship was discernible between horizons or sites. The silica : alumina ratios showed a random distribution with values ranging from 3.29 to 0.02. The lowest ratio values occurred at those sites with volcanic ash present in appreciable (more than 10 percent) quantities. The alumina : iron oxide values ranged between 9.31 and 0.33 with the largest values occurring at sites 1, 4 and 5, again the ash associated soils.

From 0.7 to 4 times as much aluminum was extracted by oxalate as by dithionite. Again the sites where volcanic ash was present in significant amounts showed the greatest oxalate : dithionite extractable aluminum values.

Acid-ammonium-oxalate extracted from 0.07 to 1.07, though generally between 0.50 and 0.85, times as much iron as did dithionite. The magnitude of the ratios of these two extractions generally decreased with depth and there was a significant correlation at the one percent level with total carbon. Schwertmann (1968) indicated that high amorphous iron hydroxide content in the soil was associated with horizons showing accumulations of organic matter. This observation appeared to be partly borne out by the data though there is no significant correlation between oxalate extractable iron oxide and the total carbon content.

Some of the products of organic matter decomposition have been indicated as being amongst the major agents responsible for the mobilization, translocation and precipitation of sesquioxides in the soil pedon (Bloomfield, 1953; Duchaufour, 1965; van Schylenborgh, 1962 and Stobbe, 1961). If this is true, correlations indicated as significant, in the data collected, did not show direct relationships to the total carbon content present, suggesting that the mobility of sesquioxides must be related to a minor fraction of the total organic matter content of the soil.

Hydrogen Peroxide Extractable Iron Aluminum and Silicon:

When soil organic matter was oxidized with hydrogen peroxide water soluble chelated oxalates of iron and aluminum were formed (Farmer and Mitchell, 1963). The degree of solubilization of these two components plus silicon was determined.

The iron, aluminum and silicon values were expressed as iron oxide, alumina and silica in Table XII. Iron and aluminum, though not detectable in every case, appeared to be more readily solublized than silicon. Amounts solublized tended to decrease with depth. A relationship to organic matter content was expected and a significant correlation at the one percent level was found to occur.

Manganese Extracted by Various Treatments: Manganese has been shown to be of some genetic significance in the mid

TABLE XII -- Silicon, iron and aluminum liberated from the soil
on treatment with hydrogen peroxide.

Horizon	Depth cm	Peroxide Extracted		
		SiO ₂ %	Al ₂ O ₃ %	Fe ₂ O ₃ %
Site 1 Camelsfoot				
Ahl	0-6.3	0.198	0.461	0.105
Bm	12.5-20	ND	0.248	0.009
CB	20-43	0.024	0.025	ND
Site 2 Yanks Peak				
Ah	0-15	0.008	0.030	0.014
Bm	15-38	ND	ND	ND
C	38	ND	ND	ND
Site 3 Yanks Peak				
Ae	0-7.5	ND	ND	ND
Bf	7.5-18	ND	0.013	0.001
BC	18-50	ND	ND	ND
C	50+	ND	0.004	ND
Site 4 Fitzsimmons				
Ah	0-12.5	0.021	0.319	0.164
Bfh	12.5-30	0.008	0.614	0.128
C	44	ND	0.012	ND
Site 5 Fitzsimmons				
Ah	0-10	0.415	1.039	0.652
Bfh	10-21.5	ND	0.052	0.013
C	36+	ND	ND	ND

western United States (Daniels, Brasfield and Riecken, 1962). Manganese was determined on all solutions, after extractions were made, and the values obtained were examined to see: what relationships manganese had with the other components extracted; what genetic relationship manganese might have to soil development and how much of the materials extracted was composed of manganese.

Only dithionite and hydrogen peroxide solutions were found to have extracted measurable quantities of manganese (Table XIII). No significant correlations were found between manganese and any of the other chemical or physical properties measured.

The dithionite extraction, after sodium hydroxide extraction, extracted more manganese than the extraction from the previously untreated soil. This appeared to indicate amorphous sesquioxides and silica inhibit complete extraction of manganese. At sites 1, 2 and 3, the general trend was for manganese to accumulate in the B horizons, while at sites 4 and 5 manganese tended to decrease in the B horizons and increase again in the C horizons.

No uniform trend was indicated in the manganese content of the hydrogen peroxide solutions. At sites 4 and 5 distribution paralleled that for the dithionite solutions. At sites 1 and 2 manganese content decreased with depth and at site 3 the opposite trend was shown.

TABLE XIII -- Manganese extracted by various treatments

Horizon	Depth cm	Dithionite Extract. MnO%	H ₂ O ₂ Extract. MnO%	Post. NaOH Dith. Extract. Soil MnO%	Post. NaOH Dith. Extract. Clay MnO%
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Site 1 Camelsfoot

Ah	0-6.3	0.030	0.015	0.028	0.068
Bm	12.5-20	0.036	0.011	0.048	0.115
CB	20-43	0.017	0.003	0.014	0.029

Site 2 Yanks Peak

Ah	0-15	0.027	0.011	0.039	0.026
Bm	15-38	0.042	0.005	0.052	0.059
C	38+	0.027	0.001	0.034	0.094

Site 3 Yanks Peak

Ae	0-7.5	0.007	ND	0.003	0.012
Bf	7.5-18	0.011	0.001	0.049	0.053
BC	18-50	0.026	0.003	0.045	0.103
C	50+	0.011	0.003	0.020	0.086

Site 4 Fitzsimmons

Ah	0-12.5	0.050	0.013	0.102	0.039
Bfh	12.5-30	0.022	0.009	0.038	0.030
C	44+	0.024	0.010	0.041	0.103

Site 5 Fitzsimmons

Ah	0-10	0.009	0.011	0.074	0.043
Bfh	10-21.5	0.008	0.004	0.015	0.028
C	36+	0.037	0.006	0.029	0.211

Manganese has been found to be more soluble under reducing conditions and in soils of low pH (Buckman and Brady, 1969). The range of conditions encountered at the 5 sites and lack of significant correlation indicated further investigation was necessary before interpretations could be made. Daniels et al., (1962) found similar distributions to those at sites 1, 2 and 3 in prairie Planosols and to those at sites 4 and 5 in Gray-Brown Podzolic soils. Manganese was apparently a function of reducing conditions and/or pH in the former case and of pH, reducing conditions and an undetermined factor in the latter.

The percentage of manganese extracted in relation to the total amount of silicon, iron and aluminum extracted was generally of a low order of magnitude, though the quantities extracted compare with total amounts found in temperate region mineral surface soils (Buckman and Brady, 1969). The total manganese content of some Alberta soils has been reported and it was stated that manganese in the soil is affected by various factors, notably, soil reaction, moisture, temperature, and organic matter, respectively (Reid and Webster, 1969).

Definitive Analyses for Podzolic (Spodic) and Bf Horizons:

The results of analyses definitive for podzolic (spodic) and Bf horizons of the American and Canadian systems of

soil classification (Soil Survey Staff, 1967 and N.S.S.C., 1968) were listed in Table XIV. According to the present criteria the B horizons of each site were evaluated as to their Canadian and American designations:

	<u>Canadian</u>	<u>American</u>
Site 1	Bm	Spodic
Site 2	Bm	Cambic
Site 3	Bf	Spodic
Site 4	Bfh	Spodic
Site 5	Bfh	Spodic

The criteria for Bf horizons were met at sites 3, 4 and 5. In addition, at sites 4 and 5, the organic matter content was such that the horizons were designated Bfh.

McKeague and Day (1969) have recently suggested that 0.6 percent oxalate extractable aluminum might be a useful single criterion for characterizing podzol B horizons in the Canadian system of soil classification. A single criterion definition for a horizon as diagnostic as a podzol B horizon would appear to present a rather narrow view of the genesis of podzolic B horizons. Using the suggested criteria, the following horizons met the criteria designated for Bf horizons, the Bm and CB horizons at site 1, the Bfh and C horizons at site 4 and the Ah and Bfh horizons at site 5. Sites influenced by volcanic ash

TABLE XIV — Definitive analyses for podzolic (spodic) and Bf horizons.

Horizon	Depth cm	Oxalate Extractable				Dithionite Extractable			Pyro-Dith.Extractable				15 bar % water	
		Fe %	Al %	Fe+Al %	OM/ Fe	Fe %	Al %	Fe+Al %	Fe %	Al %	C* %	Fe+Al+C clay		
Site 1 Camelsfoot														
Ah1	0-6.3	0.54	0.74	1.28	14.3	0.56	0.18	0.74						21.6
Bm	12.5-20	0.61	1.25	1.86	9.0	1.04	0.53	1.57	0.50	0.79	1.60	0.800		10.1
CB	20-43	0.26	1.18	1.44	3.9	0.80	0.35	1.15	0.21	0.33	0.28	0.296		5.8
Site 2 Yanks Peak														
Ah	0-15	0.66	0.16	0.82	10.7	1.13	0.15	1.28						15.6
Bm	15-38	0.81	0.20	1.01	4.6	1.55	0.10	1.65	0.80	0.09	0.66	0.104		8.3
C	38+	0.83	0.15	0.98	2.5	2.73	0.11	2.84	1.30	0.09	0.38	0.120		5.2
Site 3 Yanks Peak														
Ae	0-7.5	0.33	0.08	0.41	12.1	0.25	0.16	0.41						7.9
Bf	7.5-18	2.86	0.22	3.08	1.2	2.02	0.32	2.34	1.99	0.27	1.31	0.253		6.6
BC	18-50	2.16	0.18	2.34	0.2	0.58	0.13	0.71	0.96	0.12	0.48	0.098		5.3
C	50+	1.71	0.11	1.82	0.3	0.11	0.09	0.20	0.37	0.06	0.10	0.075		3.4
Site 4 Fitzsimmons														
Ah	0-12.5	0.67	0.37	1.04	17.9	1.02	0.17	1.19						17.0
Bfh	12.5-30	1.09	0.71	1.80	8.5	1.02	0.95	1.97	0.84	1.22	3.46	0.682		12.8
C	44+	0.27	0.65	0.92	5.0	0.45	0.28	0.73	0.22	0.41	0.75	0.137		4.4
Site 5 Fitzsimmons														
Ah	0-10	0.60	0.63	1.23	29.8	0.69	0.22	0.91	0.58	0.59	3.37	0.446		22.9
Bfh	10-21.5	0.78	2.07	2.85	6.9	0.93	0.72	1.65	0.53	1.42	2.06	0.422		9.8
C	36+	0.27	0.51	0.78	2.1	0.43	0.22	0.65	0.19	0.27	0.19	0.068		3.3

* Carbon

appeared to exhibit a relatively high aluminum content in B horizons as well as in others. As the authors acknowledge, the criterion required extensive testing. From the findings indicated here and elsewhere (Bhoojedhur, 1969) the suggested criterion would have to be modified to include other criteria for precise definition.

The soil horizon designations would not have changed using the previous N.S.S.C. (1963) criteria based on dithionite extractable iron.

The criteria for a spodic horizon was met at sites 1, 3, 4 and 5.

The U.S. criteria for definition of a spodic horizon (Soil Survey Staff, 1967) uses a ratio which takes into account the fineness of the soil. This was necessary as it had been pointed out that the coarser the horizon texture the more pronounced the spodic character of the horizon will be for a given amount of illuvial material (Franzmeier et al., 1965).

The analyses indicated that a single criterion is rather meaningless for the characterization of a podzolic B horizon. In addition the textural bias that was inherent in the definitive criteria for spodic horizons is still true for Bf horizons, namely that the coarser the texture the greater the morphological expression. In fine textured materials because of the greater total surface area, it takes relatively

larger amounts of amorphous iron and aluminum to give the same morphologic expression as exhibited in coarser materials. .

SUMMARY AND CONCLUSIONS

The soils studied were from three separate alpine environments. Their morphology was described in the field and they were further characterized by laboratory analyses.

The soils at all sites have developed in areas with cold (cryic) climates (mean annual temperatures close to or below 0°C mean annual soil temperatures are generally higher).

The soils at sites 1, 4 and 5 were well to moderately well drained with dark non-Chernozemic surface horizons; developed from the accumulation and decomposition of a cyclic growth of xero-or mesophytic sedges, grasses and forbs characteristic of alpine and subalpine regions; and illuvial B horizons in which the major accumulation products were amorphous iron, aluminum and an undetermined amount of organic constituents and minor amounts of, in some cases, silicate clays mostly in the fine clay fraction. All three sites had been subject to surface additions of vitreous volcanic materials, which to a lesser or greater degree had influenced the following characteristics and properties of the soil: soil water retention, sequence of secondary mineral development, pH dependent C.E.C., amorphous constituents and soil morphology.

The soils at sites 2 and 3 were well drained and had developed under a parkland type of vegetation made up of reeds, sedges and forbs and to a lesser extent alpine fir.

Site 2 had an organic mor type surface horizon over a non-turfy Ah horizon which in turn was underlain by a B horizon which had been slightly modified by soil forming processes, though not sufficiently to exhibit the properties definitive for a podzolic or textural horizon.

Site 3 had an organic mor type surface horizon over an eluviated light-coloured horizon (Ae) which in turn was underlain by a podzolic Bf horizon in which the major accumulation product was amorphous iron. The BC horizon showed a slight accumulation of silicate clay though not sufficient to meet the requirements of a textural horizon.

The texture of the soils ranged from silt loam to loamy sand. Water retention curves showed the greater water retaining capacity of the surface horizons, this was correlated with organic matter content. Volcanic ash may have contributed to the water retentivity at some sites.

Quartz and feldspathic minerals were found to be most common in the very fine sand fractions in all the soils except at site 1 where ferromagnesian minerals were most common. Quantities of volcanic ash were present at 3 of the sites and there were indications that this had

influenced some of the properties and characteristics of these sites. The most commonly occurring clay minerals were the 10 Å micas, vermiculite and chlorite. The degree of pedogenic weathering was reflected in the occurrence of montmorillonite and kaolinite at some sites.

The soils were very strongly to extremely acid in reaction and this was found to be statistically significant in relation to amorphous aluminum. Total carbon, and thus organic matter, was found to influence the waterholding and cation exchange properties of the soils. Nitrogen and sulphur were largely in the organic form and the narrow C:N ratios encountered indicated that most of the organic matter was well humified. The percent base saturation was for the most part less than 50, the percent distribution reflecting the opposing actions of leaching and base cycling.

The content of total amorphous constituents and amorphous aluminum was greatest in the sites containing volcanic ash. Iron and aluminum showed a more parallel distribution when extracted by sodium hydroxide, dithionite-citrate-bicarbonate and acid-ammonium-oxalate than silica which exhibited a more random distribution. Amorphous iron and aluminum tended to accumulate in the B horizons at all sites except site 2. Dithionite tended to extract more iron and oxalate, more aluminum. The amount of silica, iron and aluminum extracted by hydrogen peroxide was

found to be almost negligible in most cases, however, they should be considered where subsequent extractions of these constituents are carried out, especially in association with amorphous organic matter.

Measurable quantities of manganese were extracted by dithionite and hydrogen peroxide in quantities corresponding to literature values of manganese available as a primary nutrient in temperate region soils. No correlations were found with extracted manganese.

According to the definitive analyses for podzolic (spodic) and Bf horizons the American system of soil classification was less restricting at these sites.

The geomorphological history, field morphology and laboratory analyses of these soils indicate that they are for the most part pedologically young. Simonson (1959) wrote:

Horizon differentiation is ascribed to additions, removals, transfers and transformations within the soil system. Examples of important changes that contribute to development of horizons are additions of organic matter removals of soluble salts and carbonates, transfers of humus and sesquioxides, and transformations of primary minerals into secondary minerals. It is postulated that these kinds of changes, as well as others, proceed simultaneously in all soils. It is further suggested that the balance within the combination of changes governs the ultimate nature of the soil profile.

A better appreciation of Jenny's (1941) concepts of the factors of soil formation would have rendered the

above redundant, however concepts of zonality have tended to be perpetuated by mans reliance on single process orientated classification systems.

The data obtained in the analyses of the study soils indicated the multiplicity of changes taking place in each pedon. Where more than one type of change in the soil profile had become strongly expressed the system of classification could not readily accommodate the soils without a change or modification in the system. Similar findings have been made elsewhere (Brydon, 1965; van den Brock and van der Marel, 1968/1969).

The soils were classified into the Canadian, American and World Systems as follows:

	<u>Canadian</u>	<u>American</u>	<u>World</u>
Site 1	Lithic Alpine Dystric Brunisol	Lithic Cryorthod	Dystric Cambisol
Site 2	Lithic Alpine Dystric Brunisol	Lithic Dystric Cryochrept	Dystric Cambisol
Site 3	Orthic Humo- Ferric Podzol	Typic Cryorthod	Humo-Ferric Podzol
Site 4	-	Lithic Cryorthod	Humo-Ferric Podzol
Site 5	-	Lithic Cryorthod	Humo-Ferric Podzol

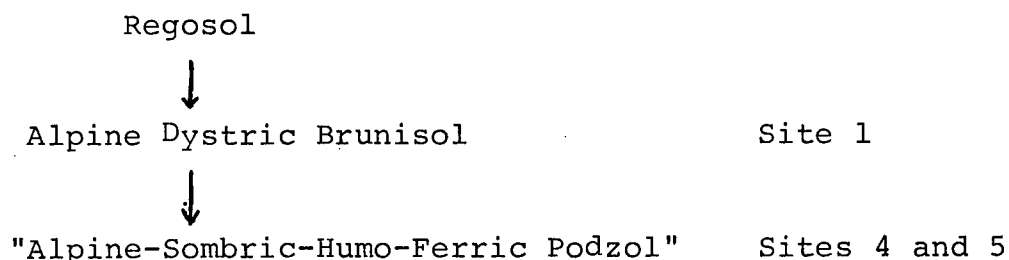
Sites 4 and 5 could not be classified using the Canadian System of soil classification. The horizon se-

quence at both sites corresponded to that defined for the Sombric-Humo-Ferric Podzol. However, the soils are excluded from this great group by the criteria for the sombric (Ah) horizons. The Ah horizons correspond closely to sombric (umbric) horizons and with slight modification to the criteria established for sombric horizons, could be accommodated.

The American system of classification places sites 1, 4 and 5 into the same great group. However, the classification is not precise as this great group (Cryorthod) fails to recognize the umbric (sombric) epipedon, which was found at sites 1, 4 and 5.

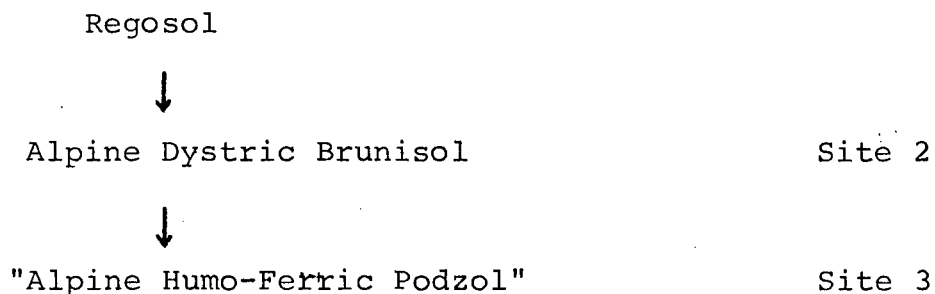
The World classification scheme has similar shortcomings to the U.S.D.A. and Canadian Systems, plus it tends to be less precise and more encompassing.

Sites 1, 4 and 5 appeared to be genetically related and similarly influenced by surface additions of volcanic ash. The following schematic relationship was postulated for these sites:



Sites 2 and 3 were not influenced by volcanic ash, the following schematic relationship was postulated for

these sites:



The Canadian System of soil classification (1968) recognises alpine soils at the subgroup level, these are, the Alpine Eutric and Alpine Dystric Brunisols. It is suggested that alpine soils may be more meaningfully classified if the following are considered:

- (a) None of the soils studied had a "turfy" Ah,
- (b) Three of the soils studied had podzolic B horizons,
- (c) The soils influenced by volcanic ash exhibited acidic Ah horizons of low base saturation and a morphology not previously considered in alpine areas, and
- (d) At site 1 the B horizon could be designated as a Bt if all cementing agents (Fe and Al) are removed. However the horizon was termed a Bm because field observations did not give any indications of clay illuviation.

If the above are considered it becomes more obvious that soils of the alpine region are not morphologically and genetically simple. . Thus, one or two classes in a natural classification system do not appear to be sufficient to classify soils in the alpine environment.

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APPENDIX I

U.B.C. Trip subrouting program correlation coefficients.

Values for 16 observations were significant as follows:

Significant $p \leq 0.01$ correlation coefficient ± 0.6662

Significant $p \leq 0.02$ correlation coefficient ± 0.6016

Significant $p \leq 0.05$ Correlation coefficient ± 0.5061

<u>Correlation Between</u>		<u>Correlation Coefficient (r)</u>
pH CaCl_2	and Dith Ex.* $\text{Al}_2\text{O}_3\%$	0.5567
	and Ox. Ex.* $\text{Al}_2\text{O}_3\%$	0.5109
	and Soil-NaOH Ex.* $\text{Al}_2\text{O}_3\%$	0.5630
	and Clay-NaOH Ex.* $\text{Al}_2\text{O}_3\%$	0.5573
N%	and Total Carbon%	0.9448
C.E.C.	and Total Carbon%	0.8738
	and Hygr. Water%	0.9145
Total Carbon%	and Sulphur%	0.9798
	and Ox./Dith. Ex.* Fe	0.6822
	and Hygr. Water%	0.8195
	and H_2O_2 Ex.* $\text{SiO}_2\%$	0.7794
	and H_2O_2 Ex.* $\text{Al}_2\text{O}_3\%$	0.8954
	and H_2O_2 Ex.* $\text{Fe}_2\text{O}_3\%$	0.8321

Dith. Ex.*

$\text{Al}_2\text{O}_3\%$	and Ox. Ex.* $\text{Al}_2\text{O}_3\%$	0.7043
	and Soil NaOH Ex.* $\text{Al}_2\text{O}_3\%$	0.8189
	and Clay NaOH Ex.* $\text{Al}_2\text{O}_3\%$	0.8277

Dith.Ex.*

$\text{Fe}_2\text{O}_3\%$	and Ox. Ex.* $\text{Fe}_2\text{O}_3\%$	0.6232
	and Soil Dith. Ex.* $\text{Fe}_2\text{O}_3\%$	0.9068
	and Clay Dith. Ex.* $\text{Fe}_2\text{O}_3\%$	0.9476

Soil NaOH

Ex.* $\text{SiO}_2\%$	and Clay NaOH Ex.* $\text{SiO}_2\%$	0.7356
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Soil NaOH

Ex.* $\text{Al}_2\text{O}_3\%$	and Clay NaOH Ex.* $\text{Al}_2\text{O}_3\%$	0.9727
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Soil NaOH

Ex.* $\text{Fe}_2\text{O}_3\%$	and Clay NaOH Ex.* $\text{Fe}_2\text{O}_3\%$	0.7018
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Soil Dith.

Ex.* $\text{Fe}_2\text{O}_3\%$	and Clay Dith. Ex.* $\text{Fe}_2\text{O}_3\%$	0.8651
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* Ex. = Extractable.