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PEDOLOGICAL INVESTIGATIONS IN THE FRONT RANGES OF THE ROCKY MOUNTAINS ALONG THE NORTH SASKATCHEWAN RIVER VALLEY

by

(C) WILLIAM WAYNE PETTAPIECE, BSc., M.Sc.

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF SOIL SCIENCE

EDMONTON, ALBERTA

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FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Pedological Investigations in the Front Ranges of the Rocky Mountains along the North Saskatchewan River Valley" submitted by William Wayne Pettapiece, B.Sc., M.Sc., in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT

This study was undertaken to assess soil development along the North Saskatchewan River Valley in the Front Ranges of the Rocky Mountains.

Field investigations revealed that the soils are dominantly comprised of Orthic Gray Luvisols and Degraded Eutric Brunisols on the benches, Cumulic and Orthic Regosols and Degraded Eutric Brunisols on the fans, and Orthic Regosols on the steep slopes. Many shallow soils underlain by rock are also encountered. Podzolic soils occur near treeline with Alpine soils above. The majority of soils are developed from an aeolian overlay with two definite periods of deposition implicated in the formation of the polygenetic soils on the benches. Soils on the fans adjacent to the river are characterized by little more than the addition of organic matter, but with increasing distance from the center of the valley, and increase in elevation, pedological weathering, and profile differentiation become increasingly pronounced.

Some of the more important features governing soil formation in the area are: the high carbonate content of much of the material which retards weathering and restricts the depth of pedologic activity, the valley winds which strongly influence microclimate and are active in deposition, the high volcanic ash content in the almost continuous layer of loess which influences surface soil character and weathering phenomena, and the activity of mass wasting and its disruption of soil materials.

Clay mineral investigations indicate the formation of montmorillonite by synthesis and degradation in a slightly acidic environment.

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INTRODUCTION

The study of soils in the Prairie Provinces of Canada has traditionally had an agricultural bias. This was a natural result of the initiation of soil research and soil surveys by agricultural agencies. From a pedological point of view this imposed restrictions and meant that soils in areas obviously outside the agricultural domain received very little attention. Not only has this resulted in a distinct lack of knowledge and appreciation concerning mountain soils in Alberta but also that the Canadian Soil Classification System, as evolved, does not take full cognizance of the many rather special soil phenomena found in the mountain regions. In more recent years there has been a general expansion in all aspects of pedology.

It was felt that at least preliminary information should be obtained on the soils of the mountainous regions of Alberta, as to both character and process. Such a study would prove valuable from a practical standpoint as well as from the purely pedological concern for increasing the knowledge of Canadian soils.

A location in the Front Ranges of the Rocky Mountains was considered most desirable with a preference for the central part of the province. The North Saskatchewan River Valley (Figures 1a and 1b) was selected for the study because it also offered ready accessibility. Windy Point (R 15, W 5) was chosen as the eastern boundary of the area because (1) it coincided with the McConnell Thrust Fault which marks the eastern edge of the Front Ranges and thereby limits the geology to the predominantly carbonate rocks of Paleozoic age, and (2) east of this point the valley becomes more poorly defined and of limited access.

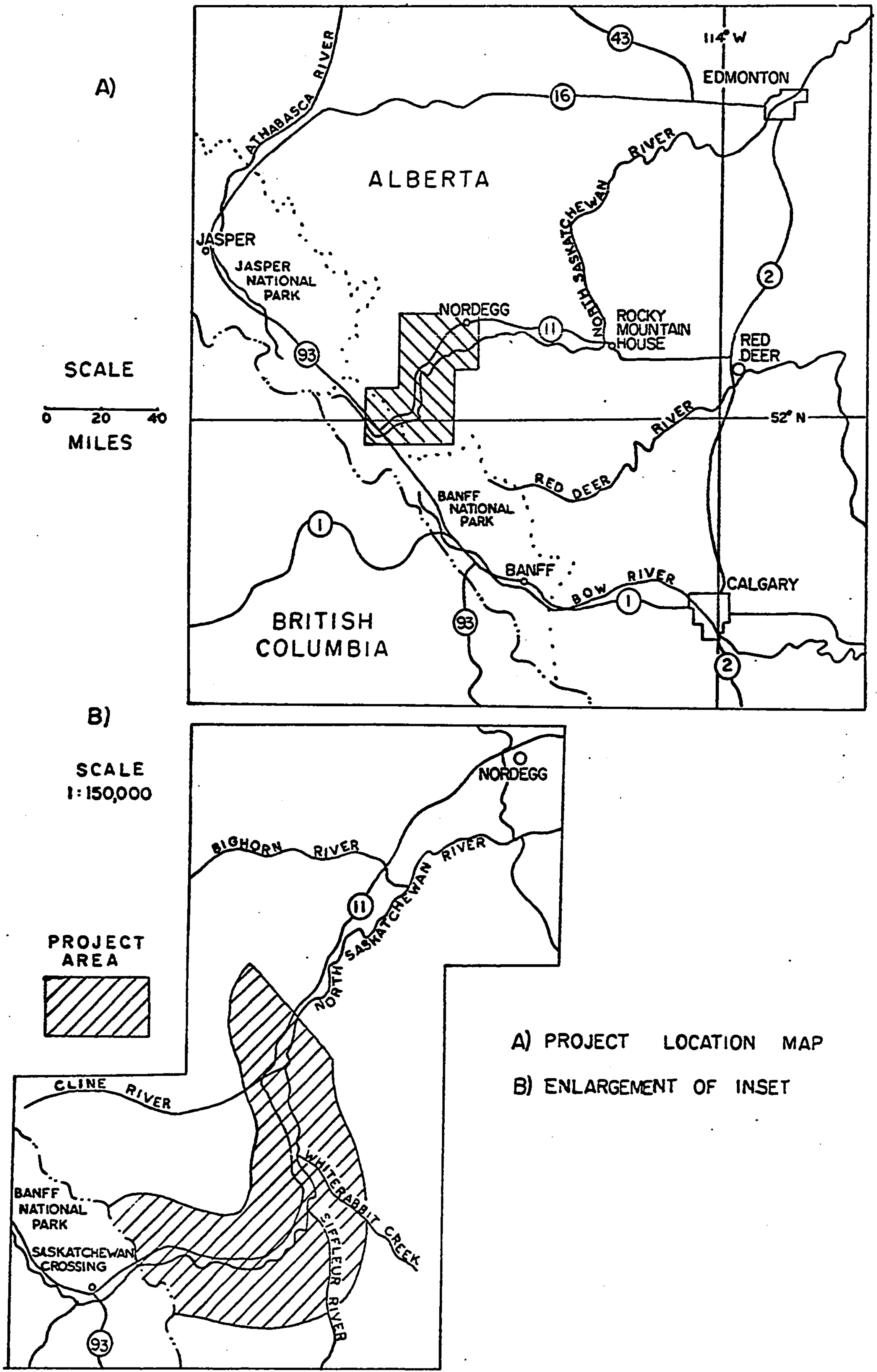


FIGURE 1a. Project Area Location Map.

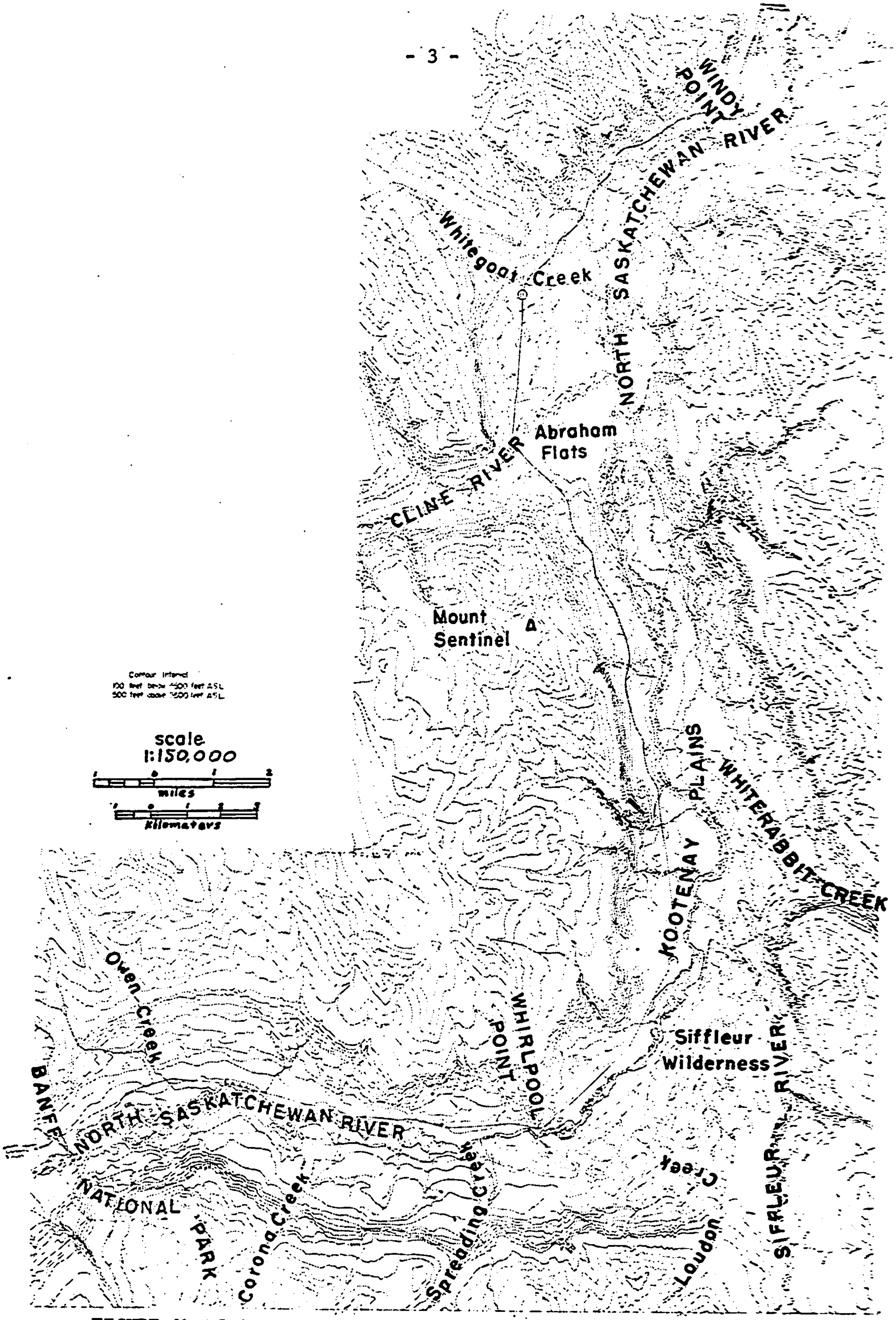


FIGURE 1b. Orientation Map of Project Area.

Banff National Park was chosen as the western boundary, partly as a convenience but also because it was the approximate western limit of the Front Ranges, and because photographic coverage at a scale of 1:1500 extended only a few miles west of this point.

The initial approach to the field work was to conduct a preliminary survey of the area to obtain some concept of the soils present, their classification, and possible modes of formation. This phase was followed by more intensive investigation of selected areas and the sampling of major soil types for characterization and for special studies. The field data were complemented by chemical and mineralogical analyses to assist in the interpretation of the soil features and for characterization of the soils. Special projects or problems were undertaken as they presented themselves and as time allowed.

The field work was done during the summer of 1967, with the characterization analyses essentially completed in 1968 and a special clay mineral study in 1969.

PART I - PHYSIOGRAPHY

Geology

Bedrock Geology

North and Henderson (1954) subdivided the Rocky Mountain system into four subprovinces. They are, from east to west, the Foothills, the Front Ranges, the Main Ranges, and the Western Ranges. The Front Ranges subprovince is bounded on the east by the McConnell Thrust Fault and on the west by the Castle Mountain Thrust. These fault lines cross the North Saskatchewan River Valley at Windy Point and in the vicinity of the Banff National Park boundary, respectively, and were taken as the eastern and western boundaries of the project area (Figure 2). The project area thus lies wholly within the Front Ranges subprovince. The source area for the glacial materials includes, as well, that portion of the Main Ranges east of the Continental Divide.

"The Front Ranges are comprised for the most part of a series of sub-parallel, west dipping thrust blocks" (North and Henderson, 1954). The result is the thrusting of Paleozoic formations over the Mesozoic beds found east of the McConnell fault. The individual blocks are rather strongly folded and while Paleozoic sediments dominate, some Mesozoic materials are usually found associated with each block. The eastern ranges expose the younger Carboniferous and Devonian, dominantly limestone, formations, while the western ranges expose older Paleozoic formations such as Cambrian quartzites. Limestones and dolomites are the predominate rocks with minor amounts of argillites and sandstones.

L E G E N D

Age	Lithology
Jurassic	sandstones and shales
Triassic	
Mississippian	limestones and dolomites (chert)
Devonian	
Cambrian	
Lower Cambrian	sandstones and shales (quartzite)
Precambrian	

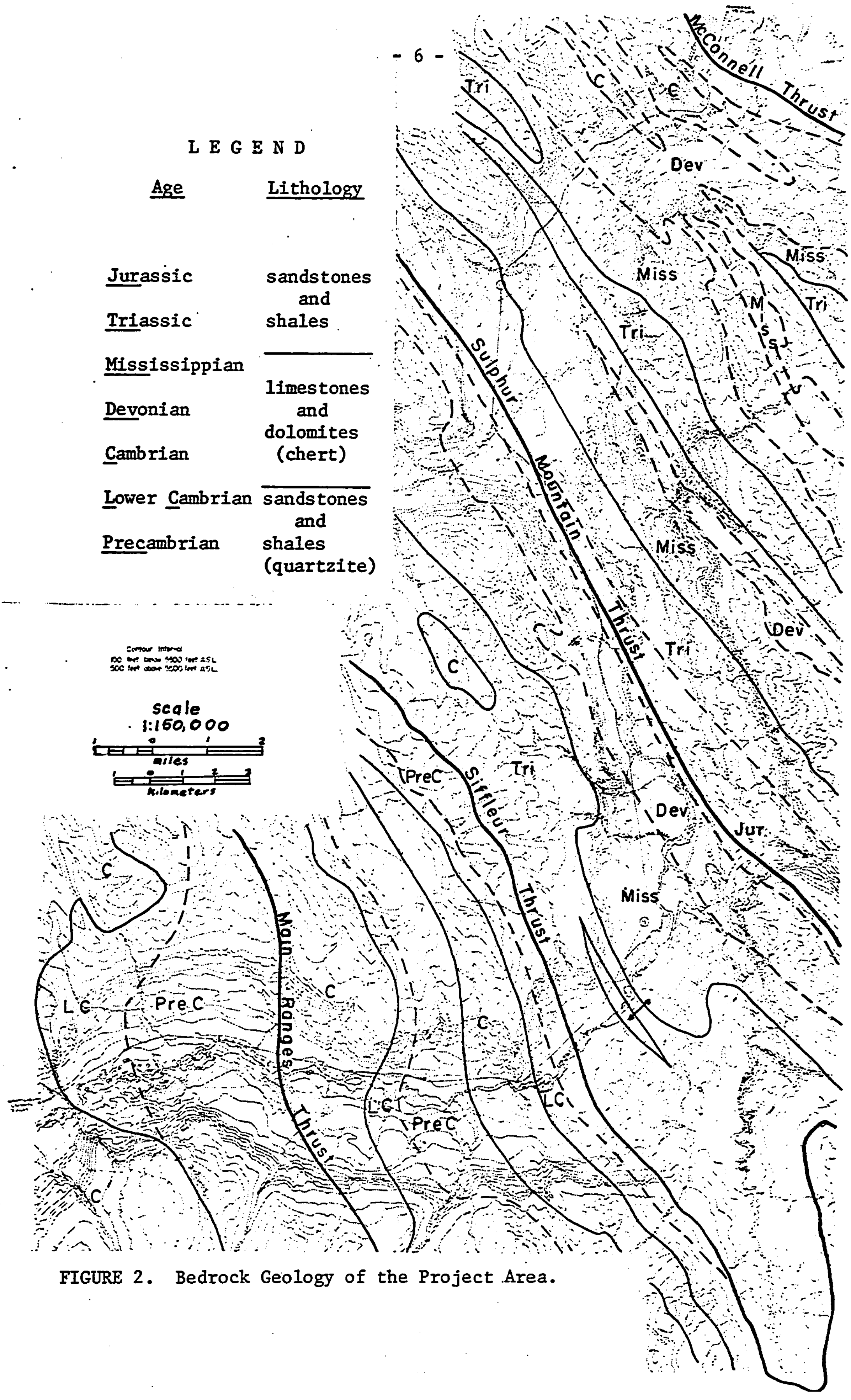


FIGURE 2. Bedrock Geology of the Project Area.

The Main Ranges and particularly the belt along the Continental Divide contain almost all of the highest peaks of the Canadian Rockies. In the area south of the Columbia Icefields the youngest of the Paleozoic beds are probably of Upper Devonian age with the oldest being Mid Cambrian. Dolomites are more prevalent in the Main Ranges (the Lower Paleozoic formations) than in the Front Ranges.

The gross landform features as modified by erosion, reflecting both glacial scouring and present day mass wasting, are controlled by the underlying structures. The relatively flat lying materials of the Main Ranges tend to form bench and slope topography with rather symmetrical valleys. In the Front Ranges, by contrast, the dominantly subsequent valleys are asymmetric (Rutter, 1965). This is a result of the greater erodability of the southwest valley walls which are backslopes comprised of varying lithologies as compared to the northeast valley walls which are generally dip slopes and comprised of single rock types.

Pleistocene Geology

Introduction. Rutter (1965a) working in the Bow River Valley, found evidence of at least two (possibly three) major glacial advances with two minor advances. He placed this glacial activity in the latter part of the Wisconsin Stage (from about 40,000 to 10,000 years ago). If earlier glacial advances had taken place in this area all evidence has been obliterated or removed by the later ones.

More recent minor glacial advances are documented by Heusser (1956). It is his premise that there was a general ice maximum from about 1500 to 1900 A.D. The advances of this era did not, however, descend the major valleys and their contribution to the history of the project area are probably confined to more recent outwash facies.

Glaciers undoubtedly originated along the Continental Divide, with only minor amounts of ice and debris from west of it. The ice flowing down the North Saskatchewan River Valley could be drawn from a 60 mile front, from the present Columbia Icefields in the north to the Bow Pass in the south. Much of the northern ice may have been diverted over the Sunset Pass and down the Cline River Valley. The major ice masses left in the area are the Columbia, Lyell, Mons, and Freshfield icefields along the Divide, and the Murchison and Wilcox fields along the eastern edge of the Main Ranges.

Geomorphology. The valleys are characteristically U-shaped which reflects severe glacial scouring. The erosion in the side valleys was less severe giving rise to some hanging valleys, such as can be seen at Whitegoat Creek. In the east-west portion of the valley, approaching the Park boundary, cirque development can be observed on the north facing mountains.

The height of glacial abrasion along the valley walls is normally quite well delineated. It is often apparent as a break in slope with somewhat rounded features below and more jagged outlines above. It can also be determined by the height of erratics on the mountainside. Heusser (1956) reported heights of 8,000 feet at Banff, and 8,500 feet near Field (on the Divide). Rutter (1965a) used break in slope and lateral moraines to determine glacier maxima and reported values of 7,300 feet to 8,000 feet along the Bow River Valley. Rough estimates along the North Saskatchewan Valley indicate heights similar to those of Rutter, with the relative height decreasing downstream. The eastern extremity of the area has only a small portion of the mountains exceeding 8,000 feet (A.S.L.). Notable here is Mount Sentinal (9,425 feet) on which the height of glaciation was estimated at about 7,000 feet. Toward the Park, and the Main Ranges, the mountains become much higher (Siffleur Mountain, 10,266 feet; Mount London, 10,566 feet; Resolute Mountain, 10,300 feet; Lioness Peak, 10,200 feet; Mount Cline, 11,027 feet), and with more rock above the height of glacial scouring, are much more rugged in appearance.

The materials laid down during a glacial period can be divided into four major groups: till, ice-contact material, outwash, and glacio-lacustrine deposits. The deposits attributable to glaciation in the project area are confined to the first three groups. The till for the most part is an extremely compact deposit. It is medium-coarse textured with a rather high stone content and a very high carbonate content. The extreme carbonate content appears to act as a cement. The upper 20 cm of the deposit has the appearance of a gravelly or cobbley overlay which could be a result of surface wash or it could be a non-geologic feature associated with tree rooting. During recession of the ice there would likely have been considerable meltwater flow which could conceivably have removed the fines from the surface leaving a loose gravelly horizon. The presence of this "washed till" made it difficult to distinguish till from outwash in the absence of exposed sections. It was quite possible that ice-contact material was also present and added to the difficulty of recognizing the different materials. Till is found as the surface material bordering the valley walls (Figures 3 and 4) on a landform which will be called a bench. A notable exception is the Siffleur area where the landform may be more properly described as a somewhat grooved and/or dissected till plain. The till for the most part appears to lie on pre-eroded rock benches or as a capping over outwash. The benches generally slope to the center of the valley, the slope being most pronounced near the valley walls. The depth of till seems to be quite variable depending to some extent on the topography of the underlying material. The outwash is quite coarse with only a very small fraction less than 2 mm in size, and generally moderately well to well sorted. Sections show evidence of cross-bedding and truncation. As will be discussed later, these deposits are often infused and cemented with calcium carbonate for 2-3 meters from the surface. This added to the dilemma of separation from till where sections were not available.

Ice-contact material is debris deposited adjacent to glacier ice during ablation. As water is involved in the process, sorting and washing take place, but to varying degrees. The result is a poorly sorted deposit which may contain pockets or inclusions of till or outwash. Some poorly sorted, rather coarse material on the benches was tentatively interpreted as ice-contact material. It generally occurred nearer to the river and as it was a continuation of the till land form, it might simply have been a more deeply "washed" phase of the till. It is possible, however, that pockets of this material could occur within the till. Identification was more certain where the landform became more kame-like as occurred on the south side of the river west of Whirlpool Point, and on the north side of the river to the east of the point. McPherson (in press) arrived at a similar distribution of surficial deposits.

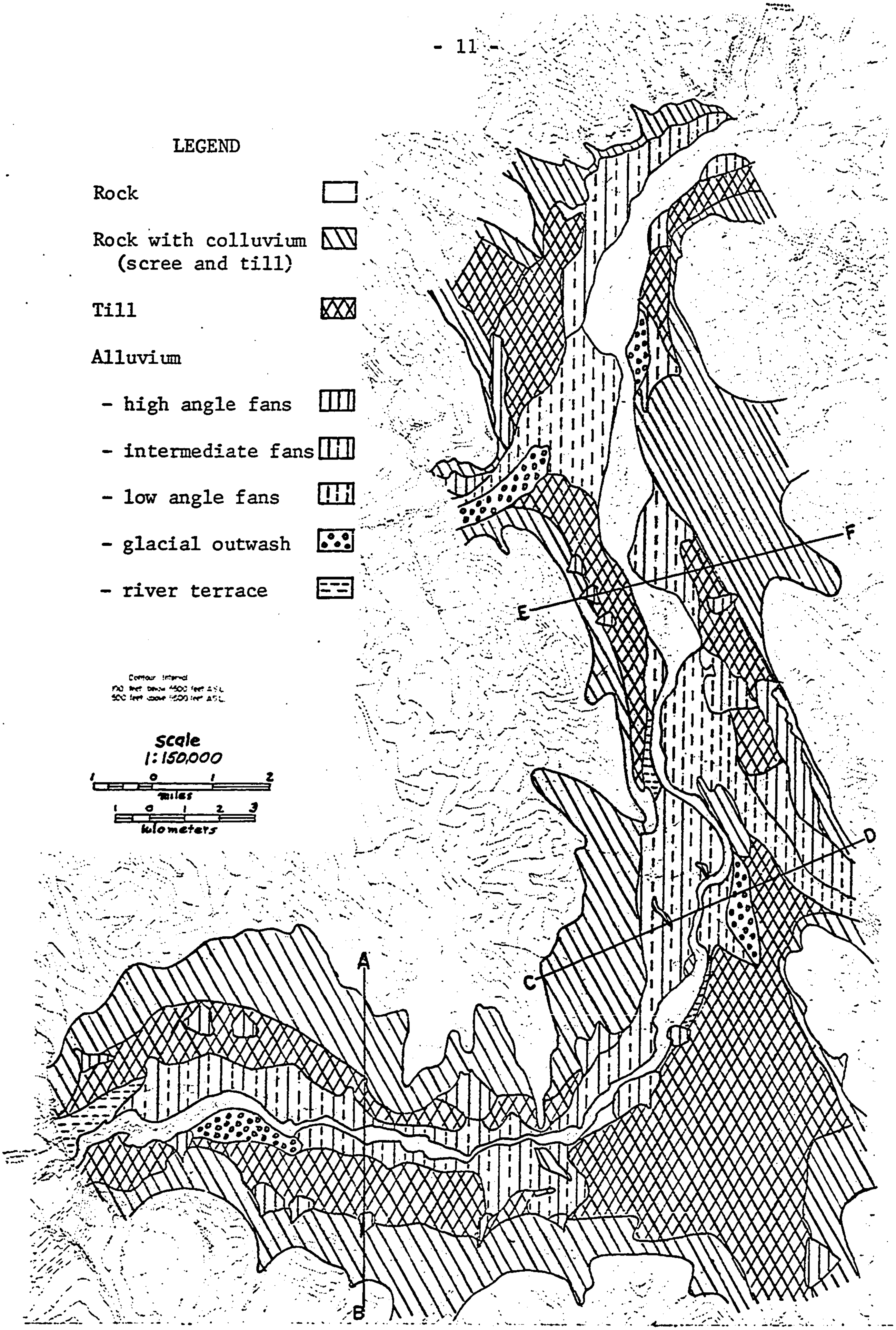


FIGURE 3. Map of (a) Landform and Parent Material.

(b) Section Locations.

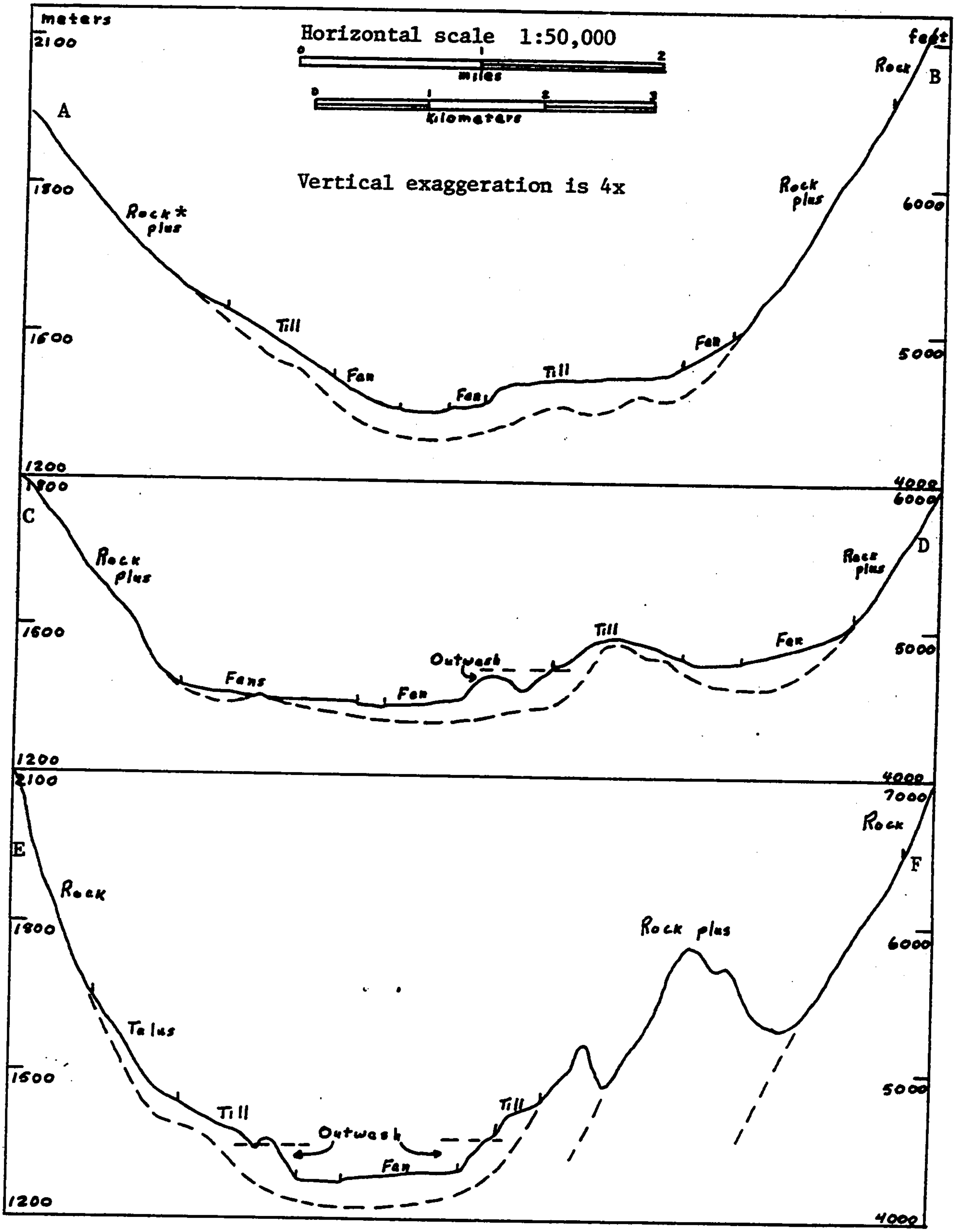


FIGURE 4. Valley Cross-sections (for location see FIGURE 3).

*Rock plus = Rock with colluvium (scree and till).

Sections at different locations along the valley indicated an interesting glacial history although no attempt was made to describe these sections in detail or to work out the chronology of the deposits. Some of the features noted were: (1) Till was the surface deposit over most of the lateral benches, with minor gravel inclusions. (2) Between the Siffleur and Cline rivers the till was often observed as a capping over extensive outwash deposits which may have a thickness in excess of 200 feet. (3) The extensive till area west of the Siffleur may also have been underlain by outwash although this is not known. There seemed to be some ice-contact material in this area and also on the north side of the river around Whirlpool Point. It is possible that the rock ridge confining the valley at Whirlpool Point had some effect on glacier advance (or retreat) and could be responsible in part for the ice-contact material in this area. (4) A road cut just west of Whirlpool Point exposed a section with outwash overlying till. This indicates a glacial advance previous to the outwash phase which, as mentioned, is generally overlain by a more recent till.

A change in the depositional environment in the Siffleur area appears to be evident. The base of the till sheet seems to be at an elevation of 4,700 to 4,800 feet near the Park boundary, and decreases in elevation to just west of the Siffleur River. Immediately east of the river the base of the till is again found at about 4,750 feet and to decrease uniformly to the north with about a 1 per cent slope, to 4,300 feet west of Windy Point. There is also a corresponding rise in the elevation of the outwash deposits north of the Siffleur River. It is possible that the above features owe their existence to glacial phenomena associated with the Siffleur Valley, to a later glaciation extending only as far as the Siffleur, to the abrupt change in valley direction, to the bedrock forming a resistant base in this area, or to a combination of these factors.

Recent Geology

Introduction. A date of about 9,300 years B.P. was obtained for charcoal in a section sampled just west of the study area (Westgate and Dreimanis, 1967), and may be considered as a minimum date for deglaciation of the valley. Glacier ablation would have released large amounts of water and it is likely that erosion was somewhat accelerated in the immediate post-glacial period. It is probable too, that a significant amount of fan development took place at this time. Decreasing erosion rate likely ended this phase of valley development with the valley possibly looking much as it does today. The altithermal period (Hanson, 1949b; Horberg, 1954; Richmond, 1965) dated at 4,000 to 6,500 years B.P. was a time of a relatively warm and dry climate, and it is suspected that major valley forms were established by this time. A volcanic ash sampled at Saskatchewan Crossing (3 miles west of the area) has been identified as Mazama ash (Westgate and Dreimanis, 1967) and has an established age of 6,600 years B.P. Its preservation, and the presence of two ash layers overlying it, suggests that wholesale mass wasting had slowed by this time and that some degree of stability had been achieved. The most recent ash at the same site was dated between 2,100 and 2,700 years B.P. An ash found about 4 feet above present river level in the project area is tentatively correlated with this ash, and if this is correct, it would suggest that the major landforms had been established by that time. Also implied is that the climate and hydrology have not varied significantly in the last 2,000 years.

Geomorphology. Three phenomena account for the majority of materials deposited since the glacial period:

(1) The building of fans. This process is active today but, as discussed above, must have been many times as pronounced in the millenia immediately following deglaciation. Stream deposition of this type has added large amounts of material to the valley and the extensive fan development is a major land form in the area. A side effect of fan building is its control on the form of the river. Major fans force the river to one side of the valley or the other, confining it laterally, and hence inhibiting its braided character.

(2) The accumulation of talus (and scree). This process is of some importance along the steeply sloping valley walls. The aerial extent of these deposits is not great but a large volume of material has been added in this manner and it has significantly modified the shape of many slopes.

(3) Aeolian deposition. The entire area appears to have been blanketed with material of subaerial deposition. This loessial covering is relatively uniform on the lateral benches, averaging 15 to 20 cm. More variation is apparent closer to the river. In locations advantageous to deposition by valley winds, the loess may achieve depths of a meter or more. Because of mass wasting there is little evidence of overlay material on the steep slopes.

Other sources of material are represented. Many may be interrelated with the above processes but their importance has not been fully evaluated. Included here are deposits reflecting the processes of mass wasting which modify and reorganize existing materials and the additions of volcanic material. It would appear that the loessial overlay is at least partly of volcanic origin and layers of pure ash were encountered. A small amount of recent alluvium is present in the river channel where erosion and deposition would appear nearly to balance in this environment.

Three types of fans were recognized. One type has slopes of 5 to 10 per cent and is a result of deposition by small streams. The material deposited is generally quite coarse, subangular and poorly sorted. Some sorting from head to toe was noted on the longer fans such as in the Kootenay Plains area. The second type of fan is that built by larger streams and has slopes of less than 2 to 3 per cent. Here the material was better sorted and more rounded. There was a greater amount of finer material with up to 1 to 2 meters of stratified fine sands in some locales. All the material is calcareous. The third type is found at the break between the valley walls and the benches. The slopes are generally in excess of 20 per cent and these forms grade to talus slopes.

Talus and scree materials tend to be very coarse and angular. The proportion of finer material increases with depth in many cases. Scree material is finer in size (gravel vs cobbles) and subangular to subrounded. Again there is an increase of fines with depth.

The loessial overlay is quite uniform in particle size distribution, falling essentially in the coarse silt and very fine sand sizes. The material is invariably loose, structureless, and soft or fluffy. It feels somewhat gritty, as do the volcanic ash deposits, which suggests that ash makes up a significant portion of the loess.

The colluvial material is generally similar in texture to the till, although it is not as compact or as calcareous. Where colluvium is from a talus source it tends to be quite coarse.

Volcanic ash occurs in layers 1 to 5 cm thick. White in color, it is dominantly in the coarse silt to very fine sand size ranges and feels somewhat gritty.

Alluvium varies from the coarse gravelly mid-stream deposits to the fine sands and silts of overbank deposits.

Climate

Climatic data for the mountainous regions are limited and for the most part confined to lower elevations and valley locations. Banff and Jasper, stations with long term records to the south and north of the area, are both located in large valleys in the Front Ranges. While Jasper is about 1,000 feet (300 meters) lower in elevation than the project area, records from both these stations should be relevant to the valley bottom. Nordegg, immediately to the east of the project area, is in the foothills. Data are shown in Table I.

At Jasper, Banff, and Nordegg, July is the only month normally free of frost. At Lake Louise frost occurs in all months. The Lake Louise data was included to show the effect of higher elevation-lower temperatures, and increased precipitation with a higher snow contribution.

TABLE I. Selected Climatic Data[1]

Station	Elevation (feet A.S.L.)	Temperature (°F) Mean Ann.	January Max.	January Min.	July Max.	July Min.	Precipitation (in.) Mean Ann.	% as Snow
Jasper	3,480	37	22	2	73	45	16.4	30
Banff	4,583	36	21	3	72	44	18.7	42
Nordegg	4,300	34	22	2	66	39	22.2	38
Lake Louise	5,032	32	20	-6	71	38	30.8	63

[1] Data taken from McKay, Curry and Mann (1963).

In 1954 the Eastern Rockies Forest Conservation Board set out a network of storage precipitation gauges in the headwaters regions of the North Saskatchewan River. The records for those gauges located in the project area are given in Table II.

TABLE II. Storage Precipitation Gauge Data[1]

Gauge[2]	Elevation (feet A.S.L.)	Years of Record	Precipitation (inches) Oct.-May	May-Oct.	Annual
1	4,800	4	7.0	8.8	15.8
2	4,400	10	3.7	7.4	11.1
3	5,200	4	10.1	10.6	20.7
4	4,500	8	9.0	7.2	16.2
5	5,300	4	8.2	9.4	17.6

[1] Data taken from Management Report No. 2 (1968), Eastern Rockies Forest Conservation Board. Comparison with standard Meteorological Service gauges indicates approximately 20% undercatch for the storage gauges.

[2] Note Fig. 5 for location.

Site 2, located on the grassed Kootenay Plains, is a very arid location (in 1966-67 this gauge recorded only 5.6 inches precipitation). This probably reflects a "rain shadow" effect. However, another factor may be the valley winds which undoubtedly influence the climate in the area. There is no quantitative measure of the effect of these winds, but their influence on evapotranspiration and on storm patterns, particularly as they affect the valley bottom, must be of major significance.

Other precipitation records indicate that by an elevation of 6,000 feet (2,000 meters) the precipitation is probably well in excess of 20 inches (500 mm) per annum, and that by 7,000 feet (2,300 meters) it likely exceeds 25 inches (625 mm). With this in mind and using the available storage gauge records a speculative isohyetal map was drawn up (Fig. 4). It must be emphasized that this map is, in part, conceptual and was prepared only to indicate the disparities in precipitation which may occur over short distances.

A general consideration of the area indicates a cold, subhumid-humid climate with a short growing season. However, generalities can be very misleading in mountainous regions because of the extreme variability in climatic parameters over short distances. The differences are mainly due to elevation and aspect, although other factors such as winds and rain shadow effect are modifying influences and may be locally important. Aspect is probably the most important single factor with marked differences between north and south exposures. Aspect affects insolation,hence evaporation, and therefore plays a major role in determining the humidity of a site. This in turn affects vegetation and soils.

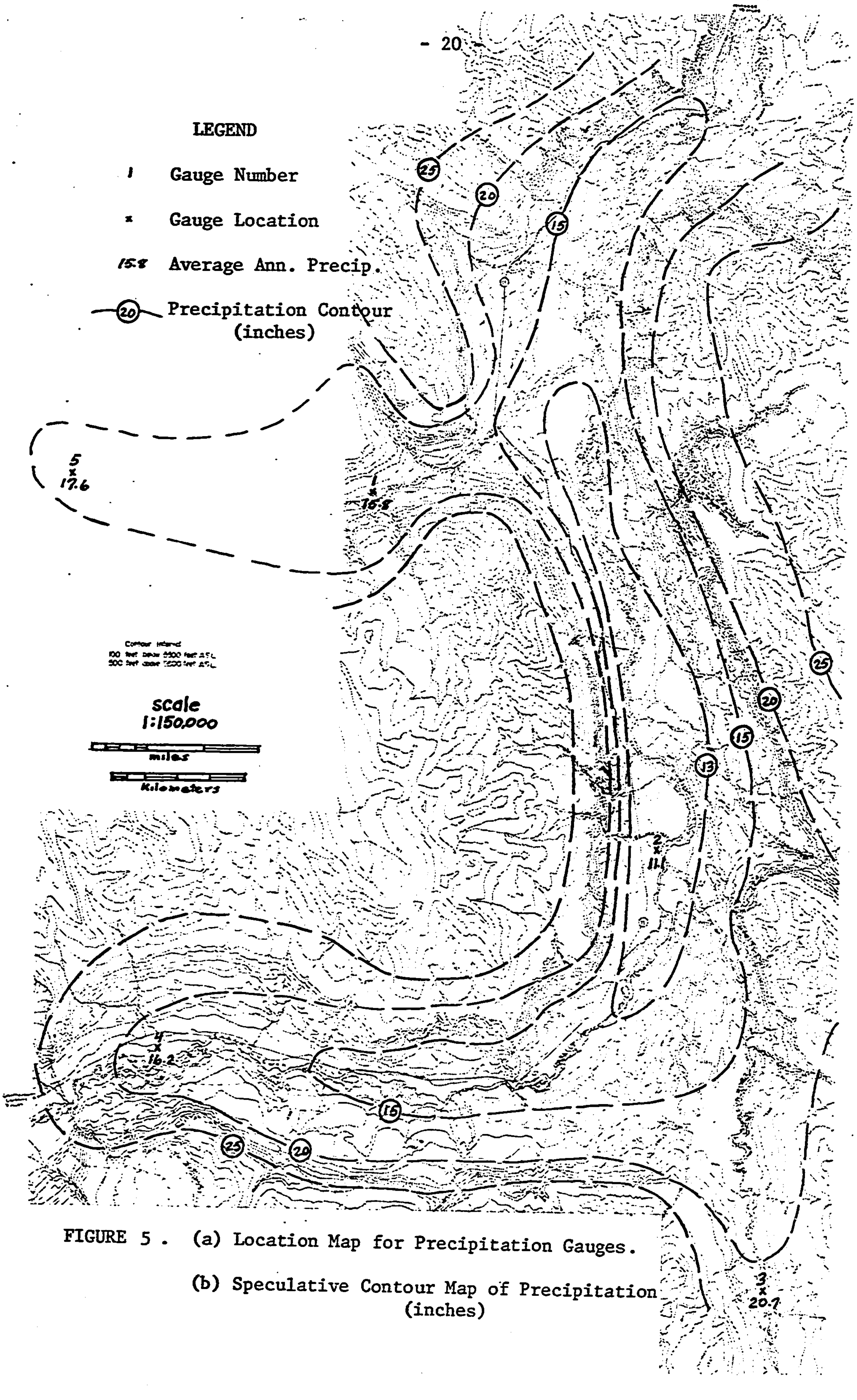


FIGURE 5 . (a) Location Map for Precipitation Gauges.

(b) Speculative Contour Map of Precipitation (inches)

Vegetation

The project area falls within Rowe's (1959) East Slope Rockies Section of the Subalpine Forest Region. This region is characterized by a vegetative climax of Engelmann spruce (Picea engelmanni)[1] or Engelmann-white spruce (Picea glauca) hybrids with alpine fir (Abies lasiocarpa) (Rowe, 1959; Moss, 1959).

Cormack (1953) states of this area that "the most striking and important feature of the forest cover is the disturbance caused by fire". The result of burning is the dominance of lodgepole pine (Pinus contorta var. latifolia). Only small areas of spruce-fir were noted and these were found in generally cooler, moister, north-facing sites and/or at relatively high elevations and were generally more mature stands. The majority of the forest consists of rather pure stands of pine with lesser amounts of mixed pine-spruce stands. Both these types readily fall into stage two (immature forest stage), described by Cormack (1953) in his four stage forest succession proposal. The extremely arid sites such as exposed slopes and ridges have very sparse tree growth although the amount of deadfall indicates a denser stand in the past. Limber pine (Pinus flexus) often dominates in these locations. Another variant from the norm is the dominance of aspen (Populus tremuloides) on the fans and talus slopes. In the very moist sites on the fans, along present stream channels or in areas of high water table, balsam poplar (Populus balsamifera) and spruce may dominate. Of interest is the presence of some Douglas fir (Pseudotsuga menzesia). It was noted in particular on the east facing slope of

---

[1] Vegetative classification is according to Moss (1959).

Sentinel Mountain. Here older Douglas fir can be seen above the younger spruce and pine and there is fair regeneration of the fir. A quite small but almost pure stand of Douglas fir is present at the end of the road leading to Cline lookout.

The dominant lesser flora encountered under the drier pine sites and/or more open stands are buffalo berry (Sheperdia canadensis), Juniper (Juniperus spp.), rose (Rosacea sp.), bearberry (Arctostaphylos uva-ursi), and rye grass (Elymus innovatus). As the moisture conditions improve, small spruce are generally noted with the lesser flora including bunchberry (Cornus canadensis), twinflower (Linnaea borealis), arnica (Arnica cordifolia), wintergreens (Pyrola spp.), and violets (Viola sp.). There is usually a decrease in bearberry and rose with increased moisture. Also, in place of the crusty lichens of the drier sites, leafy lichens (Peltigera sp.) and feather mosses are found. A notable exception to Cormack's (1953) description of these forests is the absence of any Vaccinium (blueberry) species. This is probably a result of the calcareous nature of the soil surface in the project area. Vaccinium scoparium is commonly encountered at elevations greater than about 6,000 feet A.S.L. As the maturity of the stands increases, shading and/or micro humidity increase, and a myriad of lesser flora are noted (Moss, 1955; Cormack, 1953; Horton, 1959).

There are several special ecological sites noted which are worthy of mention. The very coarse deposits along the mountain streams are covered by an almost solid mat of dryas (Dryas drumondii). Approaching the alpine and on the exposed ridges at higher elevations a grass-meadow type of vegetation is prevalent. Juniper becomes more prevalent and cinquefoil (Pontentilla fruticosa) makes an appearance. Besides the grasses, several legumes (Astragalus spp., Lupinus spp.) and many other alpine flowering herbs are present. The few trees present in these locations are somewhat stunted and often show signs of layering.

A prairie vegetation is present over a significant proportion of the area along the valley floor and lower fans. This includes the area known as the "Kootenay Plains". The "prairie" occur within 50 to 100 feet of river level and extend from Whirlpool point to the Whitegoat Creek fan. The largest areas are the Whiterabbit Creek fan and the fan opposite the Siffleur River confluence. The vegetation as mentioned is prairie-like with grasses and various species of sage (Artemesia spp.), including wormwood (Artemesia dracunculus), and wild flax (Lenum lewisii). Where subsurface moisture is present, along streams and where bedrock is close, spruce prevail, otherwise aspen is the dominant tree type. On these fans, the shrub layer is dominated by buffalo berry under a forest canopy and has rose, cinquefoil, juniper, ground cedar (Juniperus horizontalis), and silver berry (Elaeagnus commutata) in the open areas. The grassed portions, in addition to the shrubs mentioned, also contain some bearberry and many leguminous species.

PART II. LITERATURE REVIEW

Related Soil Investigations

Soil investigations in the mountains of Alberta have been limited. However, a reconnaissance survey has been conducted in the foothills to the east (Peters and Bowser, 1960), and a soil survey of the Kananaskis Forest Experiment Station was published in 1951 (Crossley) with a more recent study completed (Beke, 1969). Information is available for a few selected profiles from Banff to the Columbia Icefields along Highway Number 83 (Alberta Soil Survey, 1963).

Peters and Bowser (1960), in the area from Rocky Mountain House to Nordegg, report a dominance of Brunisolic Gray Wooded and Bisequa Gray Wooded soils. These occur under a mixed forest in an area receiving 18 to 22 inches of precipitation and are developed on a variety of parent materials varying from outwash to till. Similar soils were noted in the Hinton area (Dumanski -personal communications) where, in addition to the Luvisol subgroups, Brunisolic soils with distinct mull-like moder Ah horizons are common. Crossley (1951) reported that the main soil types found at Kananaskis were Chernozem, Rendzina, Brown Forest, Brown Podzolic, Gray Podzolic, and Podzol, as well as Alluvium and Lithosols, with the greater majority falling into the Podzolic and Podzol groups. Profile depths ranged up to 36 inches with some shallow soils (9 inches) on the more strongly calcareous material. Beke (1969), in a detailed study of the Marmot Creek basin, reports a vertical sequence of Gray Luvisols, Humo-Ferric Podzols, Dystric Brunisols, and Regosols. This is essentially in the subalpine zone, with the soil characters becoming less pronounced with elevation. He also reported the presence of volcanic ash layers in various stratigraphic positions. The Alberta Soil Survey (1963) reported Bisequa Gray Wooded and Brunisolic Gray Wooded soils, Podzols, and Brown Wooded soils along the Banff - Jasper highway. The latter were found in the valley bottoms with the Gray Wooded and Podzol types typifying the well drained uplands. All soils were somewhat shallow with the sola ranging from 8 to 13 inches (20 to 33 cm) in depth. These soils were found at elevations of 4,500 feet to 6,000 feet A.S.L. and the precipitation values are between 19 and 30 inches per year.

Johnson and Cline (1965) reported the predominant soils of the subalpine region in Colorado to be Brown Podzolic soils, Podzols, Groundwater Podzols, Lithosols, Brown Forest soils, Gray Wooded soils, and Bog soils. While the climate is roughly equivalent to that of the study area the parent material is derived essentially from crystalline rocks and has a low base status.

Kelley and Sprout (1956) in the subalpine region of eastern British Columbia indicated that Bisequa Gray Wooded and Gray Wooded soils predominate on the more strongly calcareous materials. In the transition zone to the dry Rocky Mountain Trench they reported Brown Wooded soils (these would be considered degraded in the present classification).

More information is available on mountain soils in North America, but most of it involves either areas with definite maritime climates or the drier mountains of the southern and west-central states.

Subarctic locations may be comparable to local mountain conditions in terms of climate and vegetation. One such area is central Alaska, where Kellogg and Nygard (1951) indicate a dominance of Subarctic Brown Forest soils. They felt that these soils with "color B" horizons were intrazonal soils which represented an early weathering stage of Podzol formation. De Ment (1962), in a study of the Subarctic Brown Forest soils, indicated their close relationship to the Brown Wooded (now Degraded Eutric Brunisol) soils in Canada and their sequential position to be intermediate to Gray Wooded soils. In this same area, Rieger and Juve (1961) found podzolization to be the active process on acidic parent materials. Weakly developed "Podzols" would also appear to be common to the Asian Subarctic (Russian publications cited in Wilde and Krause, 1960).

European literature suggests that the forested mountain soils are generally of the lessivé and podzol types with many areas of rather weakly developed soils (Kubiena, 1953; Duchaufour, 1965; U.S.S.R. Acad. Sci., 1962; Uziak, 1963). Perusal of these works indicate that although the gross profile characters are similar in many respects to soils in North America, there are some very significant differences as well. The main points of divergence are the pronounced Ah horizon development and the high chroma (amount of liberated iron) of the European soils. These are undoubtedly a result of a climate which is more humid and warmer than the continental climate of western Canada.

The physiographic region most closely approximating the eastern Rockies area is the north central Ural Mountains. Limited information (U.S.S.R. Acad. Sci., 1962; Papadakis, 1969) indicates that Podzolic and Podzol soils are common, along with acid nonpodzolized soils. Lithosols and Lithosolic Rankers are also common, with Braunerde, Organic, Sod Podzolic, Gray Wooded, and Brunified Rendzina occurring sporadically.

It is apparent that soils under boreal forests are dominantly of the Podzolic and Podzol types. This may be extended to the mountainous area with the realization that additional processes are active and a greater variety of soils may be found.

Soil Forming Processes

Two major soil forming processes are generally recognized in the boreal forests. These are "lessivage" and "podzolization" (Duchaufour, 1965; Fridland, 1958; Soil Survey Staff U.S.D.A., 1960). The process of lessivage involves the movement of the finer soil constituents through entrainment, without chemical breakdown. The resulting soil is characterized by a B horizon of clay (with organic matter and iron) accumulation (Duchaufour, 1965). Podzolization, on the other hand, is believed to involve the chemical breakdown of constituents in the surface horizons followed by migration of the elements. Podzol soils have B horizons characterized by the accumulation of iron and aluminum oxides and/or organic matter (Stobbe and Wright, 1959). Innumerable workers have studied organic decomposition products and indicated that they act as chelating and peptizing agents in the eluvial processes (Bloomfield, 1957; Wright and Schintzer, 1963; Duchaufour, 1965). The importance of these organic materials cannot be over-emphasized and a secondary effect may be the influence of organic acids on the base status of a soil.

The controversy over the processes of lessivage and podzolization has received attention wherever people have been studying soils of the boreal zone (Rode, 1964). The soils originally classified as Podzol were characterized by ashy leached A horizons and the presence or absence of Bt horizons was not always indicated. Both lessivage and podzolization lead to the formation of Ae horizons and as a result two separate processes were not recognized for some time. In fact, it has only been in recent years that classification systems have taken cognizance of the separate processes (Aubert and Duchaufour, 1956; Soil Survey Staff U.S.D.A., 1960; Nat. Soil Survey Comm. Can., 1968). The total extent of the variance is only poorly understood; this is generally reflected in the names given to these soils, particularly the lessive types. Some examples are Parabraunerde, Sols Lessivé, and Pseudopodzolized soils in Europe, and Gray-Brown Podzolic and Gray Wooded soils in North America. Some pedologists (Bloomfield, 1957; Uziak, 1963) have linked gleization with lessivage, and although it often appears associated, the union probably is not universal. One feature which sets the lessivé soils apart from the Podzols is their high base status (Pawluk, 1960a) and it may be that H^+ or Al^{+++} ion activity is a major determining factor in the dominance of one process over the other. It would appear that strong acidity favors chemical breakdown and the podzolic process, whereas high base status favors lessivage. It follows that a calcareous material would favor the latter while an acid parent material would favor the former. This appears to be substantiated by many of the works cited in the previous section (Kelley and Sprout, 1956; Rieger and Juve, 1961; De Ment, 1962) where the kind of soil can be correlated with base status of the parent material.

The effect of climate on soil formation is such that the role of parent material in determining pedogenic processes may be modified or even passed over. This can be illustrated by two possible development sequences on calcareous material. Consider the instance where leaching of bases slightly exceeds their release through weathering, solution, or regeneration by vegetation. This would cause a steady decrease in the degree of base saturation in the sola and whereas lessivage might have been the original process podzolization may come to the fore. The resulting soil may be a Bisequa type (Stobbe, 1952) with a miniature Podzol profile (Ae, Bf) developed within the Ae of a Lessive soil (L-H, (Ah), Ae, Bt, Ck). In the second case let us consider a cool, moist climate which favors resinous and ericaceous vegetation. This vegetation yields a very acidic humus and may allow for the direct development of a Podzol soil on calcareous material. Duchaufour (1965) suggests the following development sequence: lithosol or initial rendzina → humic carbonate soil → humic carbonate soil under mor → podzol.

The European pedologists place strong emphasis on the character of the humus and its effect on soil forming processes (Kubiena, 1953; Duchaufour, 1965). Duchaufour writes that "active mull-moder" humus is characteristic of the lessivé soils whereas podzolic soils are found under "raw humus". In contrast to this, under the climatic conditions of Western Canada, lessivé (Gray Wooded) soils are found under mor-like humus (Gross, 1946). This could be partly due to the fact that earthworms are not present in these soils.

The foregoing discussion has considered two major overall processes, and implied that these are the only processes operative, that one is active to the exclusion of the other, and that each may lead to climax soils. This is a gross over-simplification. These major processes are a combination of many physical and/or chemical reactions and as Simonson (1959) suggests, all processes can proceed simultaneously, the resultant soil illustrating the dominance of particular processes. Nikiforoff (1949) ably expressed the concept of continual soil evolution. Zonn (1966) discussed the Brown Forest - Pseudopodzolized (lessivé) - Podzol soil sequence in light of this traditionally Russian concept, suggesting that, in time, the first will evolve to the last. Whether the Lessivé and Podzol soils are viewed as individual end products or as a continuum, the ideas expressed by various workers as to the kind of weathering and other processes active in each type are very similar. The divergence of thought arises as to the stage of evolution each soil type represents. The conceptual differences are not usually mutually exclusive, but may lead to different interpretations of similar soil features or soil distribution patterns as to both cause and effect of the various contributing factors. In northwestern North America the sequence of development would appear to be Regosol - Brunisol (weak B development) - Luvisol - podzolized Luvisol (Stobbe, 1952; Kelley and Holland, 1961; De Ment, 1962).

One question which arises is whether or not a soil can be considered a climax soil (analogous to climax vegetation). Following Simonson's reasoning it would appear that the idea of a climax soil is a possibility as long as all other factors remain constant and a "steady state" exists. This must involve geomorphic considerations (Cline, 1961). For those of the evolutionary school a climax soil can only exist as a stage in development. Obviously a time constant is involved here. A case in point is the constant rejuvenation of slope soils (Retzer, 1963; Duchaufour, 1965) which is a very obvious concern in mountainous regions.

In any steeply sloping area, and particularly in mountainous country, there are many modifying processes. Instability of landform is one phenomenon which has a pronounced effect on soil formation (Retzer, 1963). Mass wasting, involving the constant shifting of material to a lower geographic position, causes mixing and profile disruption. All these changes may temporarily interrupt soil formation and if the wasting is rapid enough there will be constant rejuvenation (Uziak, 1963; Duchaufour, 1965). The "climax soil" is therefore variable from one location to another, dependent on a variety of circumstances. Undoubtedly assisting mass wasting is the influence of forest cover (Retzer, 1963). The trees also exert pressures in other ways, such as root expansion. A process in forested regions which is probably underrated as to its influence on soil formation is the uprooting of trees (Stephens, 1956) which can completely destroy in seconds what may have required several hundreds of years to form. Certainly, too, such natural acts as fires must have a modifying effect on soil processes, particularly as it affects vegetation and erosion.

Another feature of mountain areas is the variable nature of soil associations which depends, to a large extent, on local orographic peculiarities, particularly through their control of individual climatic parameters. Variations in vertical zonation with elevation and aspect (Kelley and Spilsbury, 1949) are good examples of this.

We have, therefore, a situation in which two major types of processes may be active but which may be modified to a greater or lesser extent by a variety of local factors.

PART III. SOIL INVESTIGATIONS

Introduction

The soils of the study area are different in many respects from the forest and plains soils previously encountered and classified. Many are difficult to classify using the Canadian Soil Classification System (Nat. Soil Surv. Comm. Can., 1965), and some can not be classified at all. These soils were for the most part assigned to the subgroups to which they are morphologically most similar, even though it was recognized that there was often no apparent genetic relationship to the assigned classification. The Regosolic soils as an example were separated, with respect to morphology and occurrence, at a level which approaches the soil series level of abstraction.

The climatic parameters of precipitation and wind can be correlated with soil development, as can gross vegetative differences. This is particularly true of the grassed "plains" areas. One of the more distinctive features of the area is a coarse silty overlay from which the majority of the valley soils are developed. This material has a high volcanic ash content which further complicates the question of soil genesis and classification.

It was anticipated from the search of the literature that Podzolic and Luvisolic soils would predominate in the map area. While many of the soils were redder in color than forest soils east of the mountains, very few were considered to be Podzols. Luvisols appear to represent the maximal development at lower elevations. Regosols make up a major proportion of the area surveyed. However, this apparently is not due to lack of regolith, but rather to such physical phenomena as geomorphic rejuvenation and depositional phenomena.

The report on soil investigations is divided into two major sections:

A. Field study -- The types and aerial distribution of the soils in the project area.

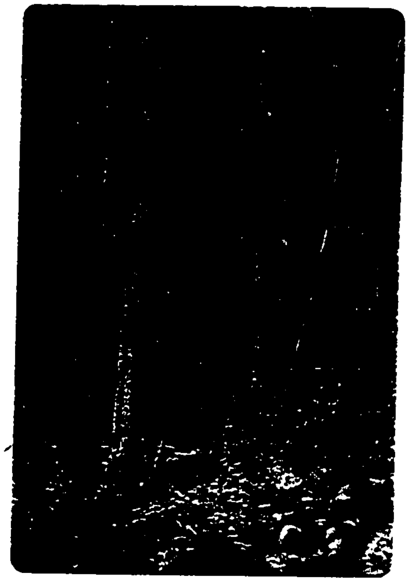
B. Laboratory study -- The genesis of the principal soils, with an attempt to define processes.

Field Investigations of Soils

Methods

Soils were examined along selected traverses. These transects generally started from the roads on either bank of the river and proceeded up-slope to the approximate orographic tree line. They were conducted at irregular intervals up to two or more miles apart, the frequency depending on landform variability and valley aspect. Aerial photographs were used at all stages of the field work. The soils were examined at approximately one-tenth mile intervals along the traverses with special regard to landform and vegetative pattern. This "detailed-reconnaissance" method of survey was felt to be the best suited for the area because of its flexibility which allowed a maximum of information to be obtained, without too much duplication, in a minimum of time, and yet maintain a reliable degree of control. At each stop the soils were described in some detail and the site

Looking south to Mount Sentinel
- Abraham Flats on left



Average stand of pine on benches
- note Shepherdia in understory

Intermediate fan -- 5-9% slope
- east of Mount Sentinel

PLATE I. Some landscape features of the project area.

Looking south to Mount Sentinel
- Abraham Flats on left

Average stand of pine on benches
- note Shepherdia in understory

Intermediate fan -- 5-9% slope
- east of Mount Sentinel

PLATE I. Some landscape features of the project area.

described with respect to vegetation, aspect, slope, and elevation.

Aerial photographs at a scale of 1:15,000 were used to assist in the field work. The mapping was done on base maps at a scale of 2 inches = 1 mile (1:31,680) and later reduced to a scale of 1:50,000.

Results and Discussions of Field Investigations

1. Soils of the Lateral Benches.

The benches appear to be dominantly till with some outwash, ice-contact material, and colluvium. Nearly all of the area is mantled with 10 to 20 cm of aeolian material which has a high volcanic ash content. It is in this overlay that the majority of soil sola are developed. This deposit is underlain by approximately 20 cm of coarse very calcareous gravel with a high root content and finally by the unmodified glacial material of the bench. The topography is of a rolling nature with general slopes of 10 to 20 per cent.

An immature pine forest is the dominant vegetative associate. In many areas, particularly towards the valley walls, spruce is also present but is of minor importance. The shrub and herb layers vary with site humidity as described in Part I.

Soil profile disruption was evident over much of the bench area. To obviate the classification problem due to profile discontinuity the map units were named with reference to the soils of maximal development. Soil classification varied from Regosolic through Brunisolic to Luvisolic with the latter dominating near the valley walls and/or in more humid site locations.

(a) Orthic Gray Luvisol

The Orthic Gray Luvisol is the dominant soil type recognized on the benches (Map units Ic, Id, Ie). This classification encompasses all those soils which have an Ae, Bt horizon sequence. The herbs present are typically arnica, twinflower, wintergreen, bearberry, bunchberry, and violet. The horizon and solum depths are quite uniform. The Ae horizons are light colored (10 YR 7/2 dry), soft to very friable silt loam and average 7 cm in thickness. A rather thin brownish zone is usually present near the surface (surface Bm). The B horizons exhibit a large range in characteristics and two main variants are recognized. The first is reddish (7.5 YR 4/6), moderately fine granular and quite clayey. The second has much less clay in the B horizon (loam texture), is duller in color (10 YR 5/4), and has less developed structure and weaker consistence. The depth of both types is about 10 cm.

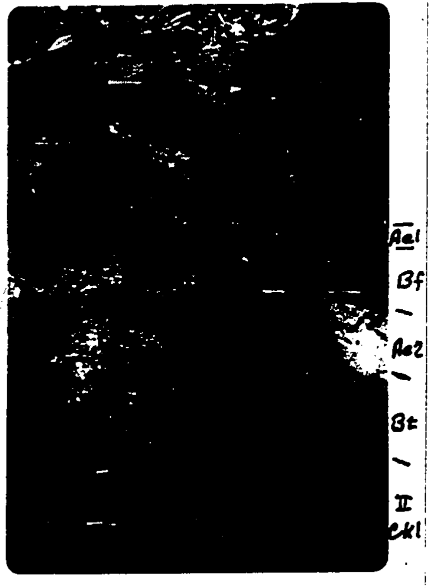
The former, seemingly more strongly developed, variant is found in those areas which appear slightly more humid;the west side of the valley from Sentinel Mountain north, and both sides of the valley near the park boundary. The second variant dominates in the Siffleur area and on the drier east side of the valley (bordering unit IIa).

Other variants are:

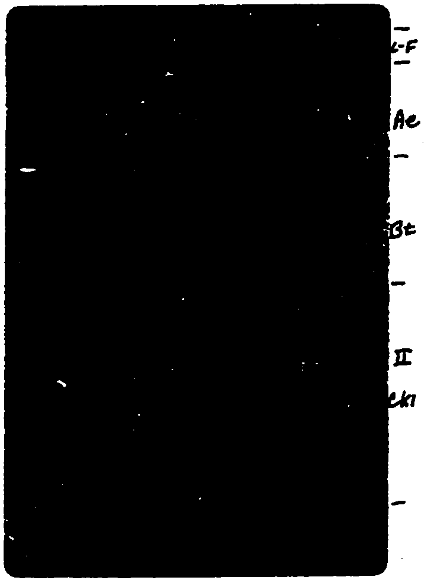
(1) Variation in the surface Bm horizon from 0 to as much as 6 cm.

(2) A solum with pebbles and cobbles.

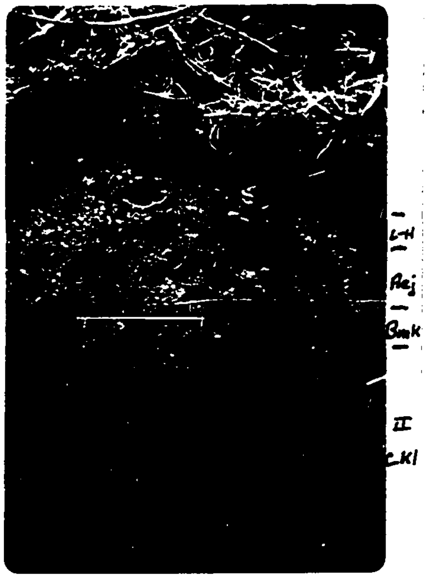
(3) An Ae horizon with well developed platy structure (this is often associated with (2)).



Bisequa Gray Luvisol (Ae1 = 2 cm)

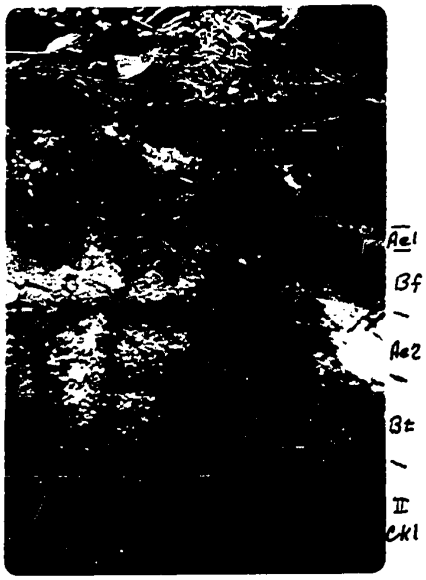


Orthic Gray Luvisol (knife handle = 10 cm)

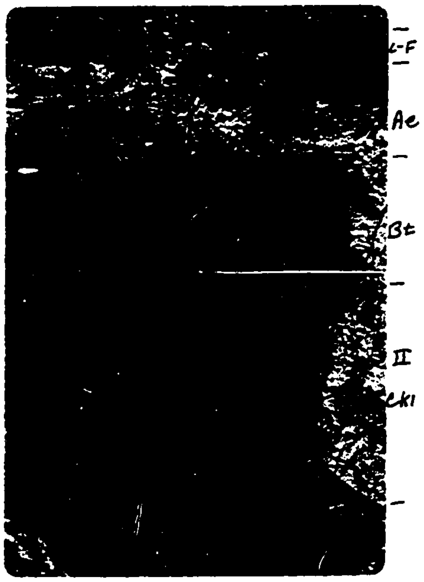


Calcareous Degraded Eutric Brunisol

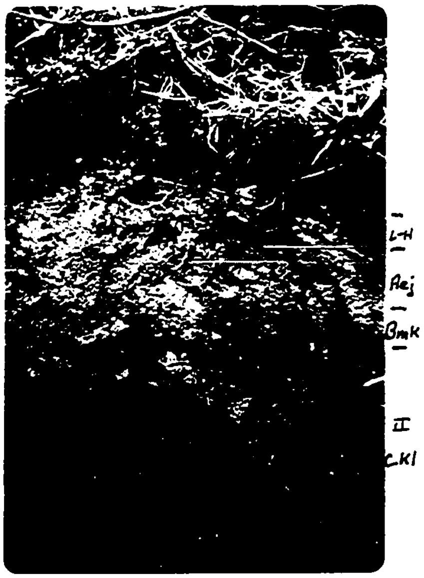
PLATE II. Photographs of Bisequa Gray Luvisol, Orthic Gray Luvisol and Calcareous Degraded Eutric Brunisol soil profiles.



Bisequa Gray Luvisol (Ae1 = 2 cm)



Orthic Gray Luvisol (knife handle = 10 cm)



Calcareous Degraded Eutric Brunisol

PLATE II. Photographs of Bisequa Gray Luvisol, Orthic Gray Luvisol and Calcareous Degraded Eutric Brunisol soil profiles.

(4) The L-F may be 10 to 15 cm thick in areas of more moist climate and/or more mature vegetation, or as thin as 2 cm in more arid locations.

(5) In the more humid areas profiles are often noted which tend towards the Brunisolic Gray Luvisol. The surface Bm is more pronounced or more commonly Ae1 and Ae2 horizons are recognized. The upper Ae horizon generally has a lower chroma and higher value than the lower Ae. For example, 10 YR 7/2 (dry) for the Ae1 and 7.5 YR 6/4 (dry) for the Ae2. This variant was noted particularly at the base of the east face of Sentinel Mountain.

(6) In one or two instances an incipient Bf horizon, about 1 cm thick, was noted immediately overlying the Bt horizon.

(b) Bisequa Gray Luvisol

These soils are found adjacent to northeast facing mountain slopes (Map unit Ia) with the exception of Sentinel Mountain. The underlying material appears to be colluvium from a till source with slopes of about 20 per cent. The understory vegetation is similar to the more humid Gray Luvisol sites in the Whitegoat Creek area, but in the Siffleur Wilderness (Loudon Creek) *Vaccinium scoparium* is also present although the soil reaction is no more than weakly acid. Some *Ledum* is present which might indicate a moister site and possibly some groundwater contribution although *Ledum* is present over much of the slope areas.

This Luvisolic subgroup is characterized by the presence of an Ae, Bf(j) Podzolic sequum overlying the Ae, Bt Luvisolic sequum.

The upper sequum which forms within the Luvisolic Ae horizon varies from 5 to 15 cm in depth.

Variations were encountered in the degree of development of the upper sequum. Following the Canadian Classification, soils with this horizon sequence would fall into both Brunisolic and Bisequa subgroups of the Gray Luvisol Great Group depending on the degree of development of the B horizon in the upper sequum. Possibly the most significant variant is the occurrence of a Bh or Bfh up to 1 cm thick in the upper B horizon of the Podzolic sequum. This strongly indicates that the podzolic process is active, in spite of the only slightly acidic reactions.

(c) Degraded Eutric Brunisol

These soils are found south and east of the river (Map unit IIa) in areas which appear more arid than the remainder of the benches. Drier site conditions are more apparent closer to the river. The forest consists of open stands of pine with a sparce ground cover. Herbs include some grasses, bearberry, minor amounts of twinflower and wintergreen, but no arnica.

The soils appear to have an Ae, Bm horizon sequence. The depths of horizons and sola are very similar to those of the Orthic Gray Luvisol (Ae about 7 cm, B about 10 cm) but the B horizon is more weakly developed. The organic L-F horizon is quite thin, rarely exceeding 2 cm.

The main variants are the degree of definition of the B horizons. They range from a weak Bt (slightly hard, weak fine granular loam) on one hand to a Bm (with 2 to 3 cm of soft, structureless coarse silt loam) on the other. In some instances the very weakly expressed Bm horizons are calcareous in the lower portion. Variations were also noted in the depth and continuity of the surface Bm horizon, and in the amount of mottling in the Aej. This mottling appears to be incipient B formation, and probably represents iron liberated by weathering.

The Degraded Eutric Brunisols grade on one hand to Luvisolic soils and on the other to Calcareous Degraded Eutric Brunisol and Regosols, depending upon site humidity.

(d) Calcareous Degraded Eutric Brunisol

This soil is found as a co-dominant with Degraded Eutric Brunisols in area IIa on the soils map. It is also found developed on aeolian covered outwash areas near the confluences of the Cline and Siffleur Rivers with the North Saskatchewan River. It appears to occupy the drier exposed sites in the landscape. The vegetation consists of open stands of pine with very little ground cover. L-F horizons are thin to absent, lichen crusts are often present on the bench areas.

The horizon sequence is Aej, (Bmk) IICk1, IICk2. The Aej is about the same depth (7 cm) as in the Degraded Eutric Brunisol but has more brownish (10 YR - 7.5 YR 6/4 d) mottles. The Bmk is a very weakly developed horizon and is difficult to differentiate particularly when very dry.

The main variant is one which appears to have the following sequence: L-F (Bm), Aej, IICk1, IICk2. That is, the horizon sequence appears to have an Ae-like horizon directly above a IICk horizon. In this variety the material overlying the IICk could not always be divided in A and B horizons, but the lower portion is often weakly calcareous while the upper 5 to 10 cm is carbonate free. Other variants are the variable depth of the surface Bm which ranged from 0 to 6 cm, and the amount of blotchiness in the Aej.

(e) Orthic Regosol II

These are soils which have been disrupted by physical disturbance. Tree throw appears to have been the chief factor on the benches. This type of soil is common throughout but becomes particularly apparent on the bench north of the Cline River.

The regosols, formed by physical disturbance of the soil mass, are characterized by very disjointed features. Recognizable portions of A and B horizons often exist but are unrelated and mixed. These soils vary from completely churned and mixed material to intact but inverted profiles.

2. Soils of the Fans

Fans cover almost half of the area surveyed. They occur wherever a stream encounters an abrupt change in slope. Three types were recognized. "High-angle" fans (slopes of 20 per cent or greater) form at the break from the valley walls to the benches. "Intermediate" fans (5 to 12 per cent slopes) are present at the base of the benches. "Low-angle" fans (<5 per cent slope) are present at the mouths of the larger confluent streams such as Whiterabbit Creek and Cline River (note Fig. 3 for distribution).

The intermediate and low-angle fans are the most extensive. They occur within one or two hundred feet of river level and it is with these landforms that the "Plains" are associated. The prairie vegetation is located from east of Whirlpool Point north to the end of the Whiterabbit Creek fan and again on the fan immediately south of the Cline River confluence. Spruce and aspen occur where moisture supply is adequate such as along present and abandoned stream courses or where rock is close to the surface (2 O'clock Creek area). Variable aspen stands are common to the majority of the forested fans downstream from Whirlpool Point although some sites of pine are also present.[1] Common accessory vegetation is rose, bearberry, and shepherdia in the forested areas, with silver willow, ground cedar, and cinquefoil in the prairie sites. Aspen forms an increasingly closed stand towards the heads of the fans. West from Whirlpool Point the fans are for the most part covered with a pine forest.

The high-angle fans are forested and are composed of generally poorly sorted materials which grade to talus slopes and often contain slide materials.

The kinds of soils vary with the type of fan and the vegetation. On the intermediate and low-angle fans below the benches, all the soils are calcareous to the surface. They range from those with dark Ah horizons under grass, to those with little discernible development on recent alluvium, to those with weak Brunisolic features under forest. The high-angle fans against the valley walls show much greater

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[1] All fans north of the Siffleur have had the trees removed in preparation for the Big Horn Dam reservoir.

variability in soil development from Regosols with no development to Luvisolic soils, depending on stability of the slope, and presumably time.

(a) Orthic Regosol IV

This is one of the major soil types found under grass in the "plains" areas (Map units IIIa and IIIb). The parent material is generally a variable coarse silt loam or sandy loam deposit over coarse fan and outwash materials, and the slopes range from 2 to 10 per cent. The sites are arid with grasses forming the dominant cover.

The soils are characterized by the presence of dark colored (10 YR 2/2 - 4/2 m) surface horizons with a somewhat high organic matter content. This horizon grades to a C horizon so that the horizon sequence is Ahk, ACk, Ck. As mentioned previously, these soils are calcareous to the surface. The structure is very weak and soft and the humus appears to be a moder type. It is felt, therefore, that these soils should not be classed as Chernozemic.

The sola vary from 5 to 15 cm and there is a corresponding variation in the definition of the A horizons. In many instances, particularly on the partially forested fans, the chroma of the surface is higher than 2. The wooded fans extending from the Whitegoat Creek to Windy Point and from Whirlpool Point to the Park are generally characterized by a darkening of the surface, but the colors tend to be brownish (10 YR 4/3 - 5/3 d) and in this respect the soils may more aptly be classed in the Brunisolic Order. On the less steeply sloping fans (Map unit IIIa) the depth of overlay (and solum) generally increases. The Orthic Regosol IV grades then to the Cumulic Regosols.

(b) Cumulic Regosol I

This soil type is co-dominant in map unit IIIa on fans of $<$ 5 per cent slope. Here there is a greater depth of fine textured material and the lusher grass growth is reflected in the dark thick Ahk horizons. As in the Orthic Regosol IV the horizon sequence is Ahk, ACk, Ck. However, buried horizons are common and there is, therefore, an irregular decrease of organic matter with depth which allows these soils to be classed as Cumulic.

(c) Calcareous Orthic Eutric Brunisol

This soil is recognized as a major constituent of the grassed fan south of the Cline River (Map unit IIc). This is in contrast to its association with the forested areas on the intermediate fans mentioned in IIa. On these plains (Abraham Flats) there is a thin, 5 to 10 cm, aeolian deposit over coarse gravel. These very shallow soils appear to have an Ahk, Bmk, IICk horizon sequence. Variations encountered are mainly in depth of overlay and solum, and depths of individual horizons. The Ahk may vary from 0 to 3 cm. This type of profile appears to grade on one hand to the Cumulic Regosol I and on the other to Degraded Eutric Brunisol.

(d) Calcareous Degraded Eutric Brunisol

This soil is found on the same landform as the previous soil, but under a pine forest. It differs from the type described for the benches (Ic) in that the sola (particularly the Aej horizons) are generally thinner and are weakly calcareous, and the horizonation is not as well pronounced. The horizon sequence is L-H, Aej(k), Bmk, IICk.

All horizons are quite variable in depth, with the solum ranging up to 25 cm. B horizon color varies from pale brown (10 YR 6/3 d) to brown (7.5 YR 5/4 d). This soil was also encountered on some of the intermediate fans.

(e) Orthic Regosol I

These are soils with little or no profile development. They are essentially soils of recent fluvial and aeolian materials.

Orthic Regosol I accommodates mountain stream beds made up of coarse, 5 to 15 cm, angular cobbles, generally covered by a mat of Dryas and fans or flood plains where the material may be coarse or fine (sandy). Burial and stratification, or erosion-deposition phenomena are involved. In limited areas wind action may result in deposition and burial at such a rate that little or no profile development takes place.

These soils make up only a very small percentage of the intermediate fans, but become more significant on the low-angle fans and terraces near river level (Map unit IIIe).

3. Soils of the Steep Slopes

The soils of the more steeply sloping areas (greater than 30 per cent) are treated as one group because all are susceptible to mass wasting processes.

All of the surveyed area was glaciated and as a result till is often encountered plastered against the rocks on the slopes and in small locally more level areas. However, because of the steepness of the slopes, particularly those in excess of 50 per cent, most of the till is found to be modified and/or covered by creep material and slope wash and would more properly be considered to be colluvium. Colluvial processes are augmented by such phenomena as snow slides. Talus and scree also contribute to colluvium and may be locally important surficial materials. The aeolian overlay of the benches and fans is noted only rarely on the slopes.

Vegetation varies from extremely sparse, on exposed scarps through immature pine and pine-spruce forests, to local stands of mature spruce and fir. At higher elevations herbs such as Vaccinium scoparium and Cassiope tetragona are found. Possibly the most significant difference from the bench areas is the increase in mosses on the northern and eastern aspects and at higher elevations.

Concomitant with differences in slope, stability of landforms, aspect, elevation, parent material, and vegetation are variations in soils. Indeed this group of soils is the most heterogeneous of all the groups. On the southern facing and generally less steep slopes, Gray Luvisols appear to be climax soils on relatively stable materials. Where colluvial action is active, disruption of profiles occurs and soils with weaker and/or discontinuous horizons are more common. This soil disturbance from downslope movement results in extreme variability over very short distances and discrete soil entities are difficult to recognize and describe. On the north and east facing slopes brighter colored (7.5 YR hue) B horizons are general and there is a tendency for maximal development to approach Brunisolic or Bisequa subgroups. However, these slopes are generally steeper and hence there is a greater percentage of disrupted profiles which are classed as Orthic Regosols II. This is particularly true at higher elevations. The L-F horizons on north facing slopes average 5 to 15 cm as compared with south facing slopes with 2 to 4 cm of L-F (thicker in mature stands and locally more humid areas). It would appear that slope and aspect are the chief factors governing soil variation on the slopes. Soil profiles classified in Regosolic, Brunisolic, and Luvisolic Orders are encountered but Regosols predominate.

(a) Orthic Regosol II

This is the largest single group of soils on the slopes, and includes all those which are a direct result of physical disturbance of the soil mass. On all slopes over 30 per cent mass wasting phenomena are active and soil disturbance is the rule. Truncation of profiles and broken or disjointed horizons prevail. Portions of A and B horizons of variable character may be recognized but bear no particular relationship to one another. This type of soil is prevalent on the more steeply sloping portions of the lower mountain slopes (Map unit IVa) and is common on the benches and scarps as well.

(b) Orthic Regosol III

These soils are found on the barren edges of the scarp facets dropping from the benches to the valley floor. They are also present on some of the slopes where scree accumulates, in which locations they are gradational to Lithosols. The sites are very dry, as indicated by the sparsity of vegetation, and appear to be a result of wind desiccation as all are upstream facing (windward) facets with no greater percentage of disrupted profiles which are classed as Orthic Regosols II. This is particularly true at higher elevations. The L-F horizons on north facing slopes average 5 to 15 cm as compared with south facing slopes with 2 to 4 cm of L-F (thicker in mature stands and locally more humid areas). It would appear that slope and aspect are the chief factors governing soil variation on the slopes. Soil profiles classified in Regosolic, Brunisolic, and Luvisolic Orders are encountered but Regosols predominate.

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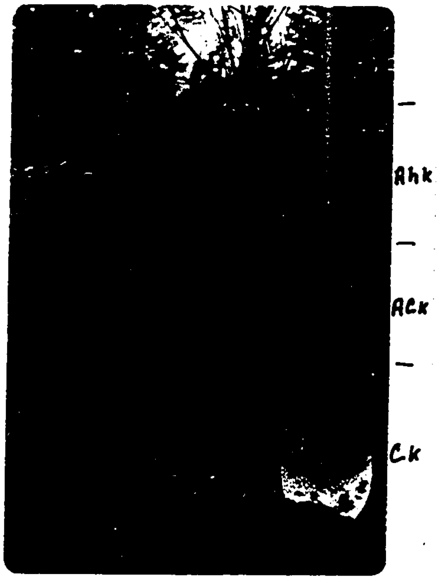
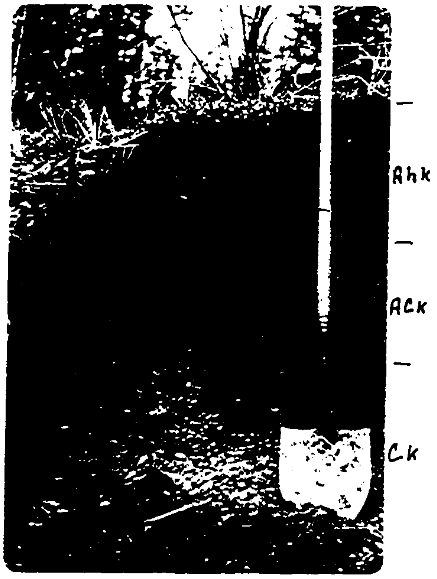


Orthic Regosol III
- 40% slope

Orthic Regosol II
- disrupted profile

Windthrow
- a soil forming process

PLATE III. Photographs of an Orthic Regosol III, an Orthic Regosol II and the effect of windthrow.



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relationship to aspect. A few stunted pines are generally the only trees present with the remainder of the association confined to such hardy plants as juniper, potentilla, bearberry, a few herbs and grasses, and lichens. Often less than 50 per cent of the soil surface is covered. The geologic material is generally coarse gravelly, and the slopes range from 50 to 75 per cent.

The surface horizon appears to be a mixture of roots and other weakly humified organic remains with coarse calcareous mineral material. The organic material content decreases with depth and by 30 to 40 cm very little is present. The horizon sequence is similar to that for the Cumulic Regosol I (namely, Ahk, ACk, Ck). The Ahk is almost identical in color (brown to dark brown, 10 YR 4/3), organic content, and physical character to the IICk1 horizon underlying the bench soils. This suggests at least a similar process for the formation of both these horizons. These soils are quite uniform over the scarps with only minor variations in depth. Where they are developed in scree the variation is greater due principally to the varying depth of scree over rock. A phenomenon peculiar to the upper scree slopes is downslope striping of the vegetation and soils. Under bearberry an Orthic Regosol III is found, whereas in the strip devoid of vegetation Orthic Regosols I on rock are present.

(c) Cumulic Regosol II

This soil is specific to talus slopes. The slopes range from 60 to 80 per cent and the material is very angular and coarse. Vegetation is restricted by rock fall and downslope wasting. Although the density of vegetation is low, there is a wide variety, particularly in the more moist sites. The trees are aspen, spruce, or pine. Small trees and shrubs may include alder (*Alnus sp.*), maple (*Acer sp.*), birch (*Betula sp.*), willows (*Salix spp.*), shepherdia, potentilla, service berry (*Amelanchier sp.*), and rose. The ground cover present is comprised mostly of grasses with some bearberry, herbs, moss, and lichens. The horizon sequence is Ak, ACk, Ck. The Ak horizon is essentially an horizon of angular talus cobbles embedded or enveloped in felted mats of organic matter (F material) and roots. There tends to be an increase of fines (sands) with depth. Solum depth is generally in the 15 to 30 cm range. Like the scree soils, these also grade to Orthic Regosols I or rock.

(d) Degraded Eutric Brunisol

This soil is common on the lee side of the scarp crenulations under well stocked pine stands with an undergrowth of shepherdia and grass. It is also fairly common on many of the steep lower slope areas.

Fairly bright (7.5 YR 5/4 - 5/6 m) Bm colors are present. Eluvial horizons are generally weak. This soil differs from the Brunisols described in Ic and IIc mainly by its variability and association with Orthic Regosols II. The instability of the surface is evident, and it appears that Degraded Eutric Brunisol is the maximal development allowable under the prevailing circumstances. Variations range from the presence of weak discontinuous Bt horizons to a profile with mottled horizons which would appear to be a mixture of Ae and Bm material and are probably Regosols rather than Brunisols.

(e) Orthic Gray Luvisol

These soils occur near the base of the lower slopes in locations where the slope is generally less than 40 per cent (Map areas Id). The parent material is generally a mixture of colluvium and till and is more resistant to erosion because of the lower slope.

The soils and associated vegetation are very similar to the Orthic Gray Luvisol described in Ia, from which they differ mainly in lack of a definite overlay. Gray Luvisols were also encountered on presently unforested southern exposures near the crests of many ridges. These areas had a moderate forb-grass cover and the dominant soil type was usually an AC soil on thin rubble over rock.

(f) Other Soils

(i) Lithosols. The upper limit of the survey area is in most instances governed by the presence of rock slopes. At this limit and of limited occurrence throughout the slope region, are areas of thin (less than 10 cm) mantles of soil materials over rock. There are also ledges and crevices down to a few centimeters in size which support such plant growth as grasses, cushion plants, and tree seedlings. All of these types of soil are considered as Lithosols. The individual soil bodies are very restricted (measured in cm). They are not recognized as soils in the Canadian classification, but have analogs in other mountain areas such as the Alps (Kubiena, 1953) where they are considered to be soils. The soils often consist of an organic layer or mat with some fine material resting directly on rock. The profiles are A, C or (A), C. They grade to rock on one

Talus Soil - 75% slope

Ledge Soil (Lithosol)

Crevice Soil (Cumulic Regosol)

PLATE IV . Photographs of talus, ledge and crevice soils.

Talus Soil - 75% slope

Ledge Soil (Lithosol)

Crevice Soil (Cumulic Regosol)

PLATE IV . Photographs of talus, ledge and crevice soils.

hand and to the Orthic Regosol III type or Organic soils (in crevices) on the other.

(ii) Peaty Soils. On some of the slopes, where water accumulates or seeps, peaty soils are present. In some instances the organic material rests directly on rock with slopes in excess of 70 per cent. Ledum sp. abounds in these places, and in fact is common to much of the north and east facing slopes.

4. Special Soil Areas

(a) Upper Mountain Slope

One traverse was made up to treeline on a moderate 20 to 40 per cent) northeast facing slope from 1,800 m to 2,100 m (6,000 to 7,000 ft. A.S.L.) (Map unit Ib). At the lower elevations Bisequa Gray Luvisols with sola up to 50 cm in depth were found. The Podzol sequum was well expressed though of mildly acid to neutral reaction. The parent material appeared to be till-colluvium with some aeolian overlay. The vegetation consisted of spruce and fir with shepherdia, moss, Vaccinium scoparium and Equisetum spp.

With increasing altitude the upper sequum became more pronounced while the Luvisolic sequum became weaker, until at about 2,050 m (6,800 ft. A.S.L.) a Podzol was encountered. The vegetation was similar to that described for the Bisequa Gray Luvisol site with the addition of Cassiope tetragona. A very definite Bfh of about 2 cm was present overlying a yellowish red (5 YR 4/8 m) Bf horizon. The solum was about 20 cm thick overlying calcareous BC and C horizons.

As the alpine zone was approached the forest cover thinned, and although the steepness of the slopes did not increase, the soils indicated increasing disruption which is probably a result of solifluction. It appears that illuviation is taking place, but depending on which features are emphasized, the soils can be classified as Degraded Brunisols or Regosols. The profiles typically showed many buried horizons which included Ae, Bm, Bf, and H horizons. No free carbonates were encountered at 60 cm.

The southern exposure at treeline had an alpine meadow type of vegetation. The soils had dark turfy Ah horizons with bright brown B horizons. The percentage of alpine soils in the project area is quite small. In most cases the treeline is governed by topography rather than climate, with the higher elevations not supporting vegetation because of the steepness of slope.

(b) Floodplains

The more recent bars in the braided North Saskatchewan River channel are made up of quite coarse gravels, with a few cm of sand capping in the higher landscape positions. The bars and lateral deposits which are somewhat higher above river level (25 to 100 cm) have a greater depth of fines (mostly sands but some silts) overlying the gravel and are more or less vegetated. The dominant tree cover is stunted spruce with accessory of potentilla, willow, swamp birch, some juniper, bearberry, sedges, and grasses. The relatively more recent deposits tend to have less spruce and more ground cover. These areas have a very hummocky microrelief with relief changes of 20 to 50 cm. The water table is close to the surface, dependent on river stage, and the soils vary in classification from Rego Gleysols to Gleyed Regosols. Minor variations are encountered in parent material, depth to water table (10 to 70 cm), amount of L-H (0 to 15 cm), presence or absence of buried horizons, and vegetation. The hummocks are characteristically more strongly calcareous than the troughs. Peat accumulations are not present. Some moderately well drained Regosols are encountered and are prevalent on the more elevated floodplain at the mouth of the Cline River (Map unit IIIc). Here stratification and buried horizons are the rule.

5. Discussion of Specific Soil Features

(a) Organic Horizons

The valley soils on the benches and fans, and soils on the more exposed south facing slopes, generally have very thin L-F(H) horizons. They range in thickness from 1 to 3 cm and consist dominantly of pine needles with little indication of a humified layer. Charcoal is often noted. Several factors may have contributed to this relative lack of an organic layer. The most obvious is that the forest stands are somewhat open and growth is not rapid, so the contribution of litter is somewhat limited. Forest fires are probably a major factor involved directly by destruction of original layers and indirectly through creation of conditions which presently exist -- an immature forest. A further factor may be the open canopy which favors rapid mineralization of surface matter.

(b) Surface Bm Horizons

The so-called "surface Bm" horizons are a ubiquitous feature in this area. They are 0 to 4 cm thick and are invariably present on all soils. Dry colors vary from 10 YR 4/3 to 10 YR 6/3. The chroma is probably due to oxidized iron, while the value varies with organic content. This horizon might be pedogenic, it might be geologic, or a combination. If fires are responsible, this color horizon could be a product of heat induced oxidation or actual burning, or it could be due to later migration of fire liberated elements left on the surface. If pedogenic in nature, the Bm could be a result of *in situ* weathering or from a breakdown of surface organic materials with subsequent downward migration of the products. Another possibility is that this horizon represents a separate deposit, either ash fall or another period of loessial deposition.

(c) Ae Horizons

The coarse silt loam texture, gritty feel, lack of structure and soft consistence of most of the A horizons of the soils point to a high volcanic ash content in the overlay material. The question was raised as to whether the observed horizonation was anything other than geologic deposition. This became particularly critical in delineating the Degraded Eutric Brunisol - Calcareous Degraded Eutric Brunisol soil complex and to a lesser extent in the Gray Luvisol soil. If indeed the horizons are geologic only, then the applied designation of Ae(j) is invalid and the classification erroneous.

Another aspect of this problem is the presence of "Ae plus Bm" or mottled Ae(j) horizons. This type of horizon is common on the weakly expressed Degraded Brunisols and also occurs on some of the slope soils. It has a light gray (10 YR 7/2 d) matrix color with yellowish brown to strong brown (10 YR - 7.5 YR 5/6 d) blotches. The mottles are considered to be concentrations of Fe liberated by weathering and are interpreted to be an indication of incipient B formation. This evidence lends support to the implications of the classification as used, although it is recognized that geology is a prime factor governing the soil morphology.

(d) Pebble Coatings

A phenomenon associated with the migration of constituents is that of staining and coating of pebbles in the profile. The particular soil constituents involved are calcium carbonate, clay, and iron oxides. Downward leaching of carbonates is indicated by the presence of encrustions of calcium carbonate on the underside of rocks in the lower section of the soil solum and particularly in the upper portion of the C horizon. Clay coatings are present around pebbles in Bt horizons and iron oxide coatings are present in reddish horizons not having clay accumulation. The presence of iron oxide coatings was taken as an indication of the presence of "free iron" resulting from the podzolization process. These horizons were classed as Bf or Bfj horizons, which was in contrast to the horizons of high chroma which do not have iron coatings on the pebbles and which were called Bm horizons.

(e) Bt Horizons

There is quite a wide range in character of the Bt horizons present in the Luvisolic soils. As mentioned earlier colors range from strong brown (7.5 YR 5/6 m) or even approaching yellowish red (5 YR 5/6) in the extreme, to yellowish brown (10 YR 5/4 m). The latter have the lowest clay content, about 20 per cent, while the redder variants have well over 30 per cent clay size material. Concomitant with the higher clay percentages is a better defined structure and a harder consistence. The fine granular structure makes clay skin identification quite difficult.

The first assumption is that these soils were Luvisols and the Bt horizons are illuvial in nature. However, the Ae horizons (as mentioned in part c) are quite uniform irrespective of the underlying B and are in many respects very like unaltered volcanic ash. If this is the case a source for the illuvial B is lacking. An alternative is *in situ* weathering of a former surface material which, however, is not compatible with the classification as a Luvisol.

(f) IICk1 Horizon

This horizon, as named, is confined mainly to the bench soils where it occurs immediately below the loessial overlay. It averages 20 cm in thickness, is a very coarse gravelly sandy loam, is strongly calcareous, and has a high organic content. The organic material is essentially roots and root sloughings and imparts a dark brown (10 YR 3/3 m) color to the horizon.

The horizon coincides with the "washed till" thought to be a result of the post-glacial removal of surface fines by slope wash.

However, the loosening action of tree roots might also yield a horizon of this type. The high root content is undoubtedly due to the extreme compactness and/or very high carbonate content of the underlying material which strongly inhibits root penetration, and therefore concentrates the roots near the surface.

Horizon designation is difficult because this horizon in no way resembles the horizons above and resembles the material below only in coarseness of texture and carbonate content. To add to the problem, this horizon is almost identical with the surface horizon of the Orthic Regosol III (described in 3 b) where it is called an Ahk horizon. Both horizons are essentially a mechanical mixture of root matter and the calcareous coarse gravelly mineral material, and the question arises as to whether both horizons should have the same designation. The term "IICk" is a compromise, with the realization that this is a singular horizon, and that the implications of the "C" designation do not really apply.

(g) Horizons of Carbonate Accumulation

Cca horizons were not formally recognized although they undoubtedly exist, particularly in the coarser textured materials. Carbonates have been moved downwards as discussed in (d) but sections are rare, and compactness and stoniness of the material impede digging to the extent that pits of sufficient depth to identify Cca horizons are not practical. The effects of carbonate leaching are hard to assess but one result appears to be the cementation of the upper portion of the bench material. This is particularly noted in the outwash materials where material identification, in the absence of sections, is quite difficult.

(h) Profile Discontinuity

Profile discontinuity is easily explained on the more steeply sloping areas by slope phenomena. On the bench areas the major contributor to soil disruption appears to be tree throw. It seems particularly prevalent in the more open stands where recent falls and hummocky micro-relief attest to its significance. The strong valley winds are obviously a factor. What is probably more important is the relatively shallow (seldom exceeding 40 cm) rooting habit of the trees and the fact that the surface material is quite loose. The trees are therefore somewhat loosely anchored and are susceptible to overthrow.

Laboratory Investigations of Soils

Methods and Materials

1. Mineralogical Analyses of Fine Sands

(a) Specific Gravity Separations

The fine sands were divided into four fractions based on specific gravity separations at 2.50, 2.82, and 2.96 using bromoform-benzine, bromoform, and tetrabromoethane, respectively.

(b) Grain Mounts

Heavy minerals (S.G. Fractions >2.82) were mounted on glass slides in aroclor (Refractive Index = 1.67). Representative sets of light minerals were mounted in Caedax (Refractive Index = 1.54). Equivalent sets of light minerals were mounted for staining.

(c) Staining Technique for Light Mineral Identification

Mineral grains were mounted using a 2:1 mixture of castolite: thinner. The mixtures were heated with stirring until quite fluid. It was then poured into aluminum weighing pans to a depth of 3 to 4 mm. Several hundreds mineral grains were added and stirred to give even distribution. Two to four drops of castolite hardener were stirred into each mount and the mount cured for two hours or more in an oven at 80°C. After curing the mounts were cooled and representative areas about 20 x 30 mm were cut from each. The upper surface was ground smooth and the chip mounted on a glass slide using Lakeside 70 thermoplastic cement. The new upper surface (with grains) was then ground lightly to give fresh grain surfaces.

The mounted chip was inverted over 48 per cent HF (at a height of about 3 cm) for 30 to 60 seconds, depending on room temperature. The slide was then placed into a saturated sodium cobaltinitrite solution for 20 to 25 seconds and rinsed with water. The slide was dipped into a 5 per cent $BaCl_2$ solution and immediately rinsed. This was followed by placing the slide in a potassium rhodizonate solution (0.05 gm in 20 ml water) for about 10 seconds and rinsing. After drying, a cover slip was affixed with Permount.

Potash feldspars take on a heavy yellow stain, the plagioclase feldspars take on a reddish stain, and quartz is unaffected.

2. Micromorphological Analysis

The oriented clods sampled for this purpose were allowed to air dry. They were then impregnated using castolite under vacuum following the general procedure outlined by Pettapiece (1964). Thin-sections were prepared from the impregnated clods and were examined with the aid of a polarizing microscope. The features were described according to terminology suggested by Kubiena (1938) and Brewer (1964).

3. Identification of Components in the Clay Size Range

(a) Clay Separations

Fine and coarse clays were separated using a centrifuge procedure after sample pretreatment with sodium acetate, pH 5, hydrogen peroxide, and citrate-dithionite (Kittrick and Hope, 1963).

(b) X-ray Diffraction Analysis

Oriented glass slide mounts of K and Mg saturated clays (Jackson, 1956) were made for both the coarse (2 - 0.2 μ) and fine ($<0.2\ \mu$) clay fractions. X-ray diffraction patterns were obtained with a Philips x-ray diffractometer using nickel filtered CuKα radiation. The clays were subjected to the following treatments:

i. Mg saturated, air dried (Mg-air)
ii. Mg saturated, glycolated (Mg-glycol)
(Slides were glycolated by placing in an ethylene glycol saturated atmosphere at 60°C for 48 hours.)
iii. K saturated, air dried (K-air)
iv. K saturated, heated to 300°C for 4 hours (K-300)
v. K saturated, heated to 550°C for 4 hours (K-550)

The above procedures were conducted before and after the clays were treated with NaOH for the removal of amorphous material.

(c) Differential Thermal Analysis

Ca saturated coarse and fine clays were subjected to D.T.A. on an Aminco Thermal Analyzer (model 4-4442) using calcined alumina as a reference material. The procedure was repeated for NaOH treated clays.

(d) Surface Area Determinations

Surface areas of the clay samples were determined by adsorption of ethylene glycol monoethyl ether (Heilman *et al.*, 1965). The procedure included ovendrying at 60°C and running a known standard with each set. Surface area was determined before and after pretreatment for the removal of amorphous materials.

(e) Electron Microscopy

Samples of 0.01 to 0.05 per cent clay suspensions were dried onto formvar films supported on 300 mesh per inch copper grids. The mounts were examined using a Philips EM100B electron microscope.

(f) Quantitative Estimates of Individual Clay Components

(i) Amorphous Material. The selective dissolution procedure of Hashimoto and Jackson (1960) was used. This technique involves boiling the sample for 2.5 minutes in 0.5 N NaOH which dissolves Si and Al not bound in well crystallized structures. Dissolved aluminum was determined colorimetrically using Aluminon (Hsu, 1963) and silicon by the Molybdate method (Kilmer, 1965).

(ii) Kaolinite plus Halloysite. The same procedure as for amorphous material was used following the heating of the sample to 525°C which destroyed the structure of kaolinoid minerals (Hashimoto and Jackson, 1960).

(iii) Montmorillonite and Vermiculite. The cation exchange method of Alexiades and Jackson (1965) was used as an estimate of the amount of expanding clays. Vermiculite was determined by the decrease in cation exchange due to K saturation and drying at 110°C, assuming irreversible collapse. Montmorillonite was determined by subtracting the exchange capacity of other components from the total exchange capacity (K saturated) assuming a C.E.C. of 110 me/100 gm for montmorillonite and allophane and 5 me/100 gm for the external surface of all other minerals.

(iv) Quartz plus Feldspars. A modification of the selective dissolution method of Kiely and Jackson (1965) was used. This method involves a pyrosulphate fusion followed by an NaOH treatment. The modification was to use the residue weight for a total component (quartz plus feldspar) determination rather than fusion of the residue to determine species. This was done in the knowledge that material other than quartz and feldspars was likely to be present in the sample of high volcanic ash content. Also, potassium pyrosulfate was substituted for the sodium salt.

(v) Illite. An HF-HCl fusion (Pawluk, 1967) was used with the dissolved elements determined by atomic absorption. The fusion was carried out on clay samples before and after NaOH removal of amorphous material. Fusion analysis was also carried out on the "quartz plus feldspar" residue in order to obtain a measure of the K content of the non-clay mineral portion of the sample. Because of the presence of volcanic glass in some of the samples and the inclusion of an NaOH treatment in the pyrosulfate fusion analysis, the K content after NaOH treatment was used as the total sample K content. The K content of the total sample less that of the "non-clay" fraction was considered to be the K content of illite (mica). Per cent illite was calculated assuming a 10 per cent K_2O content (Jackson, 1956). Total iron was also determined as part of the analysis.

(vi) Chlorite. A thermal gravimetric method (Alexiades and Jackson, 1967) was used. This method is based on structural hydroxyl loss of chlorite between 300°C and 950°C after subtraction of the water contribution from other constituents present. No correction was made for the oxidation of ferrous iron.

Results and Discussion of Laboratory Investigations

1. Mineralogical Analysis of Selected Fine Sand Fractions

Mineralogical analysis of the fine sand fractions was conducted to characterize the various pedogenic horizons and to ascertain the volcanic ash contribution to these horizons. Profiles and horizons were selected to represent the range of characters noted in the field. Profiles represented are Degraded Eutric Brunisol (D6757 to 61, D6864 to 66, D6871 to 75), Orthic Gray Luvisol (D6797 to 101, D6884 to 85), and Bisequa Gray Luvisol (D6791 to 94). Horizon types included are surface Bm (D6871), Aej (D6757, D6864, 65 and 72), Luvisol Ae

(D6797, D6793, D6884), Podzol Ae (D6791), Bm (D6833 and 73), Btj (D6859), Bt (D6798 and 94, D6885), Ck (D6760, 61 and 101, D6874 and 75), and an ash sample. As outlined previously the fine sands from the selected samples were divided into four groups based on specific gravity separations at 2.50, 2.82, and 2.95.

Distribution of the specific gravity separates (Table III) shows marked variations among horizons. Of particular note are the high percentages of grains in the S.G. fraction <2.50 and the relatively higher amounts of heavy minerals (S.G. > 2.95) for the surface horizons, and the large percentages of grains falling into the S.G. fraction 2.82 - 2.95 for the IICk (till) horizons. The former are particularly significant when compared to a volcanic ash sample (D67 ash).

Tables IV, V, VI, and VII indicate the major grain types found in the respective separates. The term volcanic fragments refers to those volcanic grains which could not be specifically identified. In the light (S.G. < 2.82) fractions these are dominantly glass with light mineral (probably plagioclase) inclusions. In the heavy fractions (S.G. > 2.82) they are dominantly pyroxenes which could not be classified as to ortho- or clino- forms. All pyroxenes and amphiboles are volcanic in origin. The S.G. fraction in which they fall depends upon the amount of encrusting glass. Carbonate minerals were not identified as to species. It is assumed that those in the S.G. fraction < 2.82 are calcite, those in the S.G. fraction 2.82 - 2.95 are dominantly dolomite with some calcite, and those in fractions with S.G. > 2.95 are dolomite and magnesite.

The S.G. fraction <2.50 (Table IV) contain a high percentage of volcanic shards and fragments. This is particularly true for those horizons which have a significant percentage of the fine sand in this fraction. For those horizons which have less than 1 per cent grains in this fraction (Bt and IICk horizons) a different suite of grains are present. Three types are worthy of mention. First are those classed as "opal" which appear to be formed by silica replacement (fossilization) of plant materials. The cellular arrangement of the material is evident, and some are nearly amorphous. Second are aggregates of plant remains, opal, and small grains of carbonates and quartz which appear to be cemented with amorphous materials (SiO_2 ?). These are interpreted as channel or root fillings. Third are a group of highly weathered grains which appear to be volcanic in origin (but older than the surface ash).

The S.G. fraction 2.50 - 2.82 (Table V) is composed dominantly of quartz, with significant amounts of volcanics in the surface horizons and carbonates in the subsurface horizons. There appears to be a tendency for higher carbonate contents in the IICk1 than the IICk2 horizons (note D6760 and 61, D6886 and 87). The ash is composed mainly of fragments (glass encased minerals) as compared to the S.G. fraction <2.50 where it is comprised dominantly of glass. It was noted that the glassy volcanic material took on a feathery rhodizonate stain indicating the presence of Ca and/or Na. The 21 per cent quartz and feldspars in the ash sample are likely of volcanic origin (without encrusting glass), but there could also be some contamination from other sources. This likely results in underestimation of the amount of volcanic material in this fraction.

TABLE III. Specific Gravity Separations of Selected Fine Sand Fractions

				Specific Gravity Separation (%)			
Profile	Sample No.	Depth (cm)	Horizon	<2.50	2.50-2.82	2.82-2.95	>2.95
Degraded Eutric Brunisol	D6757	2- 8	Aej	30.9	67.2	1.3	0.6
	D6759	8-18	Btj	11.8	87.3	0.5	0.4
	D6760	18-40	IICk1	0.3	80.9	18.7	0.1
	D6761	40+	IICk2	0.3	77.4	22.2	0.1
Orthic Gray Luvisol	D6797	0- 8	Ae	2.4	97.1	0.2	0.3
	D6798	8-16	Bt	0.2	99.6	0.1	0.1
	D67101	40+	IICk2	0.2	79.2	20.4	0.2
Bisequa Gray Luvisol	D6791	0- 2	Ae1	54.5	38.4	1.9	5.2
	D6793	5-12	Ae2	6.6	92.9	0.1	0.4
	D6794	12-22	Bt	0.5	96.8	2.3	0.4
Degraded Eutric Brunisol	D6864	0- 3	Aej1	28.8	68.9	0.9	1.4
	D6865	3-10	Aej2	14.5	84.2	0.5	0.8
	D6866	10-25	Bm	6.8	92.1	0.9	0.2
Degraded Eutric Brunisol (calcareous)	D6871	0- 5	Bm	13.6	84.8	0.6	1.0
	D6872	5-13	Aej	25.9	71.2	0.9	2.0
	D6873	13-20	Bm	7.3	92.0	0.1	0.6
	D6874	20-40	IICk1	0.3	72.5	27.0	0.2
	D6875	55+	IICk2	0.3	74.1	25.5	0.1
Orthic Gray Luvisol	D6884	0- 8	Ae	43.0	52.7	1.7	2.6
	D6885	8-20	Bt	0.8	97.8	1.2	0.2
	D67Ash	--	--	75.3	21.3	1.1	2.3

TABLE IV. Grain Types in the Specific Gravity Fraction <2.50 of Some Fine Sands (% of total fraction)

Sample No.	Horizon	Volcanic Glass	Volcanic Fragments	Quartz	Potash Feldspar	Sodic-Calcic Feldspar	Carbonate	"Opal"[1]	Others[2]	% Volcanic
D6882	IICk2	36	-	25			3	3	33	36
D67Ash	Ash	94	5	tr	tr	tr	-		tr	100
D6757	Aej	95	5	tr	-	tr	-			100
D6759	Btj	95	4	1	-	-	-		tr	99
D6797	Ae	92	4	1	2	-	-		tr	96
D6794	Bt	20	-	20			2	8	50	20
D6871	Bm	92	4	1	tr	1	-		2	97
D6872	Aej	92	7	tr	tr	tr	-		tr	99
D6884	Ae	95	4	-	-	-	-		1	99
D6885	Bt	43	6	10			1	7	33	49

---

[1] "Opal" refers to plant structures which have been replaced by SiO_2.

[2] For those horizons which have very high % of "Others" in the lower solum and below, there are two types: (a) highly weathered and/or coated grains, and (b) aggregates of small quartz and carbonate particles apparently cemented by SiO_2.

TABLE V. Grain Types in the Specific Gravity Fraction 2.50 - 2.82 of Some Fine Sands (% of total fraction)

Sample No.	Horizon	Volcanic Glass	Volcanic Fragments	Quartz	Potash Feldspar	Sodic-Calcic Feldspar	Carbonates	Others[1]	% Volcanic
D6757	Aej	20	3	56	6	2	-	12	23
D6759	Btj	10	3	67	6	4	-	11	13
D6760	IICk1	tr	-	76	3	1	16	5	tr
D6761	IICk2	tr	-	80	4	1	11	5	tr
D6797	Ae	4	-	81	5	1	-	10	4
D6798	Bt	-	-	89	6	1	-	4	-
D6799	IICk1	-	-	81	5	3	5	5	-
D67101	IICk3	-	-	70	4	1	11	15	-
D6864	Aej1	4	22	61	7	1	-	5	26
D6865	Aej2	1	11	79	5	1	-	2	12
D6866	Bm	1	3	84	5	1	1	6	4
D6884	Ae	6	34	42	10	2	-	6	40
D6885	Bt	1	2	79	3	3	1	11	3
D6886	IICk1	-	tr	75	2	1	15	8	tr
D6887	IICk2	tr	1	78			12	8	1
D67Ash		-	78	11	9	1	-	1	79

[1] Others consist almost entirely of grains unidentifiable as a result of weathering (and coatings). Many appear to be of volcanic origin.

TABLE VI. Grain Types in the Specific Gravity Fraction 2.82 - 2.95 of Some Fine Sands (% of total fraction)

Sample No.	D6757	D6759	D6760	D6761	D6797	D6798	D6871	D6872	D6873	D6874	D6875	D6884	D6885	D67Ash
Horizon	Aej	Btj	IICk1	IICk2	Ae	Bt	Aej1	Aej2	Bm	IICk1	IICk2	Ae	Bt	
Ortho-Pyroxene	27	16	-	-	17	tr	17	20	14	-	-	23	tr	35
Clino-Pyroxene	12	-	-	-	7	-	3	4	4	-	-	5	-	8
Amphibole	14	4	-	-	11	1	12	20	10	-	-	19	1	14
Mica[1]	4	1	-	-	1	3	4	1	2	tr	-	1	1	tr
Chlorite[2]	-	-	-	-	1	2	2	2	(7)	-	-	1	1	-
Carbonates	-	52	100	100	2	85	3	8	6	100	100	1	91	-
Volcanic Fragments	38	16	-	-	47	2	53	43	32	-	-	48	1	32
Rock Fragments	-	-	-	-	5	3	-	-	19	-	-	1	3	-
Opaques[3]	-	-	-	-	1	2	2	1	3	-	-	-	1	1
Others[4]	6	5	-	-	8	1	3	2	3	-	-	2	-	tr
% Volcanic	91	36	-	-	82	3	85	87	60	-	-	95	3	100

[1] Includes all mica types.

[2] Includes all species + chloritoid.

[3] Opacity generally due to weathering.

[4] Most are unidentifiable -- due to weathering, crystallinity or coatings.

TABLE VII. Grain Types in the Specific Gravity Fraction >2.95 of Some Fine Sands (expressed as % of non-opaques)

Sample No.	D6757	D6759	D6760	D6761	D6797	D6798	D6871	D6872	D6873	D6874	D6875	D6884	D6885	D67Ash
Horizon	Aej	Btj	IICk1	IICk2	Ae	Bt	Aej1	Aej2	Bm	IICk1	IICk2	Ae	Bt	
Ortho-Pyroxene	50	55	2	-	43	6	50	55	57	6	5	44	24	47
Clino-Pyroxene	7	10	-	-	8	tr	9	7	7	-	-	13	2	7
Amphibole	17	16	-	-	12	2	12	17	9	5	1	15	5	15
Zircon	-	tr	7	8	3	19	1	-	1	6	9	-	10	-
Tourmaline	tr	1	13	7	3	26	1	-	2	9	13	-	17	-
Chlorite + Chloritoid	-	-	4	6	tr	5	-	-	-	15	14	-	8	-
Mica	tr	-	-	1	-	tr	-	-	1	6	2	tr	-	1
Andalusite	-	-	2	1	tr	3	-	tr	tr	-	1	-	tr	-
Apatite	-	-	tr	1	-	-	-	-	-	tr	1	-	-	-
Carbonates	-	tr	33	35	tr	2	2	-	-	21	8	-	4	-
Weathered Volcanics	-	-	29	31	-	16	-	-	-	12	32	-	2	-
Volcanic Fragments	22	15	-	-	19	2	20	17	19	-	-	25	11	29
Rock Fragments	-	-	7	7	2	13	4	3	4	16	9	2	12	-
Others[1]	4	3	3	3	2	5	1	1	1	4	5	1	5	1
Mineral Groups expressed as % of Total >2.95 Fraction														
Opaques[2]	8	9	41	43	18	59	11	9	27	70	60	7	63	9
Unaltered Volcanics	88	87	1	1	64	4	80	87	67	3	2	92	17	99

[1] Others include: Epidote-Zoisite, Kyanite, Staurolite, Garnet, Rutile, and unidentified minerals.

[2] Iron minerals outnumber other opaques about 2:1. Pyrite was noted in the C horizons of the D68 samples.

TABLE VIII. Mineral Groups -- as Per Cent of Total Fine Sand Fractions

Sample No.	Depth (cm)	Horizon	Volcanic Glass and Fragments	Quartz and Feldspars	Carbonates	Others
D6757	2- 8	Aej	48	43	-	9
D6759	8-18	Btj	24	67	-	10
D6760	18-40	IICk1	-	65	31	4
D6761	40-50+	IICk2	-	69	27	4
D6797	0- 8	Ae	6	85	-	10
D6798	8-16	Bt	-	96	-	4
D67101	40-50+	IICk2	-	59	29	12
D6864	0- 3	Aej1	48	48	-	4
D6865	3-10	Aej2	26	72	-	2
D6866	10-25	Bm	10	83	2	6
D6871	0- 5	Bm	27	62	-	10
D6872	5-13	Aej	46	49	-	4
D6873	13-20	Bm	10	83	1	6
D6874	20-40	IICk1	-	58	39	4
D6875	55-65+	IICk2	-	66	30	4
D6884	0- 8	Ae	68	28	-	4
D6885	8-20	Bt	4	83	2	11
D67Ash	-	-	95	4	-	1

The S.G. fraction 2.82 - 2.95 (Table VI) is valuable in that it separates off the majority of the carbonate minerals and the amount of the sample falling into this fraction is diagnostic. It may be noted that while the Bt horizons have more than 80 per cent carbonates in this fraction the total content in the fraction is quite small (about 1 per cent) in comparison to the Ck horizons (about 20 per cent).

The S.G. fraction >2.95 (Table VII) also indicates strong profile variability with the higher percentage of volcanic grains near the surface. Two varieties of zircon (colorless and pink-hyacinth) and three varieties of tourmaline (brown, green, blue) were recognized. The heavy mineral suite is almost identical with that reported by Rutter (1965) for tills in the Bow Valley. A major exception is the category "weathered volcanics". These appear to be amorphous or cryptocrystalline and are isotropic. The refractive index is generally less than aroclor (1.67 - 1.68) and the usual colors are dull hues of brown (some purple). They appear to have small black (iron oxide?) pellet like features disseminated throughout. Opacity varies from non-opaque to almost completely opaque except at very thin edges. The grains are usually well rounded and sometimes have included birefringent grains. Plate VIII, Appendix, illustrates some representative grains. If these are indeed weathered volcanics, their presence implies the occurrence of an old ash fall.

The dominance of orthopyroxenes in the volcanic ash material suggests that this ash is comparable to the Bridge River ash of Westgate and Dreimanis (1967), thereby giving it an age of about 2,500 years. However, a "modern" ash has been reported in Washington and Idaho (Smith, Okazaki, and Aarstad, 1968) which also has a large amount of glass encrusted hypersthene. This leaves the question of age somewhat open, but would suggest a maximum of about 2,500 years.

Table VIII summarizes the results of the previous five tables. The "per cent volcanics" appears to be a good approximation of the percentage of ash material in any particular horizon.

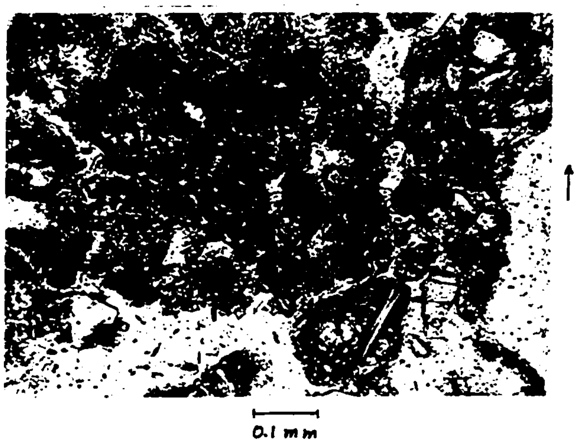
The volcanic content varies markedly down the profiles and thereby contributes to the difference in mineralogy from one horizon to the next. It is also true that corresponding horizons from different profiles are remarkably similar. Note for example in Table VIII the Aej horizons D6757, D6864, and D6872. The Bm and Bt horizons indicate similar trends. This all suggests a strong geologic influence upon the nature and character of the horizons.

2. Micromorphological Analysis

Thin sections were made of diagnostic horizons to elucidate the organization of the soil constituents. Samples were chosen to represent different degrees of profile development as determined in the field. The following field-designated horizons were used: A and AC horizons of an Orthic Regosol IV, Aej and Btj horizons of a Degraded Eutric Brunisol, Ae and Bt horizons of a weak Luvisol, Ae and Bt horizons of a well developed Luvisol, Ael and Bf horizons of the podzol sequum of a Bisequa Luvisol, and a IICkl horizon.

The well developed Gray Luvisol profile (Plate V) has microfeatures similar to those of Luvisolic soils described elsewhere

1



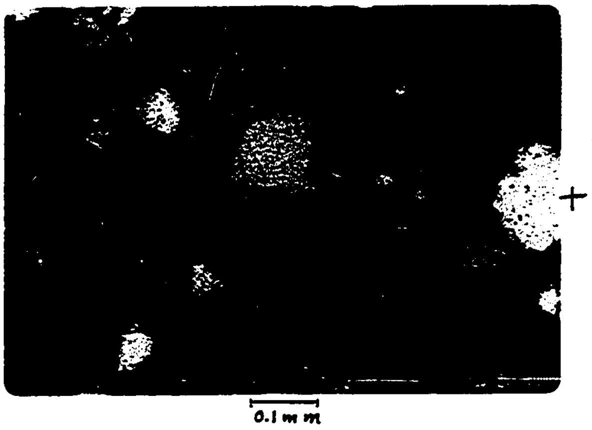
A higher magnification of Plate VI, No. 3, illustrating the volcanic ash content.

2

Porphyropeptic fabric with very dense plasma.

Bt - Orthic Gray Luvisol
plane polarized light

3



A higher magnification of No. 2 (above) showing strongly expressed voidal cutans.

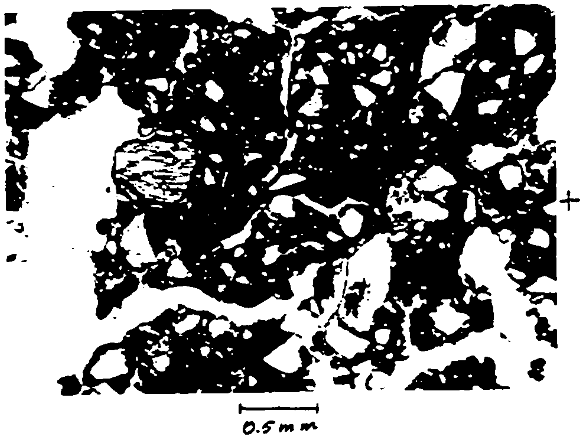
Bt - Orthic Gray Luvisol
crossed polarizers

PLATE V. Photomicrographs of Btj and Bt horizons.

1

A higher magnification of Plate VI, No. 3, illustrating the volcanic ash content.

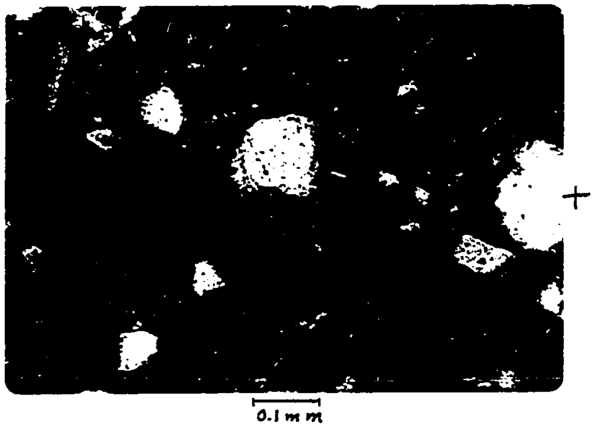
2



Porphyropeptic fabric with very dense plasma.

Bt - Orthic Gray Luvisol
plane polarized light

3



A higher magnification of No. 2 (above) showing strongly expressed voidal cutans.

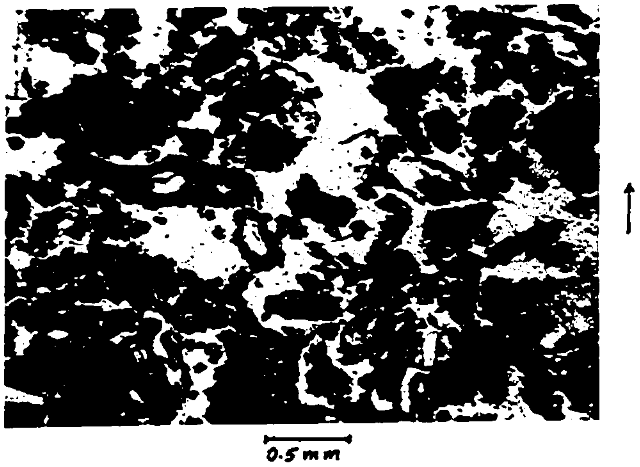
Bt - Orthic Gray Luvisol
crossed polarizers

PLATE V. Photomicrographs of Btj and Bt horizons.

(Pettapiece, in press). This is particularly true with respect to B horizons (Plate V, No. 2) which have dense plasma within the peds, and the organization of plasma into well developed pedologic features. Although no AB horizon was separated in the field, a thin section made from the lower Ae horizon indicates AB type features. The variability in plasma density appears to result from the breakdown of a former Bt horizon and suggests clay movement. The low amount and peptized nature of the plasma in the Ae horizon also suggests the lessivage process. The Ae horizons often do not exhibit the platiness associated with Luvisols but this may result from the particle size distribution of the plasma, in particular the coarse clay to fine clay ratio (Dumanski and St. Arnaud, 1966).

Several differences are noted in the profiles with more weakly expressed morphology. These soils appear to be developed from materials with a relatively high volcanic ash content. The weakly developed B horizons show very little structural organization. The plasma is only weakly organized with some orientation around skeletal material (skelsepic fabric). The well developed Bt horizons, by comparison, exhibit strongly oriented plasma along voids as well as around mineral grains (skel-vosepic fabric). The lack of voidal association in the more weakly expressed soils may be a result of poorly developed structure, and also suggests little translocation of plasma from above. Any plasma that may have come from overlying horizons was probably subsequently dispersed. The B horizons of the Brunisol (Btj) and weak Gray Luvisol (Bt) appeared to be almost identical in thin section. This reflects the similarity in color and structure of these horizons.

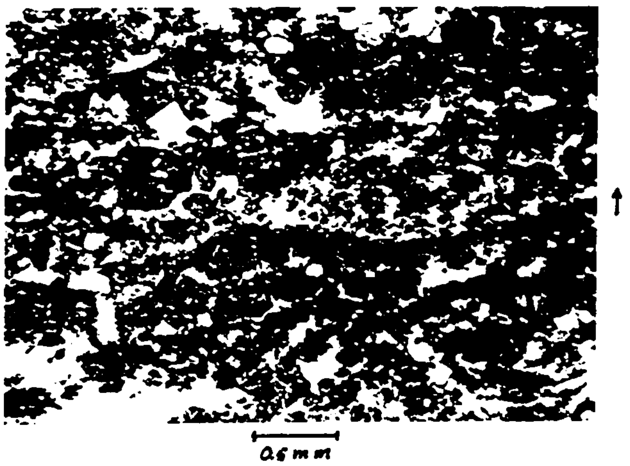
1



Disruption of banded fabric by roots.

A - Eutric Brunisol
plane polarized light

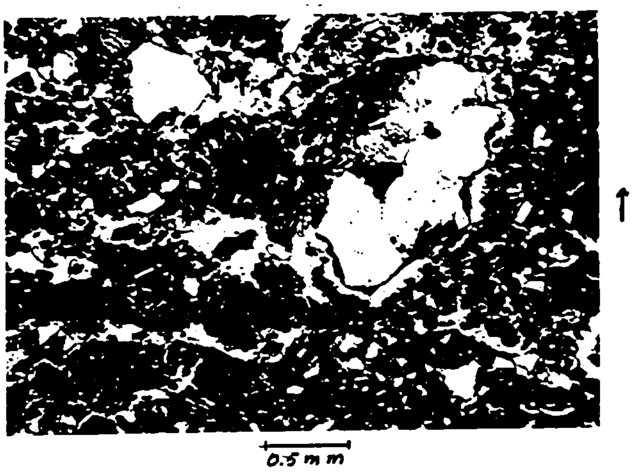
2



Banded fabric in weak platy structure.

Aej - Degraded Eutric Brunisol
plane polarized light

3

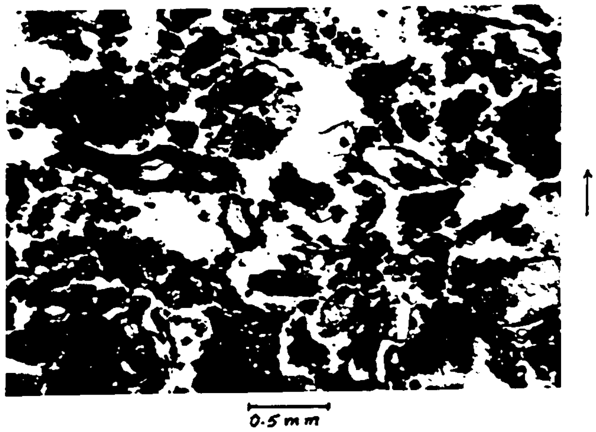


Banded to porphyropeptic fabric within weak structure.

Btj - Degraded Eutric Brunisol
plane polarized light

PLATE VI. Photomicrographs illustrating features in weakly structured horizons of high volcanic ash content.

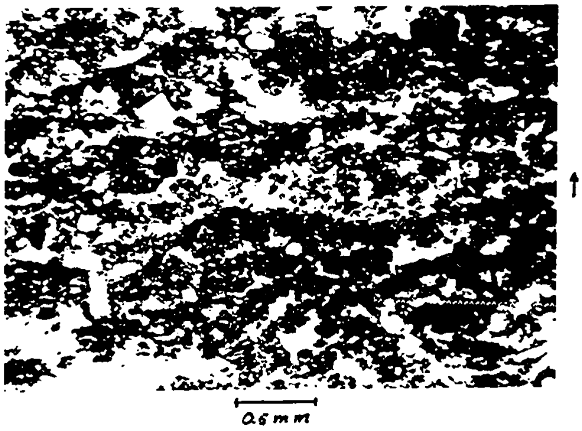
1



Disruption of banded fabric by roots.

A - Eutric Brunisol
plane polarized light

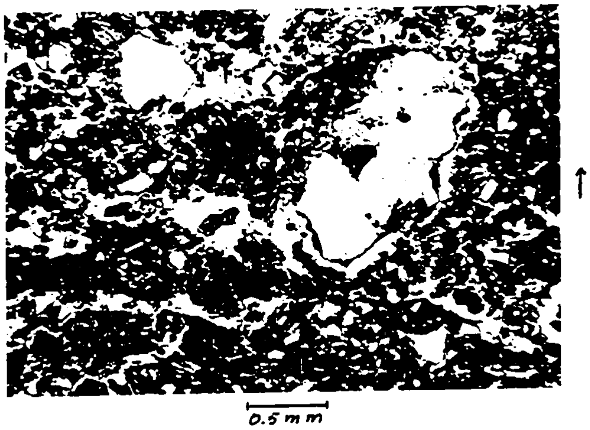
2



Banded fabric in weak platy structure.

Aej - Degraded Eutric Brunisol
plane polarized light

3



Banded to porphyropeptic fabric within weak structure.

Btj - Degraded Eutric Brunisol
plane polarized light

PLATE VI. Photomicrographs illustrating features in weakly structured horizons of high volcanic ash content.

Because the mineralogy is different (Table VIII, D6759 and D6885) the similarity in features likely reflects pedogenic processes.

The A horizons of the weakly developed profiles tend to have somewhat less plasma than the B horizons. There is less orientation of the material and with the high ash content the fabric shows little plasmic organization (insepic to asepic fabric, with only minor amounts of skelsepic). The structure is usually platy (isoband fabric) presumably reflecting ice wedging (Plate VI, No. 2). However, the structure is very weak and is easily disrupted by small roots (Plate No. 1). Organic matter content in the form of roots and root sloughings is fairly high but appears to be particulate and not intimately associated with the mineral material. The plasma appears peptized or dispersed. There is no apparent difference between the A, Aej, and weak Ae horizons which generally reflect the geologic nature of the weakly developed horizons.

The Ael and Bf horizons of the podzol sequum in the Bisequa Gray Luvisol (Plate VII), by contrast, show distinct pedologic features. The Ael horizon has well developed banded fabric, although the primary fabric within the bands is similar to other A horizons of high ash content (i.e., tending to asepic). Considerable disruption of the structure by root activity is evident. The strong color of the Bf horizon reflects the high iron content and the isoband fabric indicates a stable flocculated plasma. Small pellets of iron, typical for Podzols, may be noted.

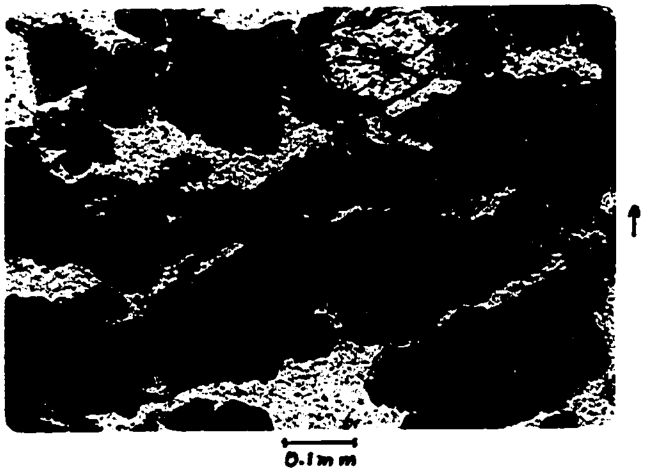
Plate VII shows features typical of the IICkl horizons. No. 3 illustrates secondary carbonate encrustations on large skeletal grains

1

Banded fabric within well defined platy structure.

Ae1 - Bisequa Gray Luvisol
plane polarized light

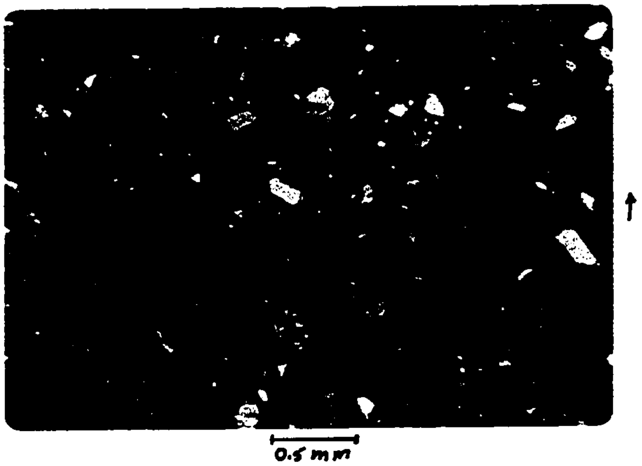
2



Isoband fabric with strong iron-organic staining.

Bf - Bisequa Gray Luvisol
plane polarized light

3

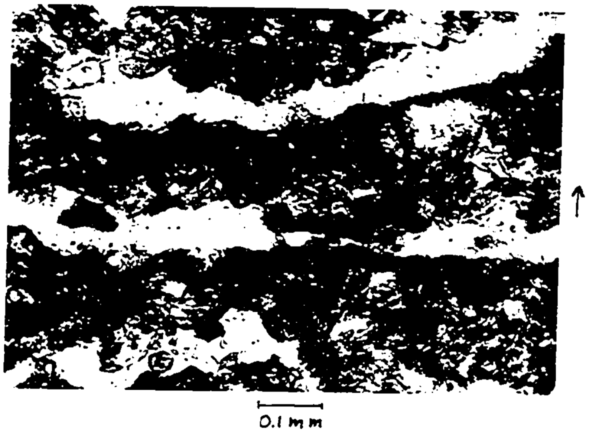


Intertextic fabric with a high content of cryptocrystalline secondary carbonates.

IICk1 - Orthic Gray Luvisol
crossed polarizers

PLATE VII. Photomicrographs of Ae1, Bf and IICk1 horizons.

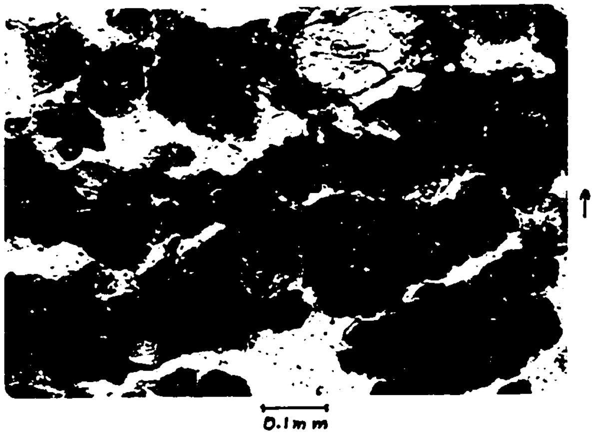
1



Banded fabric within well defined platy structure.

Ae1 - Bisequa Gray Luvisol
plane polarized light

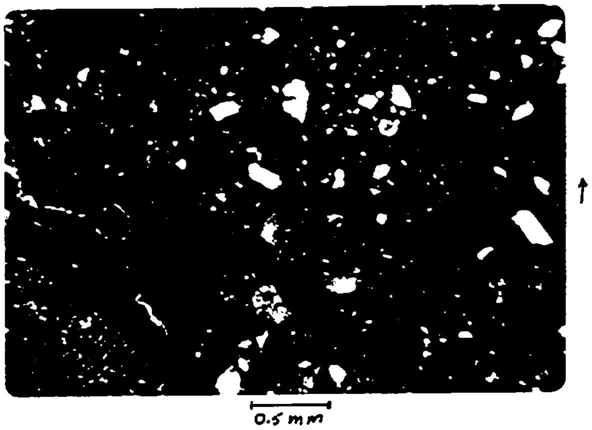
2



Isoband fabric with strong iron-organic staining.

Bf - Bisequa Gray Luvisol
plane polarized light

3



Intertextic fabric with a high content of cryptocrystalline secondary carbonates.

IICk1 - Orthic Gray Luvisol
crossed polarizers

PLATE VII. Photomicrographs of Ae1, Bf and IICk1 horizons.

as well as the infusion of carbonate into the loose flocculated plasma. This horizon has a high porosity and root content. As was the case with the A horizons, this horizon appears to have a high organic content of probable root origin, although it appears to have a higher percentage of more finely divided and possibly more humified material. The secondary carbonates are mainly massive and dark colored with incorporated impurities. De Ment (1962) mentions the occurrence of similar features in Alaska.

3. Investigations into the Nature of Selected Clay Samples

Investigations of the soil landscape units in the field suggested that some of the soils had features which were not explained by the classical approaches. The Luvisolic soils with Bt horizons of high clay content from an uncertain source, fine granular structure and reddish color are an example. Many of the major soil forming processes are at least partially defined in terms of the clay fractions and for this reason a fairly detailed study of the clay fractions was undertaken to provide some insight into the problem. With this in mind three Ae, Bt horizon sequences from Luvisols were selected. For comparative purposes, till and volcanic ash samples, purportedly the parent materials for the soils, were also selected.

The selected samples are listed as follows:

		% Clay		
Sample No.	Horizon	2-0.2μ	<0.2μ	Comments
D6761		4	4	Till
D67Ash		4	1	Volcanic ash
D6884	Ae	6	3	Weakly expressed Orthic Gray Luvisol
D6885	Bt	12	7	
D6797	Ae	9	3	Strongly expressed Orthic Gray Luvisol
D6798	Bt	16	19	
D6719	Ae	8	5	"Bleached" Orthic Gray Luvisol
D6721	Bt	26	12	

The coarse clay (2-0.2 μ) and fine clay (<0.2 μ) fractions were subjected to x-ray, differential thermal, surface area, and several chemical analyses including cation exchange, dissolution, and fusion analyses.

(a) X-ray Diffraction Analysis

X-ray diffraction patterns were obtained for oriented slides of K and Mg saturated clays. The samples were subjected to the following treatments before and after the removal of amorphous materials by NaOH: Mg saturated - air dried and glycolated; K saturated - air dried, heated to 300°C and heated to 550°C.

The following table outlines the criteria used for the x-ray identification of clay minerals.

TABLE IX. Criteria for the X-ray Identification of Clay Minerals

Treatment / Mineral	Mg		K			NaOH	
	Air	Glycol	Air	300°C	550°C	K300	K550
Illite (mica)	10.0[1]	10.0[2]	10.0	10.0	10.0		
Kaolinite	7.1	7.1	7.1	7.1	-		
Chlorite	14.2	14.2	14.2	14.2	14.2		
Vermiculite	14.2	14.2	10-14	10-12	10		
Montmorillonite	14	16-17	10-14	10-12	10		
Interstratified[3]	14	14-28	10-14	10-12	10		
"7-8Å"[4]	7-10	7-10	7-10	7-10	-	7-8	-
Quartz	peaks at 4.26 and 3.34						

[1] d - spacing in Å.

[2] Underlined characters were considered diagnostic.

[3] A variably expanding component of interstratified material.

[4] A component of uncertain identification, possibly Halloysitic.

Figures (6 - 15) illustrate representative patterns for selected samples. Table X gives a summary of the interpretation of the minerals present in the clay fractions.

Illite (mica) is present in all the clay samples. It is lowest in content in the volcanic ash and surface (Ae) horizons, and highest in the till and Bt horizons. Both coarse and fine clays reflect the same character.

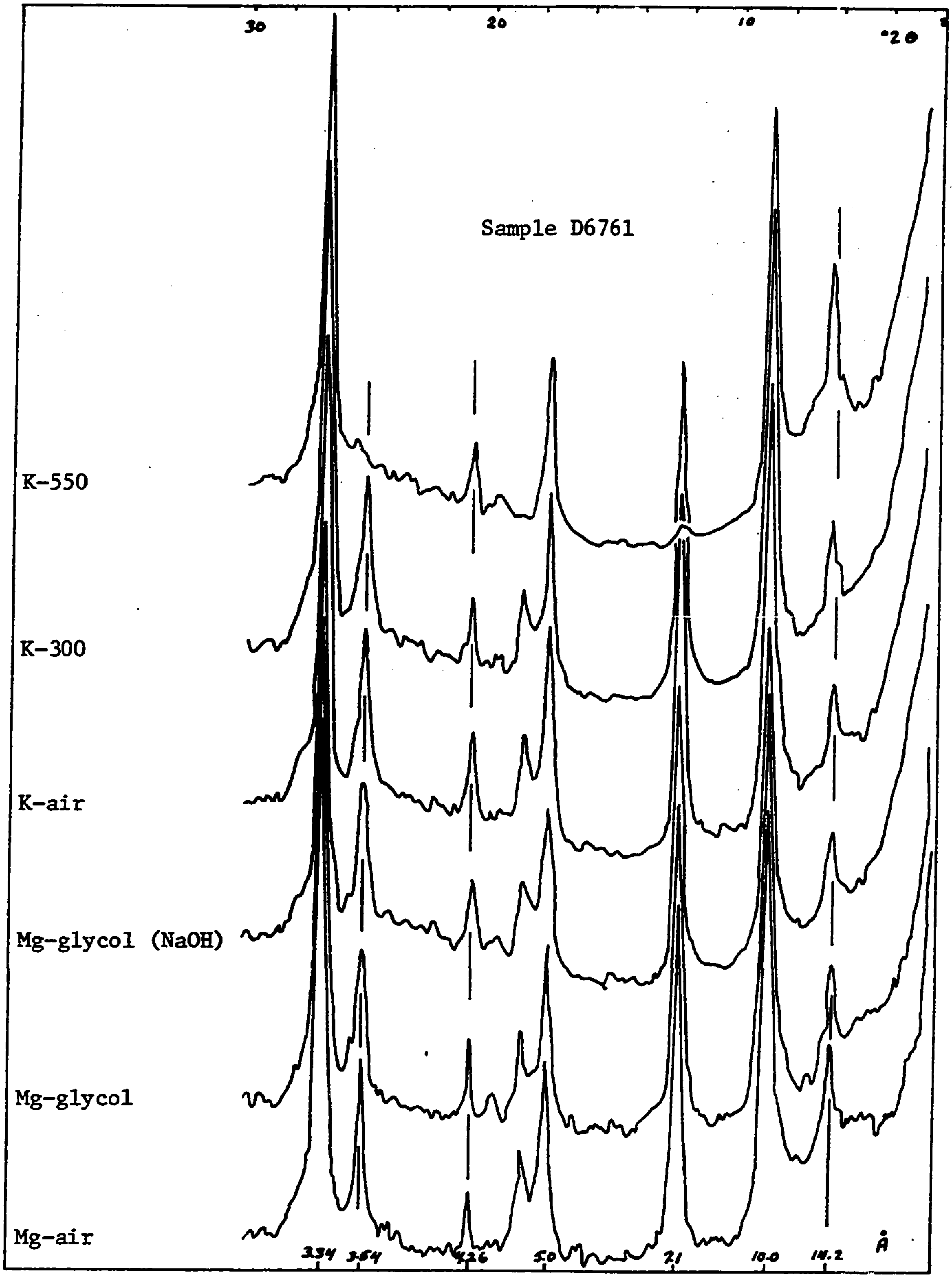


FIGURE 6. X-ray diffraction patterns of the coarse clay (2-0.2μ) fraction of a IICk2 (till) horizon.

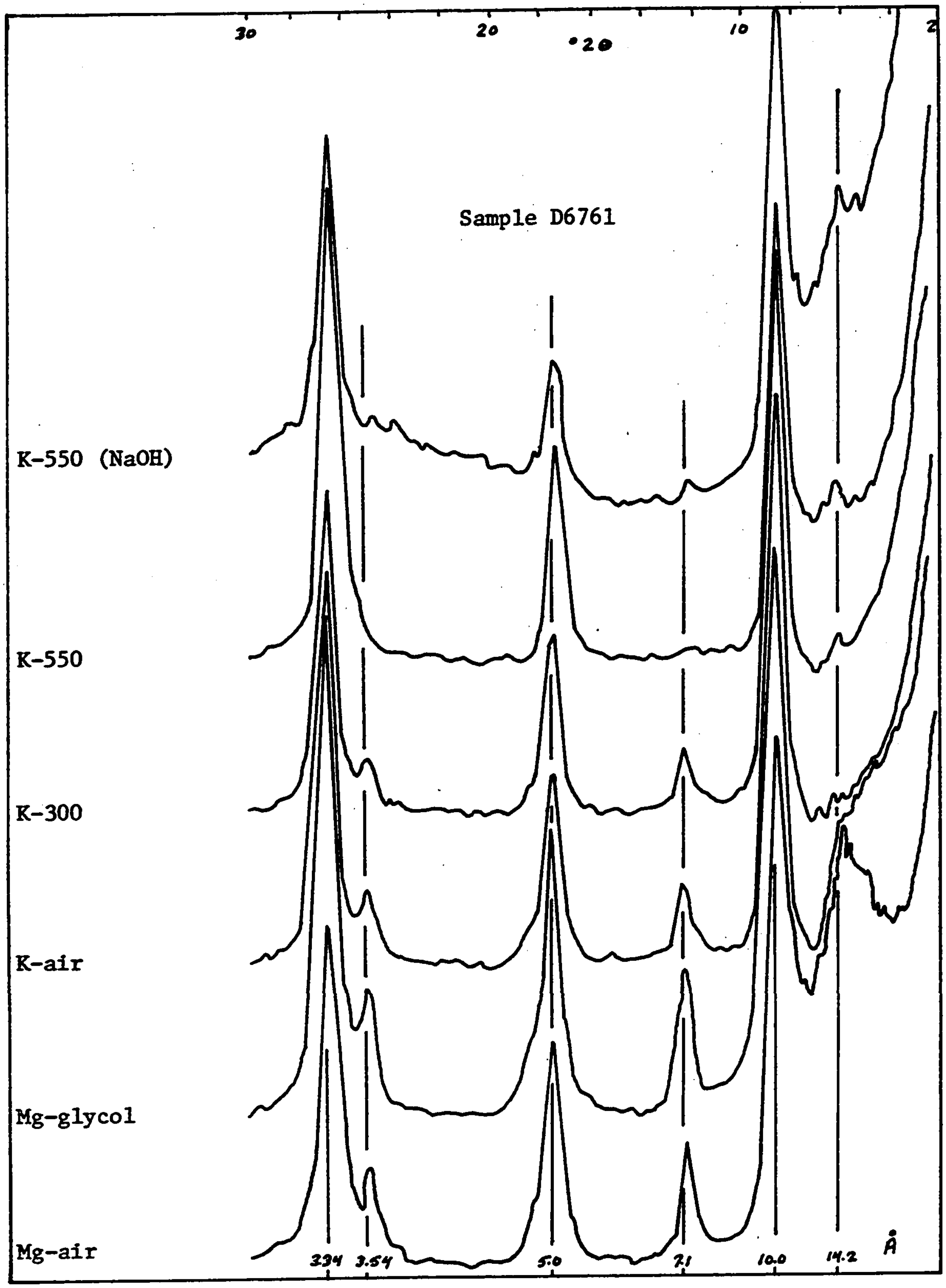


FIGURE 7. X-ray diffraction patterns of the fine clay ($< 0.2\mu$) fraction of a IICk2 (till) horizon.

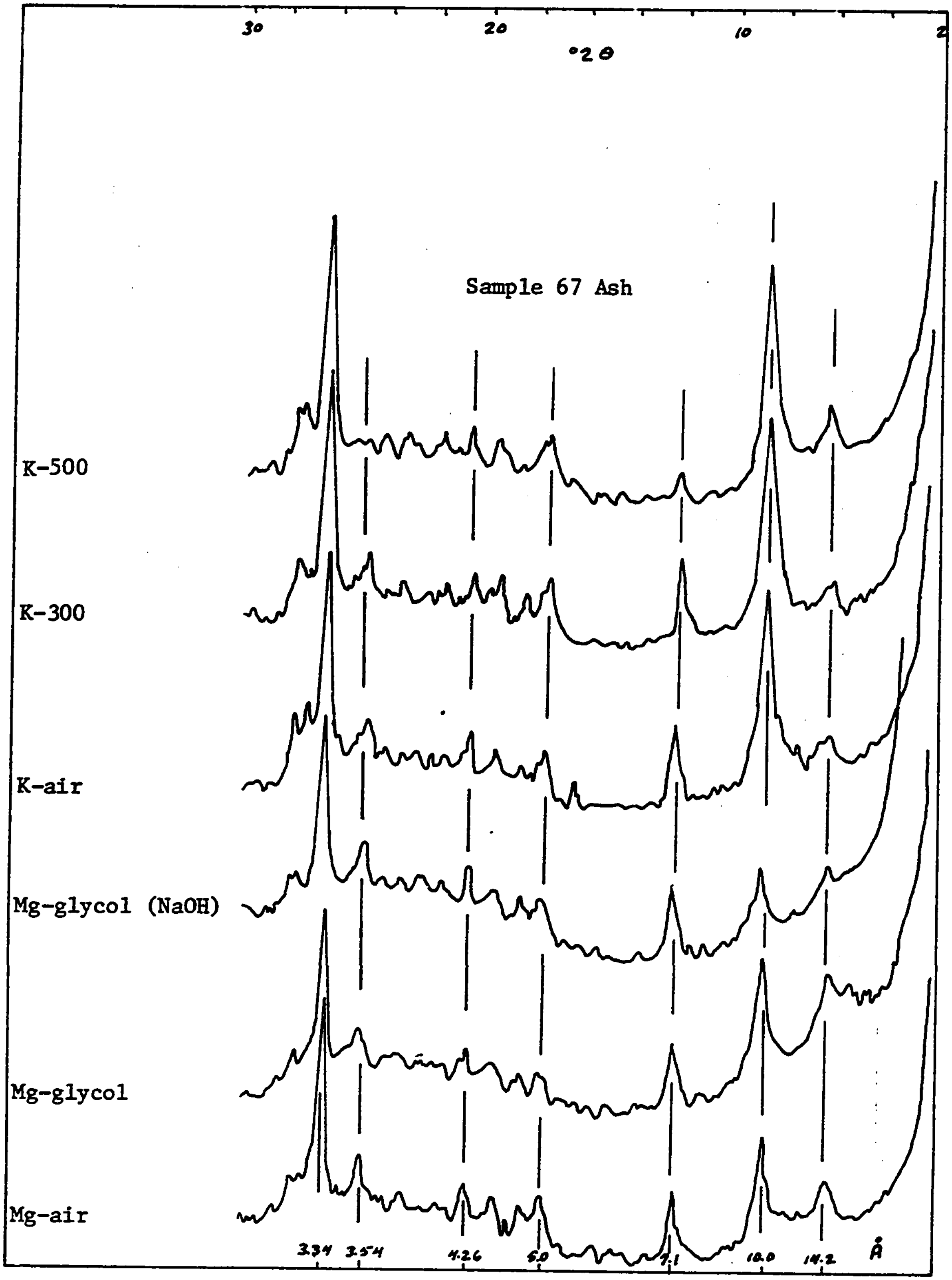


FIGURE 8. X-ray diffraction patterns of the coarse clay (2-0.2μ) fraction of a volcanic ash sample.

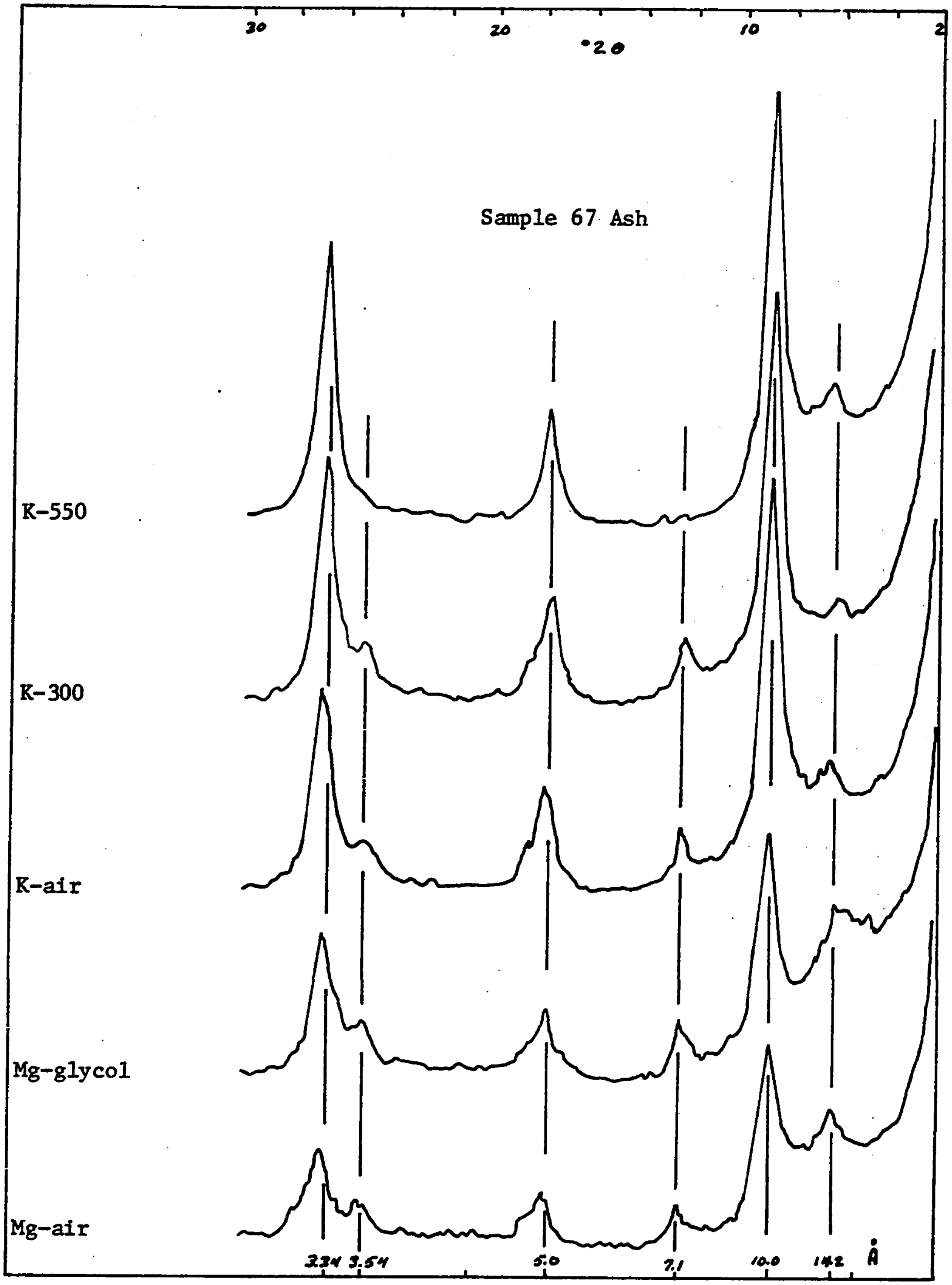


FIGURE 9. X-ray diffraction patterns of the fine clay (< 0.2μ) fraction of a volcanic ash sample.

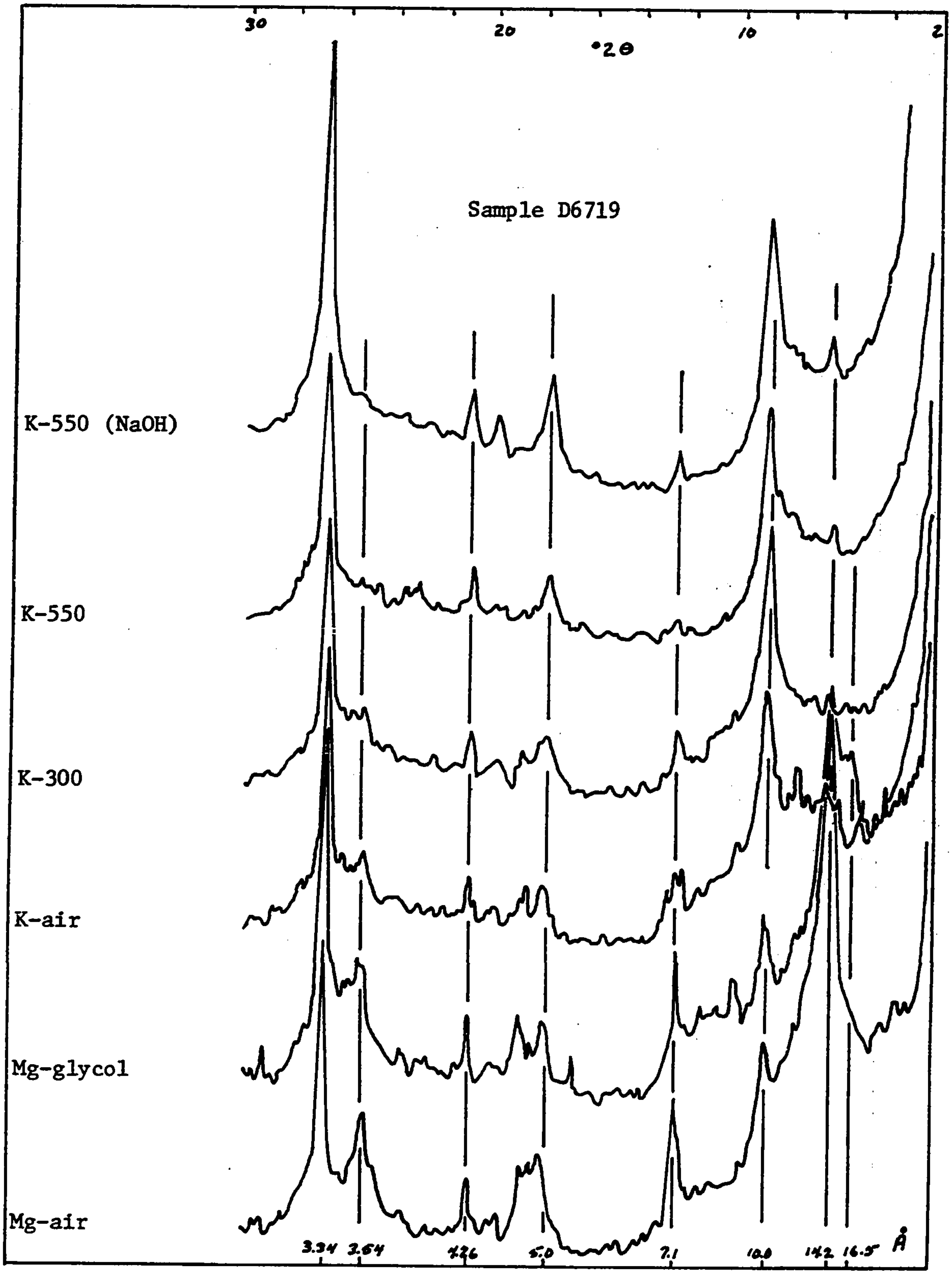


FIGURE 10. X-ray diffraction patterns of the coarse clay (2–0.2μ)fraction of an Ae horizon of a Gray Luvisol.

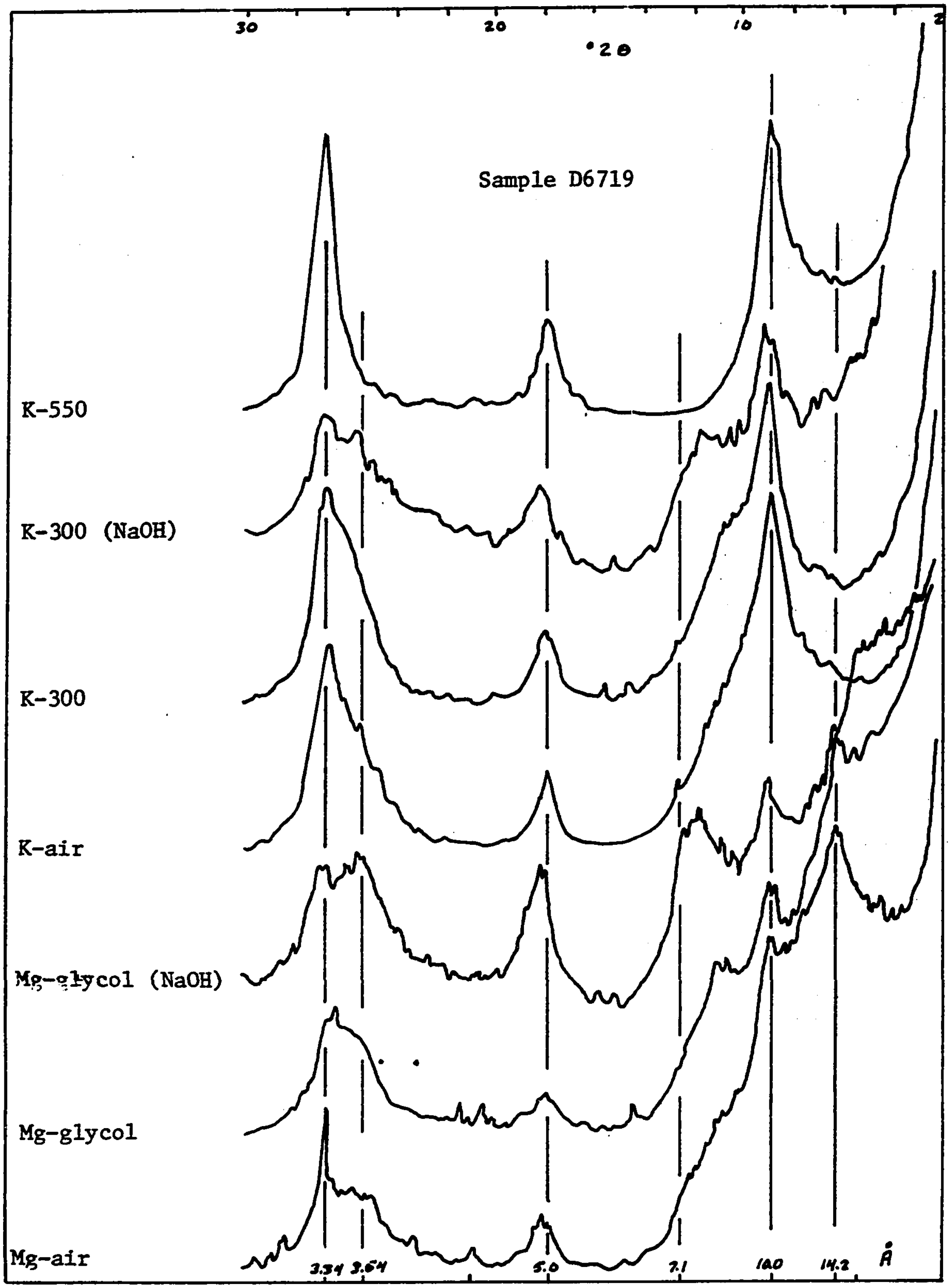


FIGURE 11. X-ray diffraction patterns of the fine clay (< 0.2μ) fraction of an Ae horizon of a Gray Luvisol.

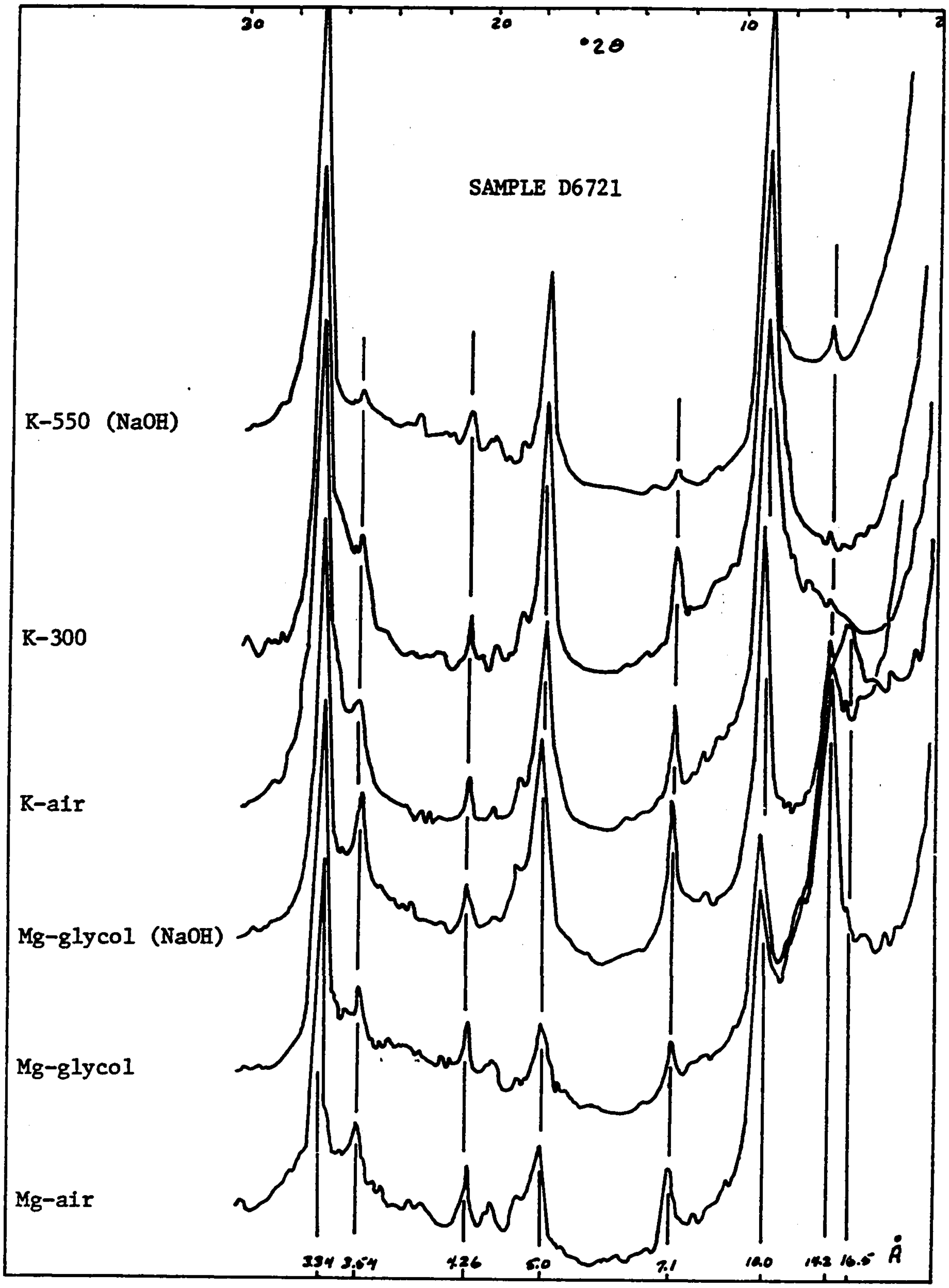


FIGURE 12. X-ray diffraction pattern of the coarse clay (2-0.2μ) fraction of a Bt horizon of a Gray Luvisol.

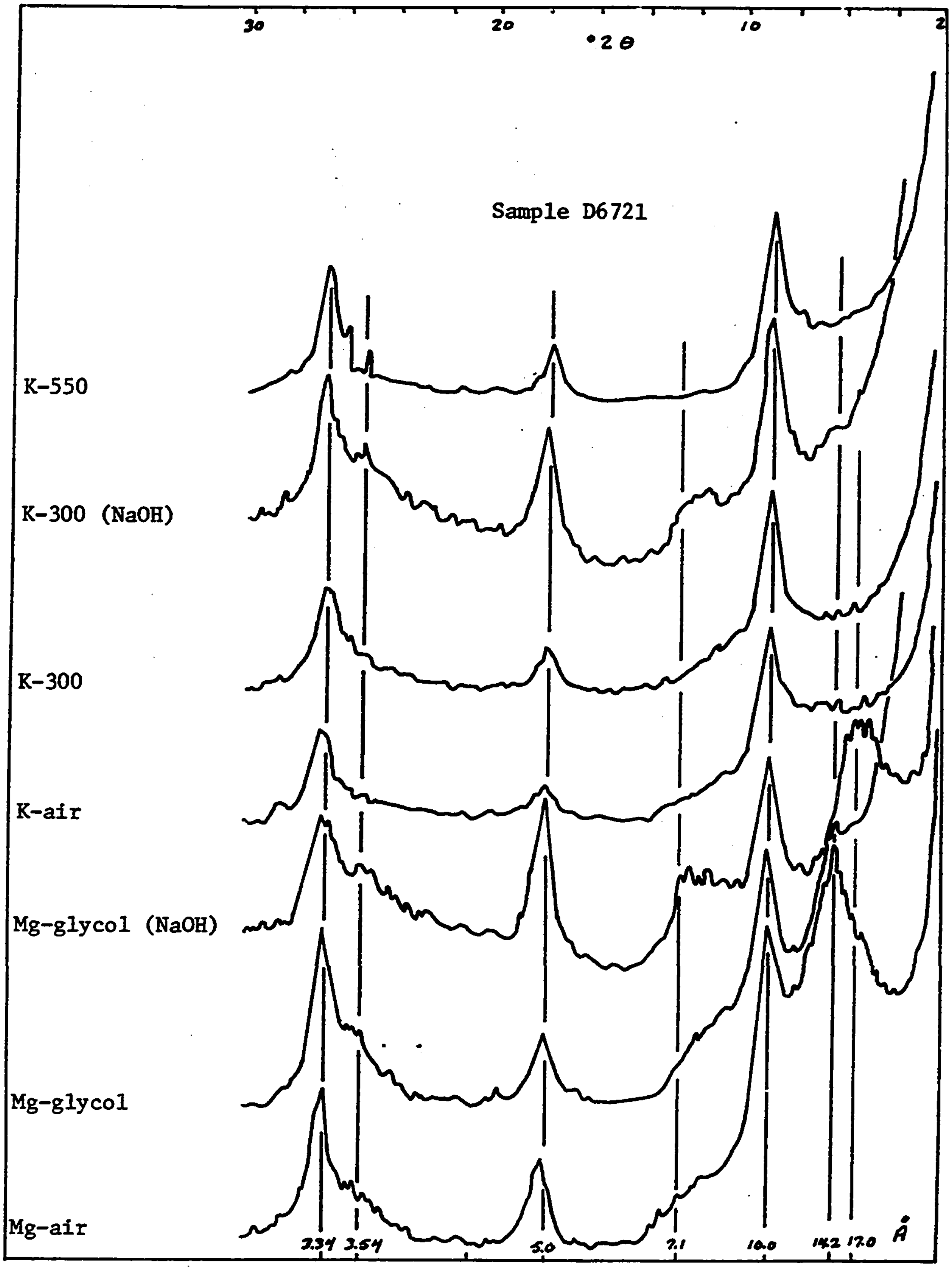


FIGURE 13. X-ray diffraction patterns of the fine clay (< 0.2μ) fraction of a Bt horizon of a Gray Luvisol.

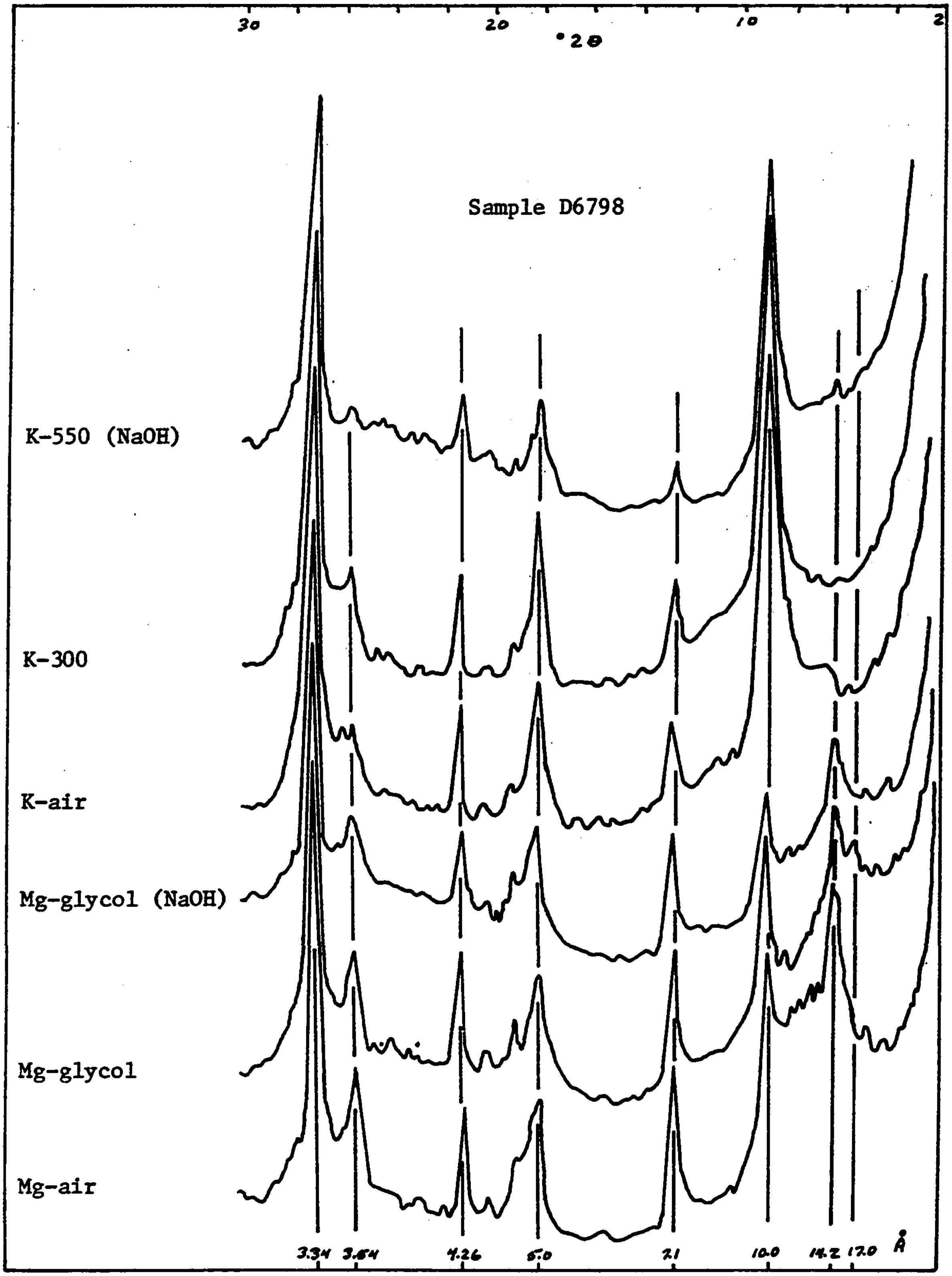


FIGURE 14. X-ray diffraction pattern of the coarse clay (2-0.2μ) fraction of a Bt horizon of a Gray Luvisol.

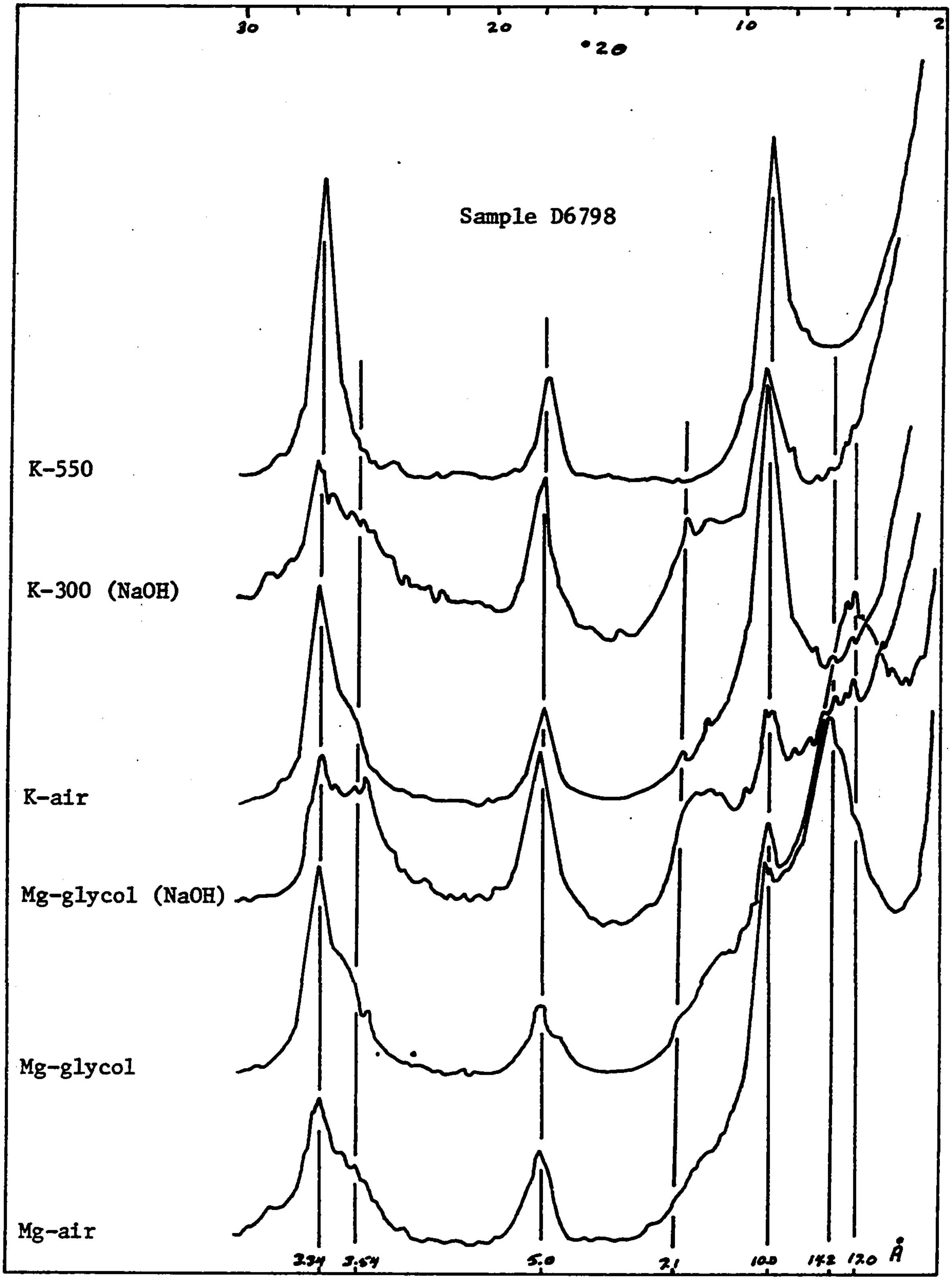


FIGURE 15. X-ray diffraction patterns of the fine clay (< 0.2μ) fraction of a Bt horizon of a Gray Luvisol.

TABLE X. Mineral Species Present in the Clay Fractions of Selected Horizons as Estimated from X-ray Charts

Sample No.	Horizon	Size Fraction μ	Qtz[1]	Ill[2]	Chl (Kaol)[3]	Verm[4]	Mont[5]	Int[6]	7-8 Å[7]
D6761	Till	2-0.2	xx[8]	xxx	xx			x	
		<0.2		xxx	xx	x		xx	
D67Ash	Ash	2-0.2	x	x	xx	x		x	
		<0.2		x	x	x		xx	
D6884	Ae	2-0.2	x	x	x	xx	x	x	x
		<0.2		x		xx	xx	xxx	xx
D6885	Bt	2-0.2	xx	xx	x	xx	xxx	xx	
		<0.2		xx		x	xxx	xxx	xx
D6797	Ae	2-0.2	xx	xx	x	xx	x	xx	x
		<0.2		xx		x	x	xxx	xx
D6798	Bt	2-0.2	xx	xx	x	xx	x	xx	
		<0.2		xx		xx	xx	xx	xx
D6719	Ae	2-0.2	x	xx	x	xxx	x	x	
		<0.2		xx		x	x	xxx	xx
D6721	Bt	2-0.2	x	xx	x	xx	xxx	xx	
		<0.2		xx		x	xxx	xxx	xx

[1] Qtz = Quartz -- from peaks at 4.26 Å and 3.34 Å.

[2] Ill = Illite or Mica -- from 10 Å peak of Mg-glycol sample.

[3] Chl(Kaol) = Chlorite, and possibly kaolinite, from 7.1 and 14.2 Å peaks.

[4] Verm = Vermiculite -- from comparison of 14 Å peak of Mg-glycol and K-air samples.

[5] Mont = Montmorillonite -- from 16.5 - 17 Å peak of Mg-glycol sample.

[6] Int = Interstratified component of indeterminate composition (incl. Mont) -- from comparison of Mg-glycol and K-air (Mg-air) samples.

[7] 7-8 Å = a component most pronounced after NaOH, disappearing upon heating to 550°C -- from K-300 (NaOH) sample.

[8] x = trace (0-10%) xx = minor (10-25%) xxx = major (>25%).

Kaolinite content is difficult to assess from x-ray diffractograms because of the coincidence of the second order peak for chlorite and the first order peak for kaolinite. This is particularly true when a high-iron chlorite is involved since heating to 550°C decreases the intensity of the 7Å spacing for both species (Brown, 1961). It appears, however, from the sharpness of the 7Å peak and its complete collapse upon heating, that there may be some kaolinite present in both clay fractions of the till sample (Figures 6 and 7), and lesser amounts in the other coarse clay fractions. The presence of kaolinite in the ash sample is questionable.

Chlorite is present in rather large amounts in the unweathered till and ash samples, particularly in the coarser fractions. It is also present in the coarse clay fractions but not in the fine clay fractions in samples from the soil sola. The lack of chlorite in the fine clay fractions of the pedogenic horizons might result from weathering.

Vermiculite as a distinct species is most apparent in the coarse clay fractions from the soil sola (Figure 10 - D6719). Its presence in the fine fractions is probably masked by the presence of randomly interstratified expanding clay mineral components. Vermiculite does not appear to be present in the till and ash samples in very significant amounts. Small diffraction peaks between 10Å and 14Å spacings for the K-550 treated clays are evidence for the presence of some vermiculite-chlorite intergrade material.

Montmorillonite is only weakly expressed in the till and ash. As a distinct species it is more prevalent in the finer fractions from the Bt horizons. Even in horizons where its content is highest there appears to be much associated interstratified and poorly organized material as indicated by the width of the peaks (Figure 13 - D6761). In some Ae horizons montmorillonite is present in "mixed layer" structures only (Figures 10 and 11 - D6719).

"Interstratified" or "mixed layer" is the term used to cover clay minerals which show variable expansion upon glycolation. The expansion is random and is expressed as a plateau from 14Å up to 24 - 30Å with perhaps a few small peaks on x-ray diffraction patterns. This type of material is very evident in the fine fractions with a higher content in samples from the soil sola, particularly the Ae horizons, as compared to the "parent materials". The "mixed layer" structure is probably comprised of illite, vermiculite, montmorillonite, and possibly chlorite interstratification.

"7 - 8Å component" is an uncertain quantity. When present it is expressed as a 7 - 10Å plateau which becomes more localized in the 7 - 8Å region upon K saturation and heating to 300°C. This character is more pronounced after NaOH treatment. Upon heating to 550°C the "hump" disappears completely. The 7 - 8Å component is noted primarily in the fine clay fractions of the solum samples with an indication of its presence in the coarse fraction of two of the Ae horizons. It is not present in the till and ash. The characteristics might indicate a halloysitic type of component. It is possible that this component might represent a lower order of some random "mixed layer" structure.

Quartz was estimated from the intensity of the 4.26Å peak. It is a significant component of the coarse clay fractions with the exception of those high in volcanic ash. It was not detected in the fine clay fractions.

The NaOH treatment for the removal of amorphous material altered the diffraction patterns in several ways. There was increased definition of the "7 - 8Å component" and chlorite peaks, and there was a marked decrease in peak intensities for the "mixed layer" structures (Figure 15 - D6798FC). Since K saturation is involved in the procedure, it is possible that much of the expanding material was at least partially collapsed and held against subsequent glycol expansion. There is a further possibility that some of the clay mineral components were removed by the NaOH treatment, but other analyses do not bear this out.

The x-ray diffraction patterns for clays from the till (Figures 6 and 7) show a well crystallized material (sharp, strong peaks) composed essentially of mica, chlorite, and quartz with a minor content of "mixed layer" component. The fine clay differs from the coarse clay fraction mainly in the lack of quartz and an increase in "mixed layer" material. By contrast, the clays separated from the ash have patterns (Figures 8 and 9) which show poor crystallinity with a low clay mineral content (small peaks, and a high background). Mica, chlorite, and quartz are again the principal components in the coarse fraction.

Diffraction patterns for clays from the Ae and Bt horizons indicate fairly well crystallized material. A comparison with the till and ash "parent materials" indicates two major differences. There is a lack of chlorite in the fine clays from the samples of the Ae and Bt horizons and a large increase in amount of expanding components. Generally, the expanding material appears to be rather poorly organized. This is most apparent in Ae horizons (Figures 10 and 11) where broad plateaus rather than well defined peaks are present in the 14 to 24Å region. The Bt horizons, with a narrower grouping of spacings in the 16.5 to 17Å region, appears to be better organized with a much higher montmorillonite content. However, these horizons still contain a large amount of randomly interstratified material.

(b) Differential Thermal Analysis

Representative DTA patterns are shown in Figure 16. The ash material shows an endothermic reaction that suggests a continuous release of water from less than 100°C to about 875°C. This, combined with the lack of prominent peaks indicates a material of poor crystallinity with a highly amorphous component. Samples from the Ae and Bt horizons have strong endotherms at approximately 515°C which are not present in the till or ash. These are believed to reflect the "mixed layer" component of the clay fractions in the sola. If the expanding component is a montmorillonite, the low temperature of the endotherm favors a high iron variety although soil montmorillonites of the beidellite type are reported to have rather low temperature peaks as well (Uchiyama, Masui and Onikura, 1962). These samples also have more pronounced low temperature doublets. These are particularly intense in the finer fractions and presumably reflect the presence of a larger montmorillonitic component. The presence of

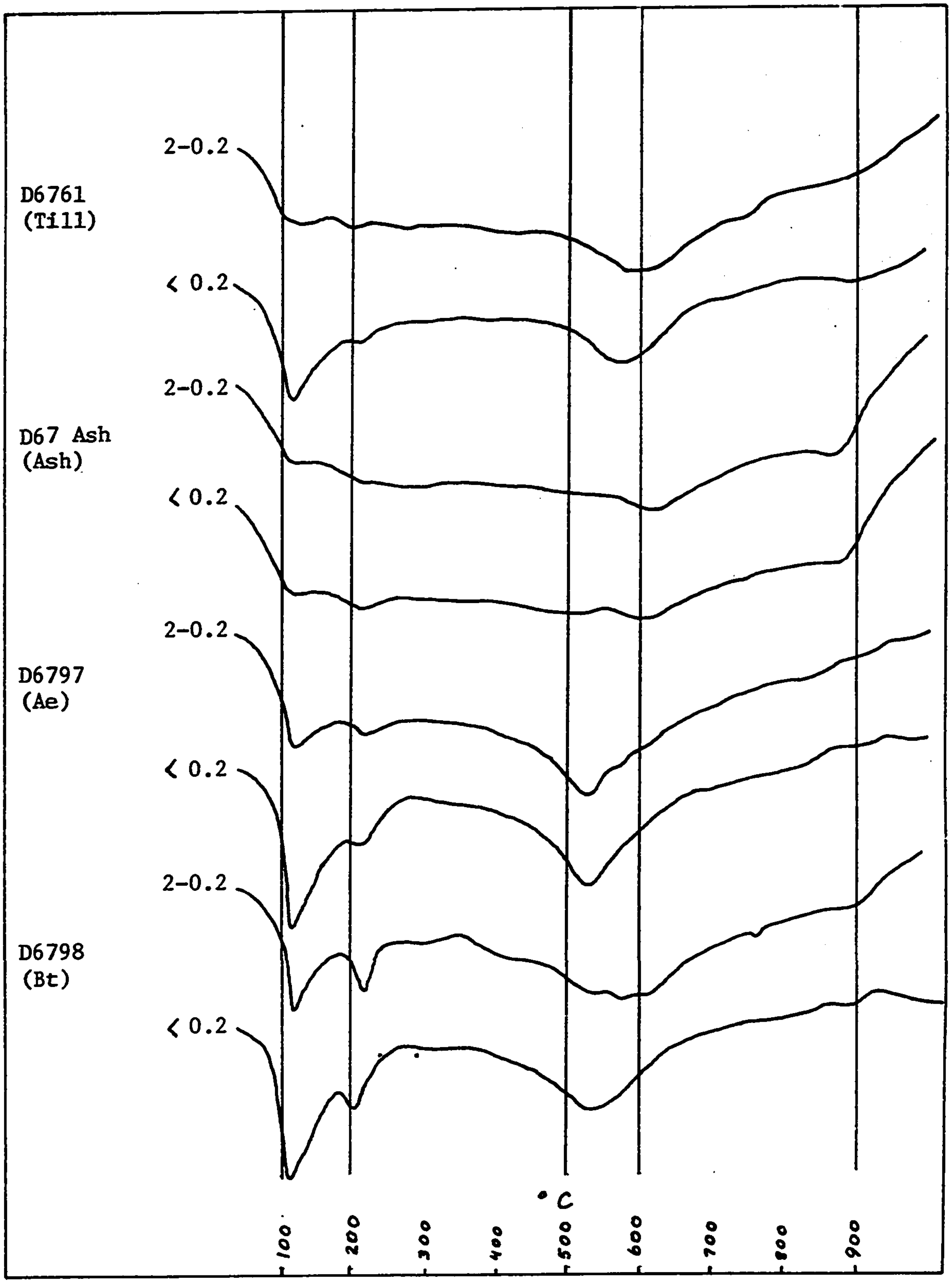


FIGURE 16. DTA patterns of coarse (2-0.2μ) and fine (< 0.2μ) clay fractions of selected samples.

quartz in the coarse clay fractions is indicated by a small endotherm at 575°C (Mackenzie, 1962). The 350°C peak was noted in the coarse clay fractions, particularly after NaOH dissolution. In fact, this was the major difference between untreated and NaOH treated samples which implies that no major crystalline clay component was removed by the treatment.

(c) Surface Area Determination

Surface area measurements (E.G.M.E. method) were conducted before and after the NaOH dissolution of amorphous materials. The results are reported in Table XI.

The surface areas of the coarse clay fraction from the Ae horizons average about 175 m^2/gm and from the Bt horizons about 300 m^2/gm. The respective values for the fine clay fraction are about 550 and 650 m^2/gm. These values are considerably higher than those reported for the till and ash samples and indicate a substantial increase in expanding layer clays and/or amorphous components. The increase in surface areas of clays from the Bt horizons as compared to those from the Ae horizons may reflect the same situation. The higher surface areas for the fine clays as compared to the coarse clays reflects decreased particle size as well as the possibility of a larger expanding clay component. The similarity in values before and after the NaOH treatment for the removal of amorphous components suggests that contribution to the surface area from the amorphous material was not high, and that the differences noted largely reflect differences in the expanding clay components.

TABLE XI. Surface Areas of Coarse (2-0.2μ) and Fine (<0.2μ) Clay Fractions of Selected Samples[1]

Sample No.	Horizon	Surface Area m^2/gm				
		2-0.2μ Fraction		<0.2μ Fraction		
		Sample[2]	NaOH[3]	Sample	NaOH	Amor[4]
D6761	Till	140	128	471	451	-
D67Ash	Ash	108	93	300	274	430
D6884	Ae	193	195	563	586	463
D6885	Bt	352	329	730	763	547
D6797	Ae	169	173	540	584	364
D6798	Bt	232	191	644	620	794
D6719	Ae	159	205	557	574	486
D6721	Bt	338	320	575	607	415

[1] Determined by the ethylene glycol monoethyl ether method.

[2] Untreated sample.

[3] Sample treated with NaOH for the removal of amorphous material.

[4] Surface area of amorphous constituents calculated using difference in S.A. for "Sample" and "NaOH" and % amorphous (Table XII).

Calculation of the surface area for the amorphous material removed from the fine clays suggest an average value of 400 to 500 m^2/gm.

(d) Electron Microscopy

Selected clay samples were investigated with the aid of an electron microscope in order to further characterize the clay fractions. The electron micrographs show that, generally, the 2 - 0.2 μ clay fraction is made up of well crystallized material (Plate IX,No. 1). The particle edges are, in the main, well defined. Some particles, probably mica, exhibit marked cleavage traces while others, possibly chlorite, show internal patterns. Particles with indistinct edges are likely montmorillonite "weathered illite". The fine clays (<0.2 μ) appeared, for the most part, to be rather poorly defined, containing globular masses. These shapes are reported as characteristic for amorphous materials as well as for some soil montmorillonites (Beutelspacher and van der Marel, 1968). Plate IX,No. 2, shows the fine clay of a Bf horizon which is extremely poorly crystallized. Some rod-shaped particles, possibly halloysite, may be noted.

(e) Quantitative Estimates of Individual Clay Components

(i) Amorphous Material. Results of the analysis for amorphous material, as determined by NaOH dissolution, show the till to have a low percentage and the volcanic ash a high percentage amorphous material, with very little variation between the coarse and fine size fractions (Table XII). Obvious differences in amorphous content are present between the coarse and fine clay fractions from the Ae and Bt horizons and presumably reflect pedogenic phenomena. A higher percentage of amorphous Si and Al occurs in the Ae as compared to the Bt horizons. This may reflect stronger weathering in the Ae horizons, the organization of the amorphous material into crystalline structures in the Bt horizons, or a lower ash content in the B horizons. However, mineralogical analysis of the fine sands indicated little volcanic material in these particular solum samples, with the exception of sample D6884, and suggests that the presence of amorphous material in these horizons is primarily a result of weathering phenomena. The SiO_2:Al_2O_3 ratios of the extracted material vary from 3 to 4 which implies that a substance of montmorillonite composition might have been removed by the procedure.

It was noted that some iron was released by the NaOH treatment and a subsequent dithionite extraction removed 1.1 - 2.1 per cent and 2.7 - 5.3 per cent iron (as FeO) from the coarse and fine clay fractions, respectively. The iron was probably associated with the "amorphous" Si and Al as occluded or combined Fe and thus could not be removed by the initial dithionite pretreatment. Amorphous material with a high iron content has been reported as hisingerite (Ingles and Willoughby, 1967).

The SiO_2:Al_2O_3:FeO molar ratios for the extracted amorphous material are reported in Table XII. With reference to the extracted Fe, low quantities of Al were removed from the till and high quantities of Si were removed from the ash. This presumably reflects the types of materials present and it is noted that clay from horizons of higher ash contents (Ae horizons) have proportionately higher amounts of Si extracted. The amorphous material of clay size from the pedogenic horizons and presumably reflect pedogenic phenomena. A higher percentage of amorphous Si and Al occurs in the Ae as compared to the Bt horizons. This may reflect stronger weathering in the Ae horizons, the organization of the amorphous material into crystalline structures in the Bt horizons, or a lower ash content in the B horizons. However, mineralogical analysis of the fine sands indicated little volcanic material in these particular solum samples, with the exception of sample D6884, and suggests that the presence of amorphous material in these horizons is primarily a result of weathering phenomena. The $SiO_2:Al_2O_3$ ratios of the extracted material vary from 3 to 4 which implies that a substance of montmorillonite composition might have been removed by the procedure.

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(ii) Kaolinite plus Halloysite. Table XIII gives the results of the NaOH dissolution determination for kaolinitic type minerals. $SiO_2:Al_2O_3$ molar ratios of 2 to 3 for materials extracted from the clays of the Ae and Bt horizon samples are approximately what may be expected for 1:1 clay minerals.

Higher values for kaolinitic minerals in the fine fractions suggest a halloysitic component as kaolinite is likely to be more prevalent in the coarse fractions (Grim, 1968). This is further substantiated by the fact that halloysite is an often recognized component resulting from the weathering of volcanic materials (Aomine and Wada, 1962) and that the Ae horizons which have a higher volcanic ash content also have a higher content of "kaolinite plus halloysite". The low values for the till suggests that the kaolinite content is indeed low in the soils of the project area.

(iii) Montmorillonite and Vermiculite. The largest amount of expanding clay mineral components is found in the fine clay fractions (Table XIV). Also, the content is greater in the clays of samples from the soil sola than from the ash or till materials. The implication is that pedogenic processes are altering the clay mineralogy and that the result is an increase in expanding type minerals. The greater relative increase is in the vermiculite content, which corresponds closely with increase in degree of profile development.

The apparent concomitant decrease in montmorillonite with increase in vermiculite suggests that the vermiculite may be forming from the montmorillonite. Alumination of montmorillonite to vermiculite (and further to Al-chlorite) is reported for volcanic ash soils in acid weathering environments (Sudo and Kodama, 1957; Masui and Shoji, 1967) and has been suggested as well for Podzols (Dixon and Jackson, 1962; Coen, 1970). Vermiculite is, however, more commonly reported as an intermediary in the illite to montmorillonite weathering sequence (Gjems, 1967; Brydon, Kodama and Ross, 1968; Coen, 1970) and in view of the near neutral pH of the environment it is suggested that vermiculite is probably forming from illite.

(iv) Quartz plus Feldspar. The Pyrosulfate method, as described previously, decomposes the phyllosilicates leaving a residue composed essentially of quartz and feldspars. Kiely and Jackson (1965) suggest a recovery of 96 per cent for quartz and 64 per cent for feldspars in the coarse clay fraction. Assuming a dominance of quartz in the residue the results probably represent a recovery of approximately 90 per cent. The results for the fine clay fractions are less reliable because of decreased particle size and with the results in the 1 to 2 per cent range, all were given a nominal value of 2 per cent.

The results (Table XV) indicate high values for clay from the volcanic ash and low values for clay from the till. The "quartz plus feldspar" contents of the Ae and Bt horizons appear closely associated with the volcanic ash content. X-ray patterns show the dominance of quartz (peaks at 3.34Å and 4.26Å) with accessory feldspar (peaks at 3.24Å, 3.46Å, 3.78Å, 3.93Å, and 4.03Å). Other minerals such as rutile and cristobolite are present in trace amounts. While the ash has the highest percentage of "quartz plus feldspar", diffraction patterns indicate that it is quite poorly crystallized in comparison to the till (Table XV). This suggests that much of the material in the "quartz plus feldspar" fraction from volcanic ash clays is most likely volcanic glass.

(v) Illite. Illite content was determined from data obtained by HF-HCl fusion of the clay samples. The results indicate illite values of approximately 50 per cent for the clay fractions from the till and about 10 per cent for clay from the volcanic ash (Table XVI). The values for illite in the Ae horizons (20 per cent) and Bt horizons (30 per cent) appear to reflect variable mixtures of the till and ash materials. However, previous results indicate that the answer may not be so simple. The B horizons, for example, contain very little fresh ash material. The lower illite content of the B horizons in comparison to the till could be a result of weathering or, more likely, by a dilution effect -- an increase in the percentage of other clays. The illite contents for the Ae horizons, with variable amounts of ash, are probably the result of all the above mentioned factors.

The iron results indicate the relatively large amounts of Fe removed by the NaOH treatment for the more strongly developed Bt horizons (D6798 and D6719). This corroborates the results for amorphous material (part a).

TABLE XII. NaOH Dissolution for Amorphous Material in the Coarse (2-0.2μ) and Fine (<0.2μ) Clay Fractions of Selected Samples

Sample No.	Horizon	Clay Size μ	% SiO_2 [1]	% Al_2O_3	% FeO	$\frac{SiO_2}{Al_2O_3}$ [2]	% Amorphous [3]	% FeO [4]	$SiO_2:Al_2O_3:FeO$ [2]
D6761	Till	2-0.2	2.3	0.5	0.3	8.5	3.0	0.7	8: 1:3
		<0.2	3.3	0.6	0.2	9.4	4.4	0.9	11: 1:3
D67Ash	Ash	2-0.2	14.8	3.3	0.1	7.8	20.0	0.5	93:12:3
		<0.2	12.8	5.3	0.3	4.2	20.0	1.9	21: 5:3
D6884	Ae	2-0.2	12.0	4.2	0.2	4.9	18.0	1.4	27: 6:3
		<0.2	14.0	6.8	0.2	3.5	23.0	2.8	17: 5:3
D6885	Bt	2-0.2	6.6	3.1	0.2	3.6	10.8	1.6	13: 4:3
		<0.2	11.1	6.4	0.3	3.0	18.3	2.4	15: 5:3
D6797	Ae	2-0.2	5.7	3.5	0.1	2.9	10.2	1.2	16: 6:3
		<0.2	13.9	10.0	0.4	2.6	25.4	2.8	15: 7:3
D6798	Bt	2-0.2	3.5	2.1	0.3	2.9	6.2	1.6	7: 2:3
		<0.2	9.9	5.5	0.2	2.9	16.5	2.7	12: 4:3
D6719	Ae	2-0.2	7.3	2.9	0.2	4.3	11.3	1.1	20: 5:3
		<0.2	14.2	7.7	0.3	3.2	24.2	2.9	16: 5:3
D6721	Bt	2-0.2	7.8	3.4	0.2	3.9	12.5	2.1	12: 3:3
		<0.2	12.4	6.1	0.3	3.5	20.3	5.3	8: 2:3

[1] Results are the average of duplicates.

[2] Molar ratios of dissolved material.

[3] % Amorphous $= \frac{\% SiO_2 + \% Al_2O_3}{0.9}$.

[4] % FeO extracted with sodium dithionite following the NaOH treatment.

TABLE XIII. NaOH Dissolution for Kaolinite plus Halloysite in the Coarse (2-0.2μ) and Fine (<0.2μ) Clay Fractions of Selected Samples

Sample No.	Horizon	Size Fraction	% SiO_2	% Al_2O_3	$\frac{SiO_2}{Al_2O_3}$ [1]	% Kaol + Hall [2]
D6761	Till	2-0.2	1.5	1.0	2.5	2.9
		<0.2	4.2	1.4	5.1	3.5
D67Ash	Ash	2-0.2	7.8	2.2	6.0	5.6
		<0.2	4.8	2.6	3.1	6.6
D6884	Ae	2-0.2	5.8	3.7	2.7	10.9
		<0.2	9.6	5.6	2.9	17.4
D6885	Bt	2-0.2	6.2	2.9	3.6	7.3
		<0.2	10.6	4.5	4.0	11.4
D6797	Ae	2-0.2	5.9	4.1	2.4	11.5
		<0.2	8.4	5.9	2.4	16.5
D6798	Bt	2-0.2	4.3	2.6	2.8	7.9
		<0.2	7.3	3.7	3.3	9.4
D6719	Ae	2-0.2	7.3	4.6	2.7	13.7
		<0.2	10.1	6.5	2.6	19.1
D6721	Bt	2-0.2	5.4	2.9	3.2	7.3
		<0.2	7.2	4.3	2.8	13.2

[1] Molar ratios.

[2] % Kaolinite + Halloysite:

(a) molar ratio 2 to 3 -- $$\frac{\frac{\%\ SiO_2}{46.5} + \frac{\%\ Al_2O_3}{39.5}}{2} \times 100$$

(b) molar ratio >3 -- $$\frac{\%\ Al_2O_3}{39.5} \times 100$$

TABLE XIV. Per Cent Montmorillonite and Vermiculite Based on Cation Exchange Analyses of the Coarse (2-0.2μ) and Fine (<0.2μ) Clay Fractions of Selected Samples

Sample No.	Hor- izon	Clay Size μ	Ca/Mg[1] me/ 100 g	K/NH_4[2] me/ 100 g	Amor[3] %	Ca/Mg[4] me/ 100 g	% Verm[5]	% Mont[6]	Total[7] Exp
D6761	Till	2-0.2	21.5	22.0	3.0	12.4	-	13	13
		<0.2	43.8	37.7	4.4	27.7	4	26	30
D67Ash	Ash	2-0.2	21.1	22.7	20.0	13.2	-	-	-
		<0.2	55.5	38.3	20.0	26.2	11	12	23
D6884	Ae	2-0.2	30.9	29.6	18.0	25.3	1	6	7
		<0.2	65.1	50.3	23.0	41.1	10	20	30
D6885	Bt	2-0.2	49.2	43.3	10.8	34.5	4	26	30
		<0.2	76.1	61.4	18.3	50.1	10	34	44
D6797	Ae	2-0.2	30.0	27.3	10.2	24.3	2	11	13
		<0.2	68.3	47.9	25.4	37.3	13	15	28
D6798	Bt	2-0.2	43.0	32.2	6.2	26.5	7	20	27
		<0.2	75.7	51.9	16.5	47.8	16	28	44
D6719	Ae	2-0.2	38.5	29.7	11.3	29.6	6	12	18
		<0.2	67.8	47.9	24.2	44.8	13	17	30
D6721	Bt	2-0.2	47.3	38.7	12.5	31.0	5	20	25
		<0.2	60.5	49.1	20.3	37.3	8	22	30

[1] Cation exchange determined by Ca^{++} replaced by Mg^{++}.

[2] Cation exchange determined by K^{+} replaced by NH_4^{+}.

[3] % Amorphous taken from Table XII.

[4] Cation exchange determined by Ca^{++} replaced by Mg^{++} after NaOH treatment.

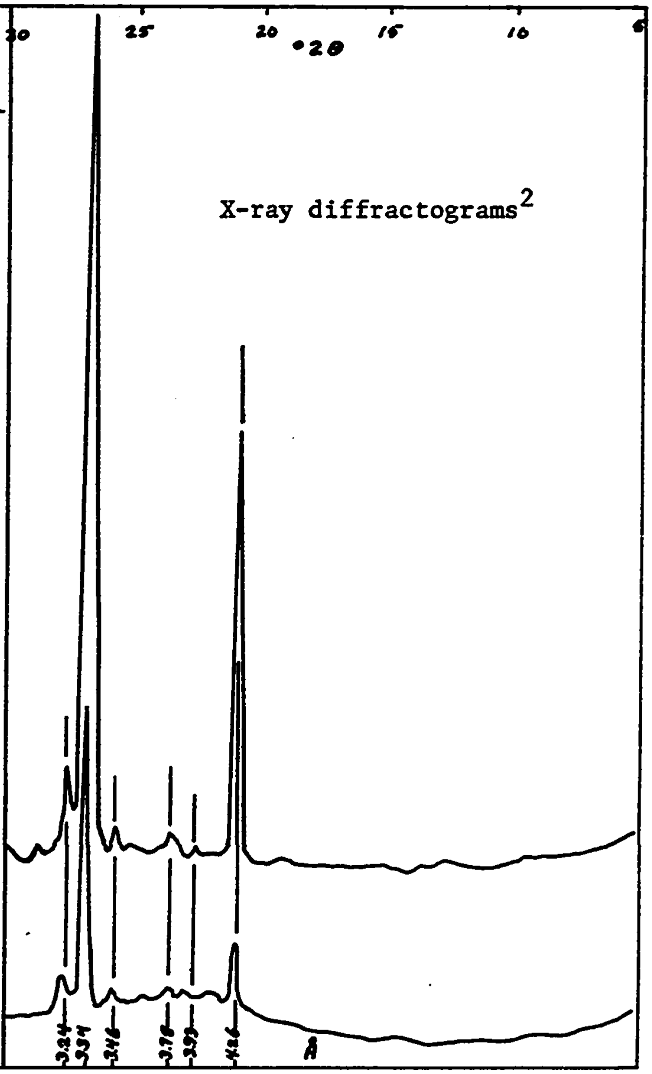
[5] % Vermiculite = [CEC (Ca /Mg) - CEC (K /NH_4)] / 1.54.

[6] % Montmorillonite = [CEC (K /NH_4) - (5 + 105 Amor)] / 1.05.

[7] % Vermiculite + % Montmorillonite.

TABLE XV. Per Cent Quartz and Feldspar Based on Pyrosulfate Fusion

Sample No.	Hor-izon	Clay Size µ	% Qtz + Felds[1]
D6761	Till	2-0.2	18
		<0.2	2
D67Ash	Ash	2-0.2	39
		<0.2	2
D6884	Ae	2-0.2	33
		<0.2	2
D6885	Bt	2-0.2	15
		<0.2	2
D6797	Ae	2-0.2	27
		<0.2	2
D6798	Bt	2-0.2	23
		<0.2	2
D6719	Ae	2-0.2	21
		<0.2	2
D6721	Bt	2-0.2	14
		<0.2	2


X-ray diffractograms[2]

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[1] % Quartz plus Feldspars -- actually includes all material not decomposed by the fusion and NaOH treatments.

[2] X-ray patterns are of slide preparations of residues.

TABLE XVI. Illite and Iron Determination by HF - HCL Fusion in the Coarse (2-0.2μ) and Fine (<0.2μ) Clay Fractions of Selected Samples

Sample No.	Hor-izon	Clay Size μ	Total K_2O %	NaOH[1] K_2O %	S_2O_7[2] K_2O %	Illite[3] K_2O %	% Illite[4]	Total[5] FeO %	NaOH FeO %
D6761	Till	2-0.2	5.81	5.57	0.61	4.96	50	5.90	4.93
		<0.2	6.12	6.37	0.04	6.33	63	6.99	6.20
D67Ash	Ash	2-0.2	4.39	3.74	3.08	0.66	7	3.78	2.59
		<0.2	4.17	4.25	0.57	3.68	37	5.50	3.29
D6884	Ae	2-0.2	3.46	2.73	(1.00)[6]	1.73	17	3.76	3.79
		<0.2	2.12	2.00	(0.04)	1.96	20	8.66	6.75
D6885	Bt	2-0.2	4.25	3.82	(0.65)	3.17	32	6.60	5.47
		<0.2	2.50	2.29	(0.04)	2.25	23	10.95	8.34
D6797	Ae	2-0.2	3.17	2.89	1.04	1.85	19	4.66	3.49
		<0.2	2.77	2.36	0.04	2.32	23	8.36	5.13
D6798	Bt	2-0.2	4.13	4.13	0.66	3.47	35	5.74	3.65
		<0.2	2.92	2.97	0.04	2.93	29	9.69	6.30
D6719	Ae	2-0.2	3.40	2.92	(1.00)	1.92	19	4.41	3.88
		<0.2	2.00	2.02	(0.04)	1.98	20	7.86	5.55
D6721	Bt	2-0.2	4.66	4.18	(0.65)	3.53	35	5.90	4.19
		<0.2	3.40	3.62	(0.04)	3.58	36	10.32	5.29

[1] From fusion after removal of amorphous component with NaOH.

[2] From fusion of the "Quartz + Feldspar" residue of the pyrosulfate fusion.

[3] NaOH-K_2O - residue-K_2O

[4] Based on 10% K_2O content.

[5] Iron calculated as % FeO.

[6] In parentheses not determined, figures taken from D6797 and D6798.

TABLE XVII. Chlorite Estimation from Thermal Gravimetric Analysis of the Coarse (2-0.2μ) and Fine (<0.2μ) Clay Fractions of Selected Samples

Sample No.	Horizon	Clay Size μ	% Weight Loss 300-950°C		Chlorite OH-Water	% Chlorite[3]
			Total[1]	Other Min.[2]		
D6761	Till	2-0.2	4.60	3.56	1.04	8
		<0.2	5.70	5.23	0.47	3
D67Ash	Ash	2-0.2	5.13	2.74	2.39	18
		<0.2	6.57	5.40	1.17	8
D6884	Ae	2-0.2	5.50	4.21	1.29	9
		<0.2	6.16	6.83	-	-
D6885	Bt	2-0.2	6.22	4.89	1.33	9
		<0.2	7.16	6.38	0.78	6
D6797	Ae	2-0.2	5.41	4.03	1.38	10
		<0.2	7.45	6.95	0.50	3
D6798	Bt	2-0.2	4.84	4.60	0.24	2
		<0.2	5.50	6.25	-	-
D6719	Ae	2-0.2	5.39	4.72	0.67	5
		<0.2	6.50	7.20	-	-
D6721	Bt	2-0.2	5.28	4.94	0.34	2
		<0.2	5.70	6.71	-	-

[1] $\frac{\text{Weight loss between } 300^{\circ}\text{C and } 950^{\circ}\text{C}}{110^{\circ}\text{C weight}} \times 100.$

[2] OH-water allocated to other minerals as follows: illite, 4.5%; montmorillonite and vermiculite, 5%; amorphous, 8%; kaolinite and halloysite, 15%.

[3] $\%\ \text{Chlorite} = \frac{\text{OH-water for chlorite}}{0.14}$

TABLE XVIII. Summary of Specific Clay Mineral Determinations

Sample No.	Horizon	Clay Size μ	Qtz[1] + Felds	Ill[2]	Kaol[3] + Hall	Chl[4]	Mont[5] + Verm	Amor[6]	Total
D6761	Till	2-0.2	18	50	3	8	13	3	95
		<0.2	2	63	4	3	30	4	96
D67Ash	Ash	2-0.2	39	7	6	18	0	20	90
		<0.2	2	37	7	8	23	20	97
D6884	Ae	2-0.2	33	17	11	9	7	18	95
		<0.2	2	20	17	0	30	23	92
D6885	Bt	2-0.2	15	32	7	9	30	11	104
		<0.2	2	23	11	6	44	18	104
D6797	Ae	2-0.2	27	19	12	10	13	10	91
		<0.2	2	23	17	3	28	25	98
D6798	Bt	2-0.2	23	35	8	2	27	6	101
		<0.2	2	29	9	0	44	17	101
D6719	Ae	2-0.2	21	19	14	5	18	11	88
		<0.2	2	20	19	0	30	24	95
D6721	Bt	2-0.2	14	35	7	2	25	13	96
		<0.2	2	36	13	0	30	20	101

[1] Qtz + Felds = % quartz plus feldspars.

[2] Ill = % illite.

[3] Kaol + Hall = % kaolinite plus halloysite.

[4] Chl = % chlorite.

[5] Mont + Verm = % montmorillonite plus vermiculite.

[6] Amor = % amorphous material.

(vi) Chlorite. Results for the thermal gravimetric analysis for chlorite are given in Table XVII. The values are only approximations and results for some of the duplicate samples were variable.

Chlorite values are higher in the coarse clay fractions, and generally more chlorite is present in the "unweathered" parent materials than in the sample from the soil sola. High values for the Ae horizons reflect the high chlorite content in the ash materials present in these horizons. The decrease in chlorite content with increasing profile development suggests a weathering sequence associated with morphological expression.

(vii) Summary of Quantitative Estimates of Clay Minerals. Quantitative estimates for component distribution in the clay fraction are given in Table XVIII. The sum of individual components ranges from 88 to 104 per cent, with the Ae horizons and ash being lower (88 to 98 per cent) and the Bt horizons higher (96 to 104 per cent). The proximity of the totals to 100 per cent suggests that the determinations for individual components are valid within reasonable error.

(f) Summary of Clay Mineral Analyses

There is general agreement between the x-ray interpretations and the analyses for individual clay components (note Table X and Table XVIII), although specific results may be at variance for a number of reasons. For example, the x-ray interpretations consider quartz alone while the quantitative estimates include feldspars and volcanic glass as well.

The higher values for "kaolinite plus halloysite" in the fine clay fractions coincide with the better expression of the "7 - 8Å component" in the x-ray studies. This is further support for the presence of halloysite. The presence of kaolinite suggested by the x-ray diffraction patterns is not supported by the chemical or DTA analyses. This means that the prominent 7Å diffraction peak represents mainly chlorite and while chlorite results from the two methods correspond quite well, the x-ray data suggest higher contents than do the thermal gravimetric results.

The increase in content of "mixed layer" material in the samples from the soil sola is not as marked from the data for cation exchange measurements as in the x-ray diffraction patterns. This may be explained by the inherent difficulty in obtaining even approximate estimates of "mixed layer" components that are randomly interstratified and produce no definite diffraction peaks. The montmorillonite components show similar trends in both sets of results, but estimates for vermiculite content appear unrelated. The results from the two methods are not directly comparable because of the interstratification implications. For example, 10 per cent vermiculite present in an interstratified complex with montmorillonite, illite, and possibly chlorite could be missed entirely in the interpretation of x-ray diffractograms. The x-ray results show definite increases in montmorillonite in the B horizons which supports the case of illite as the source for vermiculite.

The determination of amorphous material by NaOH dissolution is empirical but inferences drawn from other analyses can significantly add to the characterization of this component. The surface area results, for example, indicate that the amorphous component has values of 400 to

500 m^2/gm. This is in the same range as results reported for weathered montmorillonite (Higashi and Aomine, 1962). The molar ratios for Si:Al in the dissolved material are also similar to those for montmorillonite. The similarities to montmorillonite are probably fortuitous because the DTA results indicated that no crystalline material was removed by the NaOH treatment. The fact that iron was in some way complexed with the amorphous material may imply some degree of organization of the constituents, although a random distribution of Si, Al, and Fe oxides and hydroxides is probably more realistic. In any event, it is not difficult to imagine this material crystallizing into a montmorillonite type of clay mineral, particularly in an environment with an abundant supply of bases.

General Discussion of Soil Formation

Soil Forming Factors

The gross contribution of several factors are recognized in the development of soils in the study area. The major factors are parent material, vegetation, climate (and wind), and slope.

The very high carbonate content in the majority of the parent materials severely limits the depth of pedogenic development. This is apparent from the very shallow nature of the profiles and from the fact that, generally, the sola are developed from overlying depositional material with only the lower B horizons extending into the underlying calcareous materials. In colluvium and wash materials, and where soil mixing has occurred, this relationship is more difficult to define but the shallowness of the profiles persists. In one area a Podzol was encountered on a non-calcareous fan which may indicate that the presence of carbonates favors the lessivé rather than the podzolic process.

The principal vegetative changes from forest to grassland and parkland, and to the alpine, relate well with changes in soil character. The "prairie" soils are characterized by dark colored surface horizons with a high humus content, which reflects the large additions of organic matter to the surface by the grass vegetation. Under pine and spruce forest the surface horizons have much less organic matter and are brown in color or appear eluviated. Minor vegetative species often indicate site characteristics, such as humidity, which is reflected in the soil. For example, the presence of arnica is usually associated with the presence of Bt horizons. However, relationships between soil and gross forest character are not strongly apparent since the vegetation generally reflects fire history rather than soil (and climatic) conditions. One anomaly is the occurrence of Gray Luvisols on some of the scree slopes and barren ridge crests where tree cover is extremely sparse and suggests that the forest was somewhat expanded in the past.

The climatic parameters of humidity and temperature are strongly modified by aspect and elevation. Both vegetation and soils reflect the cooler, more humid climate on the north and east facing slopes as compared to the south facing slopes. Lusher undergrowth indicates that humidity and/or precipitation efficiency also increase with elevation and distance from the center of the valley.

A climatic parameter of major importance is the effect of the valley winds. There are several aspects which may be recognized. First is the desiccating effect of the wind through its influence on evaporation and transpiration. Second is the effect of valley air currents in determining the direction of minor disturbances such as thunderstorms. Storms following side valleys are seemingly cut off or diverted along the edges when entering the main valley. A third contribution of the wind is its role as an agent of deposition. Although not directly a climatic factor it undoubtedly is important in soil formation in this environment. Burial phenomena are particcularly apparent on the lower fans. Not only does loessial deposition continually bury existing soils and alter weathering patterns but in this area its calcareous nature results in a constant recharge of calcium carbonate which suppresses pedogenic development. The greater calcareousness of the L-H horizons and upper 1 to 2 cm of the sola are evidence of this phenomenon. The dominance of any particular aspect of the wind's influence is difficult to determine because all are interrelated and the maximum expression of each would coincide. Soil patterns reflect the effect of wind as well as other climatic parameters. The areas of poorly developed soils coincide with areas where the valley winds are most prominent. This appears to be a desiccation effect as site humidity increases with distance from the center of the valley. However, carbonate recharge may be important as well. These are important factors in the complexity of wind phenomena apart from its effect on such features as tree throw and its limitation of vegetation on exposed scarps.

Slope is a soil forming factor of great importance in mountain areas. It is obvious from the field investigations that soils must be on stable materials to achieve maximum morphological expression. In other words, the "climax" soil at any location is directly dependent on the slope and the degree of mass wasting. Slope has classically been considered a passive factor in soil formation, but it would seem that, in mountainous areas at least, the active correlative of slope - mass wasting - should be emphasized since it influences the transfer of energy in the soil mass.

Processes of Soil Formation

Factors of soil formation, singly or in combination, control the processes active in soil development. Or, to be more precise, they control the relative dominance of a certain process or group of processes. By process is meant basic pedogenic actions such as additions, removals, transfer or transformation of matter within the soil system (Simonson, 1959).

Individual soil profile features such as the presence of a Bt horizon indicate something about the processes active in that profile, and the totality of soil features reflects the interplay of all the processes active on a soil.

1. Discussion of Profile Characters

(a) C Horizons

The IICk1 horizons have features which make them quite distinctive from horizons above and below. There are no properties that are similar to those of the overlying B horizons so it would appear that the processes active in the IICk1 are peculiar to that horizon. The mineralogy of the fine sands and clays indicates that IICk1 and IICk2 horizons are of similar composition. Thin section studies show that the IICk1 has a very loose, porous structure as compared to the IICk2 horizon which is extremely compact with less than 1 per cent void space in the pseudostructural units. It is also evident that the organic matter source is primarily roots and root remains. Tree roots cannot penetrate very deeply (about 20 cm) into the extremely calcareous, compact till and so spread laterally near the surface. The till, because of its lack of binding clays, and possibly the softening from partial solution of some of the binding carbonate cements, breaks into a very loose material near the surface.

Micromorphological investigations show a large content of secondary carbonates in the IICk1 horizon which indicates an influx of calcium carbonate from above, a reorganization of carbonate within the horizon, or both. The implication is that this horizon is a Cca horizon, although it cannot be identified as such in the field.

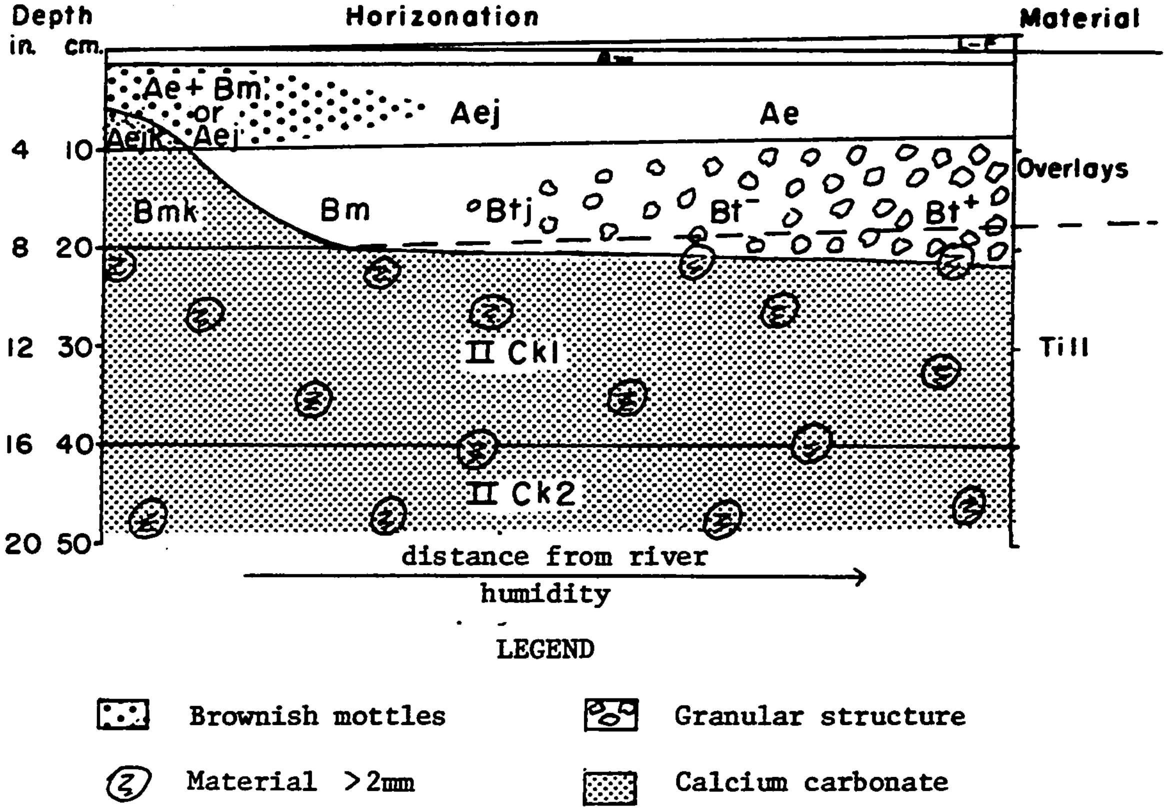
(b) Soil Sola

On the basis of field observations difficulty was experienced in differentiating the pedologic and geologic contributions to horizonation. Mineralogy of the fine sands confirms the geologic stratification in these horizons with the A horizons having the highest volcanic ash content and the B horizons the lowest. Evidence suggests that the B horizons formed first and were subsequently covered by an ashy aeolian deposition. The uniformity in depth of the surface materials overlying

B horizons of varying development supports this argument.

It is also true, however, that variations in B horizon, and in some instances Ae horizon, development can be related to the moisture regime at the site. As one moves away from the North Saskatchewan River in the Siffleur Wilderness area the micro-climate appears to increase markedly in humidity. The profile sequence encountered may be depicted diagrammatically as follows:

Diagrammatic Representation of the Soil Sequence
Calcareous Degraded Eutric Brunisol to Orthic Gray Luvisol



It appears that closer to the river there is less effective leaching and/or constant addition of carbonate materials. The loessial overlay is generally a little thicker close to the river, indicating the possibility of more or constant wind deposition, and site humidity is definitely low in this area. The result, as shown, is a soil of weak development which contains free carbonates in the solum.

A feature which is very characteristic of the initial or weakly developed soils is the presence of reddish mottles in the surface horizons. This is believed to indicate weathering of material with release of iron where leaching is insufficient to remove the released constituents. The high pH and presence of free lime would markedly lower the mobility of iron thus released. The fact that the B horizons under the mottled Ae horizons do not have significant increases in plasma also supports the concept of a weakly leaching regime.

As conditions become progressively more humid carbonates are removed from the solum and the mottles become fewer and are positioned lower in the Ae horizons. At the Degraded Eutric Brunisol stage the mottling has disappeared and the B horizons are more strongly colored and may have a slight increase in clay content. It appears that increased precipitation removes the carbonates and initiates the downward translocation of liberated iron, and other colloids, into the B horizon. There is at this stage a thin L-F layer which yields organic acids and greatly increases the efficiency of the percolating water for the translocation of soluble and colloidal constituents down the profile.

The Gray Luvisol stage is the next step in the sequence. The B horizons now have sufficient clay to be classed as Bt horizons. Along with the increase in plasma is an increase in the development of distinct structure. From the Degraded Eutric Brunisol stage to the Luvisol stage the major solum change is in the character of the B horizon while little modification is noted in the Ae horizons. There is also an increase in the thickness of L-H horizons concomitant with site humidity and profile development.

The above sequence generally fits the concepts for a lessivé soil sequence. A possible exception is the mottling in the A horizons. Rieger and Juve (1961) describe similar mottling in a podzol development sequence on aeolian material in Alaska. This suggests that the podzolic processes are also active.

The next stage in soil development recognized in Canada (Stobbe, 1952; N.S.S.C., 1968) results from the advance of the podzolic process on the lessivé soils. This involves the development of (Bm) or (Ae, Bf) horizons in the Ae horizons of Gray Luvisols. These types are found in the most humid locations on the benches -- at the base of east and northeast facing slopes. Field evidence for the presence of free oxides (horizon color and pebble coatings) was corroborated by laboratory analyses, thereby confirming the activity of podzolic processes of soil formation. A feature common to these soils and to the closely associated Orthic Gray Luvisols is the redness of the Bt horizons (7.5 YR 5/6 d). This feature reflects the release of rather large amounts of iron during weathering of the surface material with a volcanic ash component, and subsequent translocation into the B horizon. In view of the geologic stratification evident, in situ weathering is also a possibility. It appears that in this environment there is a close association of the podzolic and lessivé processes.

The close association of the two major processes is also apparent in the transition from Bisequa Gray Luvisol to Humo-Ferric Podzol found on the upper mountain slopes (as discussed earlier). The change in dominance to the podzol process with increasing elevation and associated climate and vegetation differences is identical with that suggested by Duchaufour (1965). It appears that Podzols are the dominant climax soils in the subalpine zone at elevations in excess of 1,800 m (6,000 ft. A.S.L.) when the soils are developed on calcareous parent materials. On non-calcareous materials the podzol process may dominate under conditions which may be slightly warmer and less humid and under less acidic vegetation such as found at lower elevations (for example, on the benches).

2. Discussion of Clay Fraction Studies

From previous results it appears that the sola of the profiles are made up of a mixture of materials from two major sources, till and volcanic ash. Loess components other than volcanic ash are present, and may even predominate, but the ultimate source for this aeolian material is likely the same source as the till, if not the till itself. Any changes in the mineralogy of the solum materials when compared to the till and volcanic ash should reflect pedogenic phenomena.

The differences between A and B horizons has been pointed out, but the indicated initial parent material disconformities make direct weathering relationships within and between soils difficult. However, inferences can be made. For example, there are inferred age differences between the A and B horizons which further imply different stages of weathering.

The most significant change noted in the clay fractions of the solum samples when compared to the "parent materials" is the increase in expanding material. This may be a result of:

1. A mica degradation sequence such as that of Ross and Mortland (1966),

$$\begin{tikzcd}
 & \text{vermiculite} \arrow[r] & \text{montmorillonite} \\
\text{mica illite} \arrow[ur] \arrow[dr] & & \\
 & \text{interstratified material} &
\end{tikzcd}$$

2. Degradation of other primary soil minerals such as chlorite and vermiculite (Gjems, 1967; Zvereva, 1968),
3. Synthesis from amorphous weathering products (Masui and Shoji, 1967), or
4. Some combination of the above.

There is a possibility of chlorite and/or vermiculite acting as precursors to montmorillonite. Wildman _et al._ (1968) report an iron montmorillonite forming directly from serpentine. However, there is not enough of these minerals to account for the increase in montmorillonite.

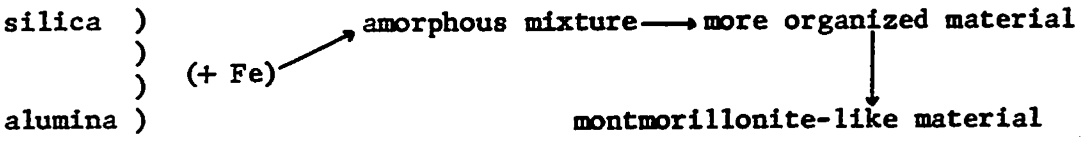
Although the possibility of syntheses of clay minerals does not seem probable in view of the present near neutral pH of the system, there is some evidence to support this. A ready source for Si, Al, and Fe is present in the easily weatherable volcanic ash, and possibly chlorite breakdown as well. The presence of amorphous material has been demonstrated and its similarity in chemical composition to montmorillonite noted. An abundance of calcium and magnesium completes the chemical prerequisites for montmorillonite synthesis. A study in Japan (Kanno, Onikura, and Higashi, 1968) suggested that more ordered structures evolve from the amorphous weathering products of volcanic materials, and several persons (Besoain, 1969; Chichester _et al._, 1969) have suggested that montmorillonite can form directly from these weathering products. The randomness of the interstratified expanding components in the material studied and its poor crystallinity, suggest the presence of montmorillonite synthesis. If there is indeed synthesis, then "aging" should result in better crystallinity and more definite structure, as possibly exemplified by the Bt horizons.

Montmorillonite synthesis may contribute significantly to the total clay component, but it appears that much of the "mixed layer" expanding component could be a result of mica degradation. Güven and Kerr (1966), studying the breakdown sequence of mica, published x-ray charts with broad plateaus and suggest that a continuous scattering in the lower angle reflections shows a random insertion of different groups of atoms between the mica layers. (This does not eliminate the possibility of amorphous to poorly organized material taking up interlattice positions.) A highly weathered montmorillonite reported by Higashi and Aomine (1962) also showed similar features. However, the removal of amorphous material by NaOH resulted in a sharp 17Å (montmorillonite) peak which was not the case in the present study. The differences may be due to the fact that the above mentioned report is concerned with weathering or breakdown sequences while in the present case it might be a result of formation. The degradation of illite to form montmorillonite has been reported in several instances in the Ae horizons of Podzol soils (Gjems, 1962; Kodama and Brydon, 1968; Zvereva, 1968).

Another possibility in this environment is that montmorillonite material could have been blown in with the other aeolian material. Coen (1970) concluded that dust was the source of montmorillonite in some Podzols in New York.

It should be noted that the above-mentioned montmorillonite formation took place in very acid environments, generally below pH 4.5. The particular environment under study has by contrast a neutral to slightly acid reaction. This implies that either the soils were in past or are periodically subjected to acid leaching, or that another process(es) must be found. Birkeland (1969) suggests that, in the Sierra Nevada Great Basin, montmorillonite has been formed authigenically in a region of low precipitation (about 20 cm annual) and neutral pH. Where leaching is more intense he suggests that halloysite is the clay mineral formed. Similar sequences have been reported for volcanic ash soils (Besoain, 1969). The situation might be similar to that suggested by Jackson (1965) where montmorillonite is formed in any basin analog where the leaching of Si, Mg, Al, and Fe is restricted.

One process which fosters alumination (desilication) is the hydrolysis of feldspars and glass which can result in the accumulation of Al in even alkaline media (Jackson, 1965). Where the products are not removed possibility for the following crystallization sequence exists:



It appears that montmorillonite formation can take place under a variety of conditions, from a variety of sources, and through several mechanisms, with mica degradation being more strongly pronounced under more acidic podzolizing conditions.

In the formation of Luvisolic soils in Canada and the Lessivé soils in Europe the emphasis is on clay movement without destruction or synthesis (Fridland, 1958; St. Arnaud and Mortland, 1963; Duchaufour, 1965), although Parfenova and Yarilova (1959) suggest that synthesis might be a factor. It is generally felt that chemical weathering in the northern Great Plains of North America has not been pronounced (Ehrlich and Rice, 1955; St. Arnaud and Mortland, 1963; Pettapiece, 1964). This is probably due, in part at least, to the generally high base status of the soils. Chemical weathering of coarser mineral fractions and alteration of clay minerals has been reported in Alberta (Pawluk, 1960b) but in no instance has montmorillonite formation been implied in Luvisol formation. The implication is that in the soils under study, processes not usually associated with the formation of Luvisolic soils are active.

Besoain (1969) notes that the weathering of volcanic ashes in regimes having a deficit of moisture and rich in basic cations favors the formation of 2:1 type minerals. There is a possibility then that the unusual clay mineral suites may be explained in part by the particular geologic nature of the material -- the presence of volcanic ash.

It appears that a combination of several processes are indicated by the clay mineral study. Clay formation, a feature not common to Luvisolic soils, by in situ weathering and synthesis, is evident in the soils under study.

Hypothesis of Soil Formation

The previous discussions have covered some of the factors and processes of soil formation in this particular mountain valley environment. The following is an attempt to assimilate the findings into a single hypothesis of soil formation for the area.

All of the soil characteristics cannot be accounted for by using geologic or pedogenic considerations alone. A pedogenic approach would have to presuppose a single period of overlay deposition which has been shown not to be the case. On the other hand a purely geologic origin cannot be valid because the time involved (6,000 to 10,000 years) would preclude some pedogenic weathering. The answer then appears to be a combination of the two approaches.

The last major deglaciation phase probably dates at about 10,000 years B.P. (Richmond, 1965; Rutter, 1965; Westgate and Dreimanis, 1967). This left the large valley features, the scoured walls and benches probably much as they are today. The majority of the fans, and some aeolian material on the benches were subsequently added. About 6,600 years B.P. the well documented Mazama Ash fall occurred (Westgate and Dreimanis, 1967). This material was retained on stable surfaces, such as the benches, particularly in sites out of the effect of valley winds. The next 2,500 years or so were warmer and drier -- the Altithermal (Heusser, 1956; Richmond, 1965). During this time there may have been in situ weathering of the surface material but, with the high carbonate content in the underlying material and the low precipitation, eluviation was probably limited. Assuming that from 4,000 to 2,500 years ago conditions prevailed that were much as today, the valley climatic patterns would also be similar and weathering would be greater near the valley walls and particularly at the base of east, northeast, and north facing slopes (this would also apply to the Altithermal period). These sites would then have the most highly weathered and strongly developed soils while in the drier sites pedogenic weathering and clay formation would be less pronounced. This may be thought of as a conditioning period with the leaching of carbonates from the immediate surface and the beginning of primary mineral weathering.

About 2,500 years B.P. another series of ash falls, from British Columbia and Washington, occurred (Westgate and Dreimanis, 1967; Westgate, pers. comm.). This fall was about 10 cm in thickness in the study area and quite uniform over much of the benches. It was much less uniform on the lower fans which are more susceptible to wind action. The cycle of weathering started over again. This time, however, because the previous cycle had already lowered the base status, it could proceed more quickly. The more humid sites would be doubly endowed because of the greater pre-conditioning of the first cycle as well as the relatively greater present weathering rate. A lower base status could develop in the surface deposit and podzolic process including release of iron might occur. Iron, as well as released Si and Al ions, and "neo-clays" might be washed into the previously weathered "B" horizons further augmenting its clay content and also imparting to it a strong reddish color. In the maximal situation a podzol forms in the upper deposit (Bisequa Gray Luvisol). As site humidity and weathering intensities decrease the soil sequence passes through well developed to weakly developed Gray Luvisols, to Degraded Eutric Brunisols, and in the most arid sites, to the calcareous Degraded Eutric Brunisols. This reflects an extreme range in soil characteristics within the confines of a relatively small area, from soils exhibiting strong pedogenic development to those whose features are dominantly controlled by the lithology of the deposit. It may be noted that those locations of strongest soil development also coincide with sites least affected by valley winds which have a strong influence upon both the degree of desiccation and the deposition of calcareous materials.

So far the discussion has centered on the relatively stable bench forms. The central valley location of the lower fans, for example, may be considered as a distinctive environment. This landform is continually under the influence of the valley winds. The aridity of the sites and the continual deposition of calcareous material result in soils which are calcareous to the surface and weakly developed. The presence of free lime and aridity combine to retard weathering processes to the extent that the accumulation of organic matter masks most other effects. This is most pronounced on the well grassed, low angle fans of the Whiterabbit and Two O'clock Creek areas (Kootenay Plains) where thick very dark Ah horizons have built up. These areas are very close to river level (less than 10 meters) and so receive more aeolian material than do those areas farther removed from the source. Farther from the river, usually under a light forest cover, there is less overlay and less grass growth. Here the soil sola are thinner and browner in color. The fans above the benches are much less stable and the materials show little, if any, signs of soil formation beyond some darkening of the surface.

The lower mountain slopes are also characterized by unstable conditions. Glacial debris plastered against the rock combined with scree and other debris is being continually shifted by mass wasting. This colluvium during stable periods develops horizonation but subsequent movement fosters disruption and truncation.

At high elevations the cooler, moister climate, and possibly a less calcareous material, results in a more acid weathering regime and the podzolic process becomes dominant to the exclusion of the lessivé process. At the treeline the podzol processes become weaker, probably because of coldness (and possibly saturation without leaching), and acid or Dystric Brunisols result. These in turn give way to turfy soils under the grasses and herbs of the alpine vegetative community.

Classification Implications

1. Luvisol Problem

The Gray Luvisol soils as considered in the Canadian classification system are soils with an Ae, Bt, C horizon sequence. They presumably develop in a single cycle of soil development through the overall process of lessivage. It is generally implied that chemical weathering is not severe and that clay formation and destruction are negligible.

The soils in the project area having an Ae, Bt, C horizon sequence were classed in the Luvisolic Order. However, if the observations, discussions, and hypotheses as expressed in this thesis are valid, several problems arise. Both the hypothesis of two weathering cycles being involved, and the evidence for clay formation indicate a genesis quite different from that usually associated with luvisolic soils. The lessivé process appears to be active but it is not responsible for the entire development of the Gray Luvisols. It appears that several processes, including some connected with "podzolization", are involved.

2. Regosol Problem

Several different kinds of soils fall into the general category of Regosols. The differences are quite apparent in the field and because of their genetic associations with landform they are readily mappable. It was for these reasons that Regosols were recognized and separated at a level below that of subgroup as defined by the National Soil Survey Committee (1968).

The Orthic Regosol I is possibly the central concept of the Orthic Regosol subgroup. It is a soil of very little development. The Orthic Regosol II, as described, consists of disrupted soils. These soils are subject to profile disturbances to the extent that only portions of horizons are recognizable. It is felt that this type might be separated at the subgroup level as is done in the American classification (Supplement to soil classification system, 1967). The terms "Ruptic" or "Turbic" are suggested.

Orthic Regosol III is a rather specific soil, found only on steeply sloping exposed scarps. It has an Ah(k), AC(k), C horizon sequence and it is characterized by an organic matter content which decreases regularly with depth.

Orthic Regosol IV is also a soil of the A, C type with regularly decreasing organic matter content. It is a rather thin (5 to 15 cm) soil, formed under grass and found on the intermediate and low angle fans where accretion is not pronounced and there are no buried horizons. The organic matter distribution in Regosol types III and IV necessitates their classification as Orthic Regosols, even though they would seem to be more closely associated with other soils of the Ah, C type which, because they contain buried horizons, are classed as Cumulic Regosols. It seems that the concept of the "Deorcic" Regosol, suggested in 1965 (N.S.S.C., 1965), with the emphasis on morphology rather than process, would circumvent the problem.

Cumulic Regosols, as the name implies, are soils developed under the influence of accretion. Cumulic Regosol I is the kind found in the "plains" areas close to the river level where it appears that wind is the principal factor affecting accretion. There A, C soils have thick, dark, non-chernozemic Ah horizons and grade to Orthic Regosol IV. As discussed above, it appears that the strict application of the present Regosol classification results in the separation of very similar soils. Cumulic Regosol II accomodates those soils where accretion results from falling rock -- the talus soils. This type also encompasses a portion of the scree soils, others grading to Orthic Regosol IV and some to rubble and Lithosols.

3. Lithosol Question

As in any mountain area there are many instances where less than 10 cm of unconsolidated material overlies rock. This material often supports plant growth and contributes to the total energy cycle at the surface of the earth and should therefore be considered as soil. These very shallow soils grade to rock debris and rock on one hand and to Lithic Regosols on the other. Lithosols and/or other very shallow soils, such as Rendzinas, are recognized in many classification schemes (Kubiena, 1953; Ugolini and Tedrow, 1963; Uziak, 1963; FAO, 1964; Aubert, 1968) with no depth criteria used to separate a soil from a non-soil. It appears that the arbitrary separation of a soil from a non-soil by a depth criterion of 10 cm is untenable, and it is suggested that a "Lithosol" division should be considered for the Canadian classification system.

SUMMARY AND CONCLUSIONS

In summary, the soils of the North Saskatchewan River Valley in the Front Ranges of the Rocky Mountains are comprised dominantly of Orthic Gray Luvisols and Degraded Eutric Brunisols on the benches, Cumulic and Orthic Regosols and Calcareous Eutric Brunisols on the fans, and Orthic Regosols on the steep slopes. Also on the slopes are many soils associated with rock. Podzolic soils occur near tree-line with Alpine soils above, but these have a very limited distribution in the area studied.

The majority of soils are developed from an aeolian overlay with two definite periods of deposition implicated in the polygenetic soils on the benches. Soils on the fans adjacent to the river are characterized by little more than the addition of organic material, but with increasing distance from the center of the valley, and increase in elevation, pedologic weathering and profile differentiation become increasingly pronounced.

Some of the more important features governing soil formation in the area are: (1) the high carbonate content of much of the material which retards weathering and restricts the depth of pedologic activity, (2) the valley winds which strongly influence microclimate and are an important agent of deposition, (3) the high volcanic ash content in the almost continuous layer of loess which influences surface soil character and weathering phenomena, and (4) the activity of mass wasting and its disruption of soil materials.

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APPENDIX

APPENDIX A

Soil Descriptions and Characterization Analyses

Methods

The soils were described in the field and the principal types were sampled by horizon for analysis. The samples were air dried, passed through a 2 mm sieve and stored in jars. The greater than 2 mm fraction was collected and reported as per cent by weight. The following analyses were conducted:

Particle Size Distribution: The pipette method, as modified by Toogood and Peters (1953) was used.

Bulk Density: The "rubber-balloon method" employing a Soiltest Volumeasure was used.

Soil Moisture: 15 atmosphere and 1/3 atmosphere (1/10 atm for samples of >70 per cent sand) moisture percentages were determined following the pressure membrane and pressure plate methods outlined in U.S.D.A. Handbook 60 (1954).

Soil Reaction: pH values were determined by glass electrode pH meter: (1) on saturated soil paste, and (2) on 0.01 M $CaCl_2$- soil mixtures (Peech, 1965).

Total Nitrogen: A macro-Kjeldahl method modified from Jackson (1958) to include a commercially available catalyst of HgO, $CuSO_4$, and K_2SO_4 (Kel-pak) was used.

Total Carbon: The method used was a dry combustion procedure utilizing an induction furnace. CO_2 evolved was determined gasometrically with a Leco Model 577-100 carbon analyzer.

Calcium Carbonate Equivalent: A manometer procedure using a Smolik calcimeter (Bascomb , 1961) was employed.

Organic Carbon: This was determined by difference from total carbon and calcium carbonate equivalent.

Exchangeable Cations and Cation Exchange Capacity: Exchangeable cations were extracted with N ammonium acetate, pH 7. Na and K were determined by atomic absorption spectroscopy and Ca and Mg were determined titrimetrically using E.D.T.A. Cation exchange capacity was determined by the replacement of adsorbed ammonium by N NaCl followed by distillation of the extract.

Free Iron and Aluminum: Two methods were used: (1) the acid ammonium oxalate method (McKeague and Day, 1966), and (2) the citrate-dithionite method (Mehra and Jackson, 1960). Iron was determined by atomic absorption spectroscopy and aluminum colorimetrically using aluminon.

Soil Sample Sites Reported

Site No.	Soil Type	Sample No.	Analysis Reported
1.	Humo-Ferric Podzol	D6730-36	x
2.	Degraded Dystric Brunisol - Humo-Ferric Podzol	D6740-42	
3.	Bisequa Gray Luvisol	D6790-96	x
4.	Orthic Gray Luvisol (bleached)	D6716-22	x
5.	Orthic Gray Luvisol	D6797-101	x
6.	Orthic Gray Luvisol		
7.	Orthic Gray Luvisol	D6883-87	x
8.	Degraded Eutric Brunisol	D6870-75	
9.	Degraded Eutric Brunisol	D6756-61	x
10.	Degraded Eutric Brunisol		
11.	Calc. Degraded Eutric Brunisol	D6707-09	
12.	Calc. Degraded Eutric Brunisol	D6787-89	
13.	Calc. Eutric Brunisol	D6762-65	x
14.	Calc. Brunisol	D6703-06	
15.	Alpine Brunisol		
16.	Orthic Regosol IV - Calc. Eutric Brunisol	D67264-265	x
17.	Orthic Regosol III	D67105-106	x
18.	Orthic Regosol IV		
19.	Cumulic Regosol I	D6737-39	x
20.	Cumulic Regosol I	D6766-70	
21.	Cumulic Regosol I	D67102-104	
22.	Cumulic Regosol II	D6728-29	
23.	Gleyed Regosol		
24.	Rego Gleysol		
25.	Volcanic Ash	D67Ash	x

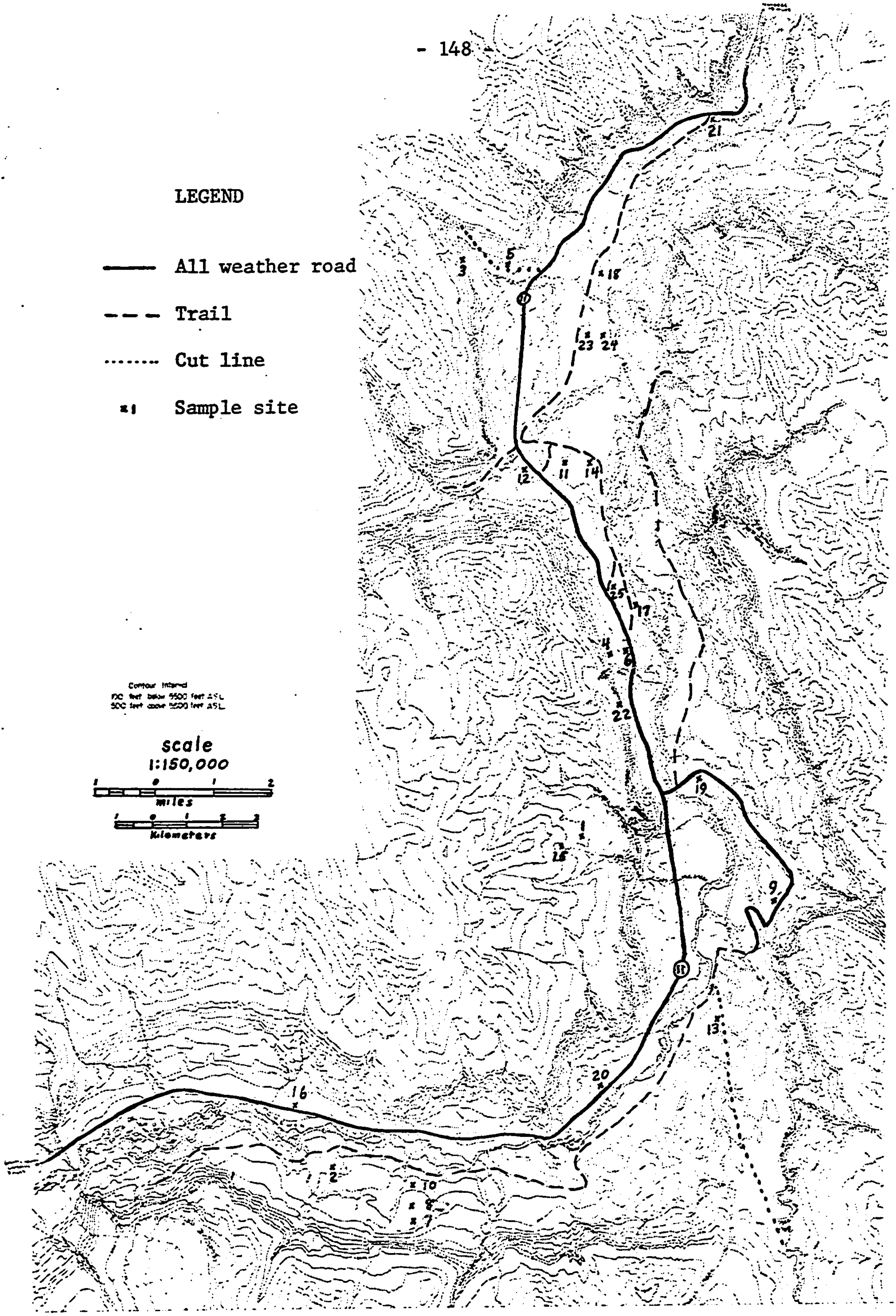

FIGURE 17. Access and Sample Location Map.

Soil Descriptions and Analytical Results

Alpine Humo-Ferric Podzol (Site 1)

Topography: 25% N.E. facing slope.

Elevation: 1,900 meters (6,300 ft.).

Vegetation: Immature spruce forest with *Vaccinium scoparium*, *Cassiope tetragona*, *Equisetum spp.*, and mosses.

Drainage: Well drained.

Parent Material: Colluvium from till with a silty overlay.

Horizon	Depth (cm)	Description
L-H	4-10 cm	Needles and moss.
Ae	0- 2	Light brownish gray (10 YR 6/2 m[1]); coarse silt loam; slightly acid; boundary[2] sharp and wavy to:
Bfh	2- 4	Dark brown (10 YR 3/3 m); coarse silt loam to loam; slightly acid; boundary gradual and wavy to:
Bf	4 -12	Yellowish red (5 YR 4/8 m); silt loam; neutral; boundary diffuse to:
Bm	12-20	Strong brown (7.5 YR 5/6 m); silt loam; neutral; some stones; boundary gradual to:
IIBCk	20-28	Dark brown (10 YR 3/3 m); gravelly sandy loam; weakly calcareous; boundary gradual to:
IICk	28-33+	Grayish brown (2.5 Y 5/2 wet); stony loam; strongly calcareous.

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[1] Munsell color notation.

[2] Boundary terms are descriptive only.

TABLE AI. Characterization Analyses of an Alpine Humo-Ferric Podzol

Sample No.	Depth cm	Hori- zon	PHYSICAL: Particle size distribution (mm) % of <2mm: sand 2-1	1-0.5	.5-.25	.25-.1	.1-.05	Total	silt .05-.002	clay <2u	<0.2u	> 2mm %	Moisture retention % 1/3 atm.	15 atm.	Bulk dens. gm/cc	S.G.separat. of FS (%) <2.50	>2.95
D6730	6 cm	L-H															
D6731	0- 2	Ae															
D6732	2- 4	Bfh															
D6733	4-12	Bf															
D6734	12-20	Bm															
D6735	20-28	IICk1															
D6736	28+	IICk2															

Sample No.	CHEMICAL: pH H_2O	$CaCl_2$	Organic matter %C	C/N	$CaCO_3$ equiv. %	Exchange analysis meq/100 gm H	Ca	T.E.C.	(Fe + Al) % Dith.	Oxal.	X-RAY: Mineralogy of clay fraction[1] Mica	Chl.-Kaol.	Verm.	Mont.	Int. Comp.[2]	Quartz
D6730	5.5	4.9	25.2	34		21.0	44.5	70.4	0.84							
D6731	5.5	5.0	2.5	23		5.8	8.2	15.1	0.33	0.32						
D6732	5.9	5.5	3.5	24		8.2	13.1	23.1	0.97	1.17						
D6733	6.7	5.6	2.1	20		5.7	9.6	17.7	0.99	1.22						
D6734	6.5	6.0	1.0	26		1.4	8.5	12.3	1.11	0.59						
D6735	7.4	7.0	1.9		17		13.8	14.1	0.89	0.55						
D6736	7.7	7.3			27				0.70							

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[1] x = trace; xx = minor; xxx = major constituent.

[2] Int. Comp. = a variably expanding component of indeterminate composition (interlayered).

Degraded Dystric Brunisol - Humo-Ferric Podzol (Site 2)

Topography: North facing fan, 20% slope.

Elevation: 1,490 meters (4,950 ft.).

Vegetation: Spruce, fir; willow; *Ledum sp.*, *Vaccinium scoparium*, bunchberry, arnica, twinflower, and moss.

Drainage: Well drained but possibly underground source of water. The soil is moist and cool.

Parent Material: Sandy and gravelly fan material with a silty overlay.

Horizon	Depth (cm)	Description
L-H	4 cm	
Ae	0- 5	Light brownish gray (10 YR 6/2 m), light gray (10 YR 7/2 d); coarse silt loam; weak fine granular; very friable; roots plentiful; strongly acid; clear wavy boundary to:
Bfj	5-10	Dark reddish brown (5 - 7.5 YR 3/4 wet), dark brown to brown (7.5 YR 4/4 m), pale brown (10 YR 6/3 d); coarse silt loam; moderate fine granular; friable; few roots; medium acid; gradual wavy boundary to:
C	10-60+	Brown (10 YR 5/3 m), very pale brown (10 YR 7/3 d); loamy sand (some gravels); fine granular; friable; few roots; medium acid.

TABLE AII. Characterization Analyses of a Degraded Dystric Brunisol - Humo-Ferric Podzol

PHYSICAL

Sample No.	Depth cm	Hori-zon	Particle size distribution (mm) % of <2mm **									> 2mm %	Moisture retention %		Bulk dens. gm/cc	S.G.separat. of FS (%)	
			sand						silt	clay							
			2-1	1-0.5	.5-.25	.25-.1	.1-.05	Total	.05-.002	<2u	<0.2u		1/3 atm.	15 atm.		<2.50	>2.95
D6740	0- 5	Ae						24	70	6	3	-					
D6741	5-10	Bfj	1.1	3.2	2.4	4.5	12.9	24	60	16	3	-					
D6742	10+	C	12.8	19.1	12.6	19.0	10.7	75	21	4	0	-					

	CHEMICAL										X-RAY					
Sample No.	pH		Organic matter		$CaCO_3$ equiv. %	Exchange analysis meq/100 gm			(Fe + Al) %		Mineralogy of clay fraction[1]					
	H_2O	$CaCl_2$	%C	C/N		H	Ca	T.E.C.	Dith.	Oxal.	Mica	Chl.-Kaol.	Verm.	Mont.	Int. Comp.[2]	Quartz
D6740	5.2	4.4	1.6	19		3.5	3.4	8.1	0.11	0.09						
D6741	5.6	4.7	1.8	22		5.9	7.5	15.3	0.59	0.75						
D6742	5.6	4.7	0.4			1.1	3.6	5.0	0.24	0.06						

---

[1] x = trace; xx = minor; xxx = major constituent.

[2] Int. Comp. = a variably expanding component of indeterminate composition (interlayered).

** Particle analysis reported on carbonate free sample.

Bisequa Gray Luvisol (Site 3)

Topography: 15% slope to N.E.

Elevation: 1,450 meters (4,900 ft.).

Vegetation: Pine forest with accessory spruce; juniper; wintergreens, twinflower, bunchberry, grasses, moss and lichens.

Drainage: Well drained.

Parent Material: Colluvium with silty overlay.

Horizon	Depth (cm)	Description
L-F	3 cm	Pine needles, some moss.
Ae1	0- 2	Brown (10 YR 5/3 m), light gray (10 YR 7/2 d); loamy sand to coarse silt loam; structureless to weak fine platy; soft; abundant roots; slightly acid; clear wavy boundary to:
Bf	2- 5	Strong brown (7.5 YR 4/4 m), reddish yellow (7.5 YR 6/6 d); coarse silt loam; weak fine platy; soft; roots plentiful; neutral; gradual wavy boundary to:
Ae2	5-12	Brown (7.5 YR 5/4 m), light yellowish brown (10 YR 6/4 d); weak fine platy; soft; roots plentiful; neutral; abrupt smooth boundary to:
Bt	12-22	Strong brown (7.5 YR 5/6 m), yellowish brown (10 YR 5/6 d); clay loam; moderate to strong fine granular; hard; few roots; neutral; abrupt smooth boundary to:
IICk1	22-32	Dark brown (10 YR 3/3 m), brown (10 YR 4/3 d); very gravelly sandy loam; weak granular; friable; roots plentiful; very strongly calcareous; gradual wavy boundary to:
IICk2	32-40+	Grayish brown (10 YR 5/2 m), light brownish gray (10 YR 6.5/2 d); very gravelly loam; massive; slightly hard; very few roots; extremely calcareous.

TABLE AIII. Characterization Analyses of a Bisequa Gray Luvisol

PHYSICAL

Sample No.	Depth cm	Hori-zon	Particle size distribution (mm) % of <2mm									> 2mm %	Moisture retention %		Bulk dens. gm/cc	S.G.separat. of FS (%)	
			sand						silt	clay							
			2-1	1-0.5	.5-.25	.25-.1	.1-.05	Total	.05-.002	<2u	<0.2u		1/3 atm.	15 atm.		<2.50	>2.95
D6790	5- 0	L-F															
D6791	0- 2	Ae1	0.5	0.3	0.2	6.4	18.9	27	63	9	5	-				55.0	5.2
D6792	2- 5	Bf	0.6	0.9	0.8	3.3	17.5	23	67	10	2	-					
D6793	5-12	Ae2	0.5	1.6	1.4	5.0	15.4	25	62	13	4	-				6.6	0.4
D6794	12-22	Bt	2.1	3.6	3.3	6.7	7.3	25	32	43	28	28				0.5	0.4
D6795	22-32	IICk1	7.4	6.2	4.8	10.3	10.3	40	35	25	13	72				0.2	0.2
D6796	32+	IICk2	10.2	8.7	6.0	11.1	10.1	47	36	17	11	68					

CHEMICAL / X-RAY

Sample No.	pH		Organic matter		$CaCO_3$ equiv. %	Exchange analysis meq/100 gm			(Fe + Al) %		Mineralogy of clay fraction[1]					
	H_2O	$CaCl_2$	%C	C/N		H	Ca	T.E.C.	Dith.	Oxal.	Mica	Chl.-Kaol.	Verm.	Mont.	Int. Comp.[2]	Quartz
D6790	6.0	5.6	26.5	31		3.0	73.6	79.0	0.62							
D6791	6.6	5.9	2.4	20		2.3	15.0	17.7	0.30	0.29	x	x	xxx	xx	xx	xx
D6792	7.2	6.2	1.2	15			14.9	15.3	0.99	2.11	x	x	xx	-	x	x
D6793	7.3	6.4	0.9	15			12.3	12.6	0.77		xx	x	xx	x	xx	xx
D6794	7.0	6.7	1.3	26			20.1	22.0	1.58		xx	xx	xxx	xx	xx	xx
D6795	7.9	7.2	2.8	20	27						xxx	xx	xx	-	x	xx
D6796	7.9	7.2			34				0.73		xxx	xx	xx	-	x	xx

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1 x = trace; xx = minor; xxx = major constituent.
2 Int. Comp. = a variably expanding component of indeterminate composition (interlayered).

Orthic Gray Luvisol (bleached) (Site 4)

Topography: Rolling topography, 10% slope.

Elevation: 1,450 meters (4,850 ft.).

Vegetation: Spruce with fir and pine; buffaloberry; bunchberry, twinflower, arnica, rye grass, feather mosses and leafy lichens.

Drainage: Well drained.

Parent Material: 25 cm loess over till or outwash.

Horizon	Depth (cm)	Description
	4 cm	Moss
L-H	7 cm	Moss, lichens and litter.
Bm	0-1½	Brown (7.5 YR 5/4 m); coarse silt loam; structureless to weak fine granular; soft; roots plentiful; neutral; gradual irregular boundary to:
Ae1	1½- 7	Light brown (7.5 YR 6/4 m), light gray (10 YR 7/2 d); coarse silt loam; structureless to weak fine platy; soft; roots plentiful; neutral to mildly alkaline; gradual wavy boundary to:
Ae2	7-21	Brown (7.5 YR 5/4 - 4/4 m), light brown to pink (7.5 YR 6/4 - 7/4 d); coarse silt loam; weak very fine granular; soft; roots plentiful; mildly alkaline; clear smooth boundary to:
Bt	21-28	Yellowish red (5 YR 4/6 - 4/8 m), strong brown (7.5 YR 5/6 d); clay loam; moderate fine granular; slightly hard to hard; few roots; neutral; clear smooth boundary to:
IICk1	28-40+	Dark brown (10 YR 3/3 m), gravelly sandy loam; weak fine granular; friable; strongly calcareous; roots plentiful.

TABLE AIV. Characterization Analyses of an Orthic Gray Luvisol (bleached)

PHYSICAL

Sample No.	Depth cm	Hori-zon	Particle size distribution (mm) % of <2mm sand 2-1	1-0.5	.5-.25	.25-.1	.1-.05	Total	silt .05-.002	clay <2u	clay <0.2u	> 2mm %	Moisture retention % 1/3 atm.	15 atm.	Bulk dens. gm/cc	S.G.separat. of FS (%) <2.50	>2.95
D6717	7 cm	L-F															
D6718	0-1.5	Bm	0.6	1.2	1.4	6.5	15.8	26	61	13	5	-					
D6719	1.5-7	Ae1	0.1	0.3	0.6	3.0	17.5	21	66	13	5	-					
D6720	7-21	Ae2	0.2	0.7	0.6	3.9	15.7	22	62	16	5	-					
D6721	21-28	Bt	0.5	1.2	1.7	4.4	10.5	18	44	38	12	10				13.7	0.2
D6722	28+	IICk1						56	34	10	6	35				3.1	0.1

CHEMICAL | X-RAY

Sample No.	pH H$_2$O	pH CaCl$_2$	Organic matter %C	Organic matter C/N	CaCO$_3$ equiv. %	Exchange analysis meq/100 gm H	Ca	T.E.C.	(Fe + Al) % Dith.	Oxal.	Mineralogy of clay fraction[1] Mica	Chl.-Kaol.	Verm.	Mont.	Int. Comp.[2]	Quartz
D6717	5.7	5.4				18.6	49.6	73.4								
D6718	6.9	6.2	5.0	25		1.6	24.6	28.7	0.60	0.27	xx	xx	xxx	x	xx	xx
D6719	7.8	7.1	0.7	18					0.36	0.12	xx	x	xxx	x	xx	xx
D6720	7.7	7.1	0.6	14					0.56		xx	xx	xx	x	xx	xx
D6721	7.4	7.0	0.8	13	2		23.2	28.6	1.00	0.23	xx	x	xx	xxx	xx	xx
D6722	8.0	7.3	4.1	68	21				0.54		xxx	xx	xx	x	xx	xx

1 x = trace; xx = minor; xxx = major constituent.
2 Int. Comp. = a variably expanding component of indeterminate composition (interlayered).

Orthic Gray Luvisol (Site 5)

Topography: Rolling topography with slopes of 10 to 20%.

Elevation: 1,440 meters (4,800 ft.).

Vegetation: Pine; buffaloberry, juniper; bearberry, wintergreen, arnica, rose, Indian paintbrush and grasses.

Drainage: Well drained.

Parent Material: 40 cm of loose material over compact till.

Horizon	Depth (cm)	Description
L-F	1-3 cm	Mostly undecomposed pine needles.
Bm	0- 1	Brown (10 YR 4/3 - 5/4 m), pale brown (10 YR 6/3 d); coarse silt loam; structureless to weak fine granular; soft; abundant roots; slightly acid; clear wavy boundary to:
Ae	1- 8	Brown (10 YR 5/3 m), light gray to very pale brown (10 YR 7/2 - 7/3 d); coarse silt loam; weak fine platy; soft; roots plentiful; neutral; abrupt smooth boundary to:
Bt	8-16	Dark brown to brown (7.5 YR 4/4 - 5/4 m), strong brown (7.5 YR 5/6 d); clay loam; moderate fine granular to fine subangular blocky; slightly hard; few roots; neutral; abrupt smooth boundary to:
IICk1	16-36	Dark brown (10 YR 3/3 - 4/3 m), grayish brown (10 YR 5/2 d) gravelly sandy loam; weak fine granular; friable; roots plentiful; extremely calcareous; gradual wavy boundary to:
IICk2	36-45+	Grayish brown to light brownish gray (10 YR 5/2 - 6/2 m), light gray (10 YR 7/1 d); gravelly sandy loam; massive or fractured; very hard; extremely calcareous; very few roots.

TABLE AV. Characterization Analyses of an Orthic Gray Luvisol

PHYSICAL

Sample No.	Depth cm	Hori-zon	Particle size distribution (mm) % of <2mm									> 2mm %	Moisture retention %		Bulk dens. gm/cc	S.G.separat. of FS (%)	
			sand						silt	clay							
			2-1	1-0.5	.5-.25	.25-.1	.1-.05	Total	.05-.002	<2u	<0.2u		1/3 atm.	15 atm.		<2.50	>2.95
D6797	1- 8	Ae	2.3	3.8	3.9	16.4	16.9	43	44	13	5	11	21	5	0.8	2.4	0.3
D6798	8-16	Bt	1.3	2.4	2.9	21.6	12.3	40	23	36	22	13	23	12		0.2	0.1
D67100	16-36	IICk1	8.5	6.0	5.0	10.0	9.8	40	41	19	9	33				0.3	0.1
D67101	36+	IICk2	8.4	6.3	5.7	13.9	13.8	48	35	17	9	32				0.2	0.2

Sample No.	CHEMICAL										X-RAY					
	pH		Organic matter		$CaCO_3$ equiv. %	Exchange analysis meq/100 gm			(Fe + Al) %		Mineralogy of clay fraction[1]					
	H_2O	$CaCl_2$	%C	C/N		H	Ca	T.E.C.	Dith.	Oxal.	Mica	Chl.-Kaol.	Verm.	Mont.	Int. Comp.[2]	Quartz
D6797	7.1	6.6	0.8	15	-		8.0	8.8	0.37	0.17	xx	xx	xx	x	xxx	xx
D6798	7.3	7.0	1.2	17	2.4		19.7	22.7	0.84	0.41	xx	x	xx	xx	xx	xx
D67100	8.2	7.5	3.5	26	50											
D67101	8.4	7.7	1.7		45						xxx	xx	–	–	x	xx

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[1] x = trace; xx = minor; xxx = major constituent.

[2] Int. Comp. = a variably expanding component of indeterminate composition (interlayered).

Orthic Gray Luvisol (weak) (Site 7)

Topography: Fluted or ridged till plain, 5% slope.

Elevation: 1,430 meters (4,775 ft.).

Vegetation: Pine with some spruce; juniper, buffaloberry; arnica, twinflower, bearberry, violet, wintergreen and grass.

Drainage: Well drained.

Parent Material: Thin ashy overlay (with stones) over till.

Horizon	Depth (cm)	Description
L-F	1 cm	Undecomposed needles.
Ae	0- 8	Brown (10 YR 5/3 m), light gray to very pale brown (10 YR 7/2 - 7/3 d); coarse silt loam; weak fine granular; soft; upper 2 cm mottled; abundant roots; neutral; clear wavy boundary to:
Bt	8-20	Yellowish brown (10 YR 5/4 m), pale brown (10 YR 6/3 d); loam; weak to moderate, fine granular; slightly firm; roots plentiful; neutral; abrupt wavy boundary to:
IICk1	20-40	Brown (10 YR 5/3 - 4/3 m); gravelly sandy loam; weak fine granular; friable; few roots; extremely calcareous; gradual wavy boundary to:
IICk2	40-50+	Light brownish gray (10 YR 6/2 m); gravelly sandy loam; massive to fractured; hard; very few roots; extremely calcareous.

TABLE AVI. Characterization Analyses of an Orthic Gray Luvisol (weak)

PHYSICAL

Sample No.	Depth cm	Hori- zon	Particle size distribution (mm) % of < 2mm: sand 2-1	sand 1-0.5	sand .5-.25	sand .25-.1	sand .1-.05	sand Total	silt .05-.002	clay <2u	clay <0.2u	> 2mm %	Moisture retention % 1/3 atm.	Moisture retention % 15 atm.	Bulk dens. gm/cc	S.G.separat. of FS (%) <2.50	S.G.separat. of FS (%) >2.95
D6883	1 cm	L-F															
D6884	0- 8	Ae	0.2	0.9	1.0	7.4	16.9	27	64	9	3	-	32	11		43.0	2.6
D6885	8-20	Bt	2.8	5.7	5.2	13.8	12.7	40	41	19	7	10	23	11		0.8	0.2
D6886	20-40	IICk1	10.0	9.9	9.3	17.2	13.5	60	30	10	3	35				0.3	0.2
D6887	40+	IICK2	3.6	8.0	9.4	21.6	16.2	59	29	12	6	43	16	8		0.3	0.2

CHEMICAL / X-RAY

Sample No.	pH H_2O	pH $CaCl_2$	Organic matter %C	Organic matter C/N	$CaCO_3$ equiv. %	Exchange analysis meq/100 gm H	Exchange analysis meq/100 gm Ca	Exchange analysis meq/100 gm T.E.C.	(Fe + Al) % Dith.	(Fe + Al) % Oxal.	Mineralogy of clay fraction[1] Mica	Chl.- Kaol.	Verm.	Mont.	Int. Comp.[2]	Quartz
D6883	6.1		35.4	32		14.5	50.0	69.0	0.25							
D6884	6.7	6.3	1.9	23		2.0	9.9	13.5	0.24	0.13	xx	xx	xx	x	xx	x
D6885	7.3	7.0	1.2	23	4.1		24.4	29.4	0.33	0.28	xx	xx	xx	xxx	xx	xx
D6886	7.9		2.3	29	50				0.24		xxx	xx	x	–	xx	xx
D6887	8.1				41						xxx	xx	x	–	–	xx

[1] x = trace; xx = minor; xxx = major constituent.

[2] Int. Comp. = a variably expanding component of indeterminate composition (interlayered).

Degraded Eutric Brunisol (Site 9)

Topography: On a bedrock controlled bench, less than 5% slope.

Elevation: 1,425 meters (4,750 ft.).

Vegetation: Open pine; buffaloberry, rose, juniper; bearberry and grass, with some twinflower, wintergreen and strawberry.

Drainage: Well drained.

Parent Material: About 20 cm silty deposit over till.

Horizon	Depth (cm)	Description
L-F	1 cm	Pine needles.
Bm	0- 2	Brown (10 YR 4/3 - 5/3 m), pale brown (10 YR 6/3 d); coarse silt loam; structureless to weak fine granular; soft; abundant roots; neutral; gradual irregular boundary to:
Ae(j)	2- 8	Brown (10 YR 5/3 m), light gray (10 YR 7/2 d); coarse silt loam; structureless to weak fine granular; soft; often has fine (7.5 YR 5/4) mottles; abundant roots; neutral; gradual wavy boundary to:
Bm(tj)	8-18	Yellowish brown (10 YR 5/4 m), light yellowish brown (10 YR 6/4 d); loam; weak fine granular; slightly hard; plentiful roots; neutral, sometimes weakly calcareous at bottom; abrupt irregular boundary to:

IICk1 and IICk2 as described for the Orthic Gray Luvisol.

TABLE AVII. Characterization Analyses of a Degraded Eutric Brunisol

PHYSICAL

Sample No.	Depth cm	Hori- zon	Particle size distribution (mm) % of <2mm									> 2mm %	Moisture retention %		Bulk dens. gm/cc	S.G.separat. of FS (%)	
			sand						silt	clay							
			2-1	1-0.5	.5-.25	.25-.1	.1-.05	Total	.05-.002	<2u	<0.2u		1/3 atm.	15 atm.		<2.50	>2.95
D6757	2- 8	Aej	0.8	1.8	1.6	7.1	20.0	32	54	14	5	-	28	12	0.7	31	0.6
D6759	8-18	Btj	0.3	1.9	2.6	8.0	17.8	31	51	18	7	6	26	11		12	0.4
D6760	18-40	IICk1	4.7	12.0	10.6	19.3	13.6	61	24	15	5	38				0.3	0.1
D6761	40+	IICk2	6.2	10.9	10.2	19.1	12.8	60	32	8	5	35	14	5		0.3	0.1

CHEMICAL											X-RAY					
Sample No.	pH		Organic matter		$CaCO_3$ equiv. %	Exchange analysis meq/100 gm			(Fe + Al) %		Mineralogy of clay fraction[1]					
	H_2O	$CaCl_2$	%C	C/N		H	Ca	T.E.C.	Dith.	Oxal.	Mica	Chl.-Kaol.	Verm.	Mont.	Int. Comp.[2]	Quartz
D6757	7.1	6.7	2.1	26			19.2	20.5	0.16		xx	x	xx	xxx	xx	xx
D6759	7.3	6.9	0.8	16			17.0	19.5	0.21		xx	x	x	xxx	xx	xx
D6760	7.9	7.5	2.6		42						xxx	xx	x	xx	x	xx
D6761	8.1	7.7			41						xxx	xx	x	x	xx	xx

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[1] x = trace; xx = minor; xxx = major constituent.

[2] Int. Comp. = a variably expanding component of indeterminate composition (interlayered).

Calcareous Degraded Eutric Brunisol (Site 13)

Topography: Dissected upland, 5% south facing slope.

Elevation: 1,425 meters (4,750 ft.).

Vegetation: Sparce pine, scattered juniper and buffaloberry; some grass, lichens.

Drainage: Well drained.

Parent Material: Silty deposit over till.

Horizon	Depth (cm)	Description
	0- 3	A crust of variable thickness (0-3 cm) which appears to be a result of recent deposition mixed with lichens; weakly calcareous; clear smooth boundary to:
A(ej)	3-10	Light gray (10 YR 7/2 d); coarse silt loam; structureless; soft; few roots; alkaline; gradual wavy boundary to:
B(m)k	10-15	Very pale brown (10 YR 7/3 d); coarse silt loam to fine sandy loam; structureless to weak fine granular; soft; moderately calcareous; abrupt wavy boundary to:

IICk1 and IICk2 similar to those described for the Orthic Gray Luvisol.

TABLE AVIII. Characterization Analyses of a Calcareous Degraded Eutric Brunisol

			PHYSICAL														
			Particle size distribution (mm) % of ≤ 2mm										Moisture retention %		Bulk dens.	S.G.separat. of FS (%)	
			sand						silt	clay							
Sample No.	Depth cm	Hori-zon	2-1	1-0.5	.5-.25	.25-.1	.1-.05	Total	.05-.002	<2u	<0.2u	> 2mm %	1/3 atm.	15 atm.	gm/cc	<2.50	>2.95
D6762	3-10	A(ej)	2.1	4.2	4.1	10.5	17.5	39	55	6	2						
D6763	10-15	B(m)k	1.8	6.2	6.3	12.7	12.7	43	47	10	6						
D6764	15-40	IICk1	3.8	11.7	11.6	21.5	13.8	63	25	12	9						
D6765	40+	IICk2	5.5	10.4	9.0	15.5	11.9	52	30	18	9						

	CHEMICAL										X-RAY					
											Mineralogy of clay fraction[1]					
Sample No.	pH		Organic matter		$CaCO_3$ equiv.	Exchange analysis meq/100 gm			(Fe + Al) %							
	H_2O	$CaCl_2$	%C	C/N	%	H	Ca	T.E.C.	Dith.	Oxal.	Mica	Chl.-Kaol.	Verm.	Mont.	Int. Comp.[2]	Quartz
D6762	7.9		1.5	22	-											
D6763	8.1		2.1	19	14											
D6764	8.0		3.4	25	26											
D6765	8.4		1.5		35											

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[1] x = trace; xx = minor; xxx = major constituent.

[2] Int. Comp. = a variably expanding component of indeterminate composition (interlayered).

Calcareous Orthic Eutric Brunisol (Site 14)

Topography: Low angle fan, less than 2% slope.

Elevation: 1,275 meters (4,250 ft.).

Vegetation: Grasses, sages, vetch, bedstraw, crocus, lichens and others.

Drainage: Well drained.

Parent Material: Thin aeolian deposit over outwash gravels.

Horizon	Depth (cm)	Description
Ahk	0- 3	Very dark grayish brown (10 YR 3/2 m), dark grayish brown (10 YR 4/2 d); coarse silt loam; weak fine granular; soft; moderately calcareous; clear wavy boundary to:
Bmk	3- 7	Brown (7.5 YR 5/4 m), light brown to pinkish gray (7.5 YR 6/4 - 7/2 d); coarse silt loam; weak fine granular; soft; weakly calcareous; abrupt wavy boundary to:
IICk1	7-24	Dark brown to brown (10 YR 4/3 - 3/3 m) pale brown (10 YR 6/3 d); cobbley (sandy loam); few roots; strongly calcareous; gradual wavy boundary to:
IICk2	24+	Grayish brown (10 YR 5/2 m), light gray (10 YR 7/2 d); gravel; strongly calcareous; no roots.

Note: This is an example of some of the very thin profiles which can be encountered.

TABLE AIX. Characterization Analyses of a Calcareous Orthic Eutric Brunisol

PHYSICAL

Sample No.	Depth cm	Horizon	Particle size distribution (mm) % of <2mm									> 2mm %	Moisture retention %		Bulk dens. gm/cc	S.G.separat. of FS (%)	
			sand						silt	clay							
			2-1	1-0.5	.5-.25	.25-.1	.1-.05	Total	.05-.002	<2u	<0.2u		1/3 atm.	15 atm.		<2.50	>2.95
D6703	0- 3	Ahk						24	66	10	1	-			0.7		
D6704	3- 7	Bmk						32	57	11	1	-					
D6705	7-24	IICk1						53	35	12	2	70					
D6706	24+	IICk2	16.8	28.6	13.1	12.9	8.8	80	14	6	1						

CHEMICAL | X-RAY

Sample No.	pH		Organic matter		$CaCO_3$ equiv. %	Exchange analysis meq/100 gm			(Fe + Al) %		Mineralogy of clay fraction[1]					
	H_2O	$CaCl_2$	%C	C/N		H	Ca	T.E.C.	Dith.	Oxal.	Mica	Chl.-Kaol.	Verm.	Mont.	Int. Comp.[2]	Quartz
D6703	8.0		4.3	13	10				0.17							
D6704	8.1		2.0	12	2				0.17							
D6705	8.1		5.3	31	27				0.12							
D6706	8.5				21				0.04							

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1 x = trace; xx = minor; xxx = major constituent.

2 Int. Comp. = a variably expanding component of indeterminate composition (interlayered).

Orthic Regosol IV to Orthic Eutric Brunisol (calcareous) (Site 16)

Topography: Intermediate fan, 6% slope to the south.

Elevation: 1,350 meters (4,500 ft.).

Vegetation: Spruce with some pine; buffaloberry, juniper; rye grass, some herbs.

Drainage: Well drained.

Parent Material: Aeolian deposition over fan material.

Horizon	Depth (cm)	Description
Surface	0- 8	Brown (10 YR 4/3 - 5/3 m), pale brown (10 YR 6/3 d); coarse silt loam; weak fine platy to weak fine granular; soft; abundant roots; neutral; gradual smooth boundary to:
Lower	8-18	Brown to yellowish brown (10 YR 5/3 - 5/4 m), very pale brown (10 YR 7/3 d); coarse silt loam; weak fine platy; soft; few roots; strongly calcareous; grades to:

Ck and IICk horizons.

Orthic Regosol III (Site 17)

Topography: Windward scarp face, 50% slope.

Elevation: 1,320 meters (4,400 ft.).

Vegetation: Bearberry, some cinquefoil, junipers, grass, milk-vetch, lichens. At least 25% of the ground not covered.

Drainage: Well drained.

Parent Material: Gravelly colluvium over gravel.

Horizon	Depth (cm)	Description
L-H	0- 1 cm	Not always present, a lichen crust.
Ahk	0-20	Dark brown (10 YR 3/3 - 4/3 m), grayish brown (10 YR 5/2 d); very gravelly sandy loam; a mixture of roots and organic remains and the mineral material; strongly calcareous; diffuse boundary to:
ACk	20-40	Brown (10 YR 4/3 - 5/3 m), light brownish gray (10 YR 6/3 d); very gravelly loamy coarse sand; similar to the Ahk but with less organic matter; grading to:
Ck	40+	Grayish brown (10 YR 5/2 m), light gray (10 YR 7/2 d); very strongly calcareous gravelly material.

TABLE AX. Characterization Analyses of an Orthic Regosol IV - Orthic Eutric Brunisol and an Orthic Regosol III

PHYSICAL

Sample No.	Depth cm	Hori-zon	Particle size distribution (mm) % of <2mm									> 2mm %	Moisture retention %		Bulk dens. gm/cc	S.G.separat. of FS (%)	
			sand						silt	clay							
			2-1	1-0.5	.5-.25	.25-.1	.1-.05	Total	.05-.002	<2u	<0.2u		1/3 atm.	15 atm.		<2.50	>2.95
Orthic Regosol IV - Orthic Eutric Brunisol																	
D67264	0- 8	A						24	61	11	-				0.7		
D67265	8-18	AC or B						37	54	9	-						
Orthic Regosol III																	
D67105	0-20	Ahk	8.8	19.4	15.1	11.2	6.7	63	31	6	3	37	22	10	1.1		
D67106	20-40	ACk	9.2	27.9	21.8	17.7	4.7	82	14	4	1	41	6	2			

CHEMICAL / X-RAY

Sample No.	pH		Organic matter		$CaCO_3$ equiv. %	Exchange analysis meq/100 gm			(Fe + Al) %		Mineralogy of clay fraction[1]					
	H_2O	$CaCl_2$	%C	C/N		H	Ca	T.E.C.	Dith.	Oxal.	Mica	Chl.-Kaol.	Verm.	Mont.	Int. Comp.[2]	Quartz
Orthic Regosol IV - Orthic Eutric Brunisol																
D67264	7.1	7.1	2.2	27	–		25.2	26.6								
D67265	7.7	7.6	1.0		23											
Orthic Regosol III																
D67105	8.5	7.8	5.7	29	24											
D67106	8.6	8.0	4.1		22											

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[1] x = trace; xx = minor; xxx = major constituent.

[2] Int. Comp. = a variably expanding component of indeterminate composition (interlayered).

Orthic Regosol IV (Site 18)

Topography: Intermediate fan, 8% slope.

Elevation: 1,250 meters (4,150 ft.).

Vegetation: Grasses (strips or groves of aspen in more moist locations, some junipers, sages and rose.

Drainage: Well drained.

Parent Material: Variable (5 - 15 cm) silty material over coarse fan material.

Horizon	Depth (cm)	Description
Ahk	0- 4	Very dark grayish brown (10 YR 3/2 m), dark grayish brown (10 YR 4/2 d) coarse silt loam; weak fine granular; soft; a mixture of mineral matter, roots and dark, well humified organic matter; moderately calcareous; gradual wavy boundary to:
ACk	4- 8	Dark grayish brown (10 YR 4/2 m), grayish brown (10 YR 5/2 d); similar to the Ahk but less organic matter and fewer roots; moderately calcareous; gradual wavy boundary to:
Ck	8-12	Dark grayish brown (10 YR 4/2 m), light brownish gray (10 YR 6/2 d); coarse silt loam; structureless; soft; few roots; strongly calcareous; abrupt irregular boundary to:
IICk	12+	Strongly calcareous coarse angular fan material.

Cumulic Regosol I (Site 19)

Topography: Low angle fan, less than 2% slope.

Elevation: 1,320 meters (4,400 ft.), about 10 meters above river level.

Vegetation: Grasses (*Agropyron*, *Festuca*, *Poa*), sages, wormwood, wild flax and others.

Drainage: Well drained.

Parent Material: Alluvium and/or aeolian material over coarser alluvium.

Horizon	Depth (cm)	Description
Ahk1	0- 2	Black (10 YR 2/1 m), very dark brown (10 YR 2/2 d); coarse silt loam; turfy to weak fine granular; very friable; abundant roots; strongly calcareous; gradual wavy boundary to:
Ahk2	2- 7	Very dark brown (10 YR 2/2 m), very dark grayish brown (10 YR 3/2 d); coarse silt loam; weak fine granular; soft; abundant roots; strongly calcareous; diffuse wavy boundary to:
ACk	7-12	A gradual transition horizon from the Ah above to the C below characterized principally by diminishing organic content.
Ck	12-40	Dark grayish brown (10 YR 4/2 m), grayish brown (10 YR 5/2 d); coarse silt loam; structureless; soft; few roots; very strongly calcareous; buried horizons common; abrupt smooth boundary to:
IICk	40+	Material with gravel lenses.

TABLE AXI. Characterization Analyses of a Cumulic Regosol I

PHYSICAL

Sample No.	Depth cm	Hori- zon	Particle size distribution (mm) % of <2mm									> 2mm %	Moisture retention %		Bulk dens. gm/cc	S.G.separat. of FS (%)	
			sand						silt	clay							
			2-1	1-0.5	.5-.25	.25-.1	.1-.05	Total	.05-.002	<2u	<0.2u		1/3 atm.	15 atm.		<2.50	>2.95
D6737	0- 7	Ahk						26	61	13	5	-	42	28	0.7	1.4	0.2
D6738	7-12	ACk						30	62	8	3	-	27	11		1.2	0.4
D6739	12-40	Ck						25	65	10	4	-					

Sample No.	CHEMICAL										X-RAY					
	pH		Organic matter		$CaCO_3$ equiv. %	Exchange analysis meq/100 gm			(Fe + Al) %		Mineralogy of clay fraction[1]					
	H_2O	$CaCl_2$	%C	C/N		H	Ca	T.E.C.	Dith.	Oxal.	Mica	Chl.-Kaol.	Verm.	Mont.	Int. Comp.[2]	Quartz
D6737	7.6	7.3	10.2	13	20											
D6738	7.8	7.5	3.6	12	24											
D6739	8.1	7.7	1.6	15	28											

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1 x = trace; xx = minor; xxx = major constituent.
2 Int. Comp. = a variably expanding component of indeterminate composition (interlayered).

Cumulic Regosol II (Site 22)

Topography: Talus slope, 75% slope.

Elevation: 1,500 meters (5,000 ft.).

Vegetation: Scattered spruce, fir, aspen; alder, maple, birch, willows, buffaloberry, cinquefoil, service berry, rose; grasses, bearberry, mosses and lichens.

Drainage: Well drained, though may get moisture from higher slopes.

Parent Material: Talus.

Horizon	Depth (cm)	Description
	0- 8	Recent rock debris.
A(h)k	8-20	Essentially an horizon of angular talus cobbles embedded or enveloped by felted mats of organic matter (F material) and roots; grading to:
ACk	20-35	Similar to A(h)k but with decreasing organic matter and often more fine (sandy) material; grading to:
C	35+	Very little organic material.

All horizons are calcareous.

Alpine and Near-Alpine Soils (Site 15)

Elevation is about 2,100 meters (7,000 ft.).

Regosol

Found at treeline;on a 20% east facing slope, under a mat of *Vaccinium scoparium*.

Horizon	Depth (cm)	Description
Ae (Ae + B)	0- 5	Somewhat mottled light brownish gray (10 YR 6/2 m) and strong brown to yellowish red (7.5 - 5 YR 5/6 m)
H	5- 7	Black (10 YR 2/1 m)
Ae (Ae + B)	7-13	
H	13-15	
Ae + B	15-25	
Bf	25-32	Yellowish red (5 YR 5/6 m)
Bm	32+	Strong brown to yellowish brown (7.5 - 10 YR 5/6 m)

No free carbonates at 60 cm.

Alpine Brunisol

Located on a 40% south facing slope under lush grass cover.

Horizon	Depth (cm)	Description
Ah	0-10	Black (10 YR 2/1 m); turfy
B1	10-20	Dark brown to brown (7.5 YR 4/4 m)
B2	20-35	Reddish brown (5 YR 4/4 m)
B3	35-45	Dark yellowish brown (10 YR 4/4 m)

Floodplain Soils (Sites 23 and 24)

Topography: Floodplain with very hummocky (20-50 cm) micro relief.

Elevation: River level.

Vegetation: Some scattered stunted spruce; swamp birch, cinquefoil, willow; bearberry, grasses, sedges and mosses.

Drainage: Imperfect to very poor, water table at 10 to 60 cm.

Parent Material: Stratified overbank fines.

Horizon	Depth (cm)	Description
Gleyed Regosol		
(L-F)H	4- 6 cm	Somewhat turfy (some Ah).
Ck	0-20	Dark grayish brown (10 YR 4/2 m); loamy very fine sand; structureless; strongly calcareous; boundary diffuse to:
Ckg	20-40+	Grayish brown (2.5 Y 5/2 wet); stratified calcareous sands.
		Water table at 50 cm.
Rego Gleysol		
L-H	to 15 cm	Variable from turfy to L-H horizons, depth to less than 1 cm.
Ckg		Gray (2.5 Y 5/1 wet); loamy very fine sand (stratified); structureless, calcareous.
		Water table at 20 cm.

APPENDIX B

Classification of Soils According to the 7th Approximation[1]

The majority of soil sola are very shallow, generally less than 20 cm (8 inches), but because the area is definitely outside the sphere of agriculture, the depth criteria for diagnostic horizons is waived. It is suggested that the adjective "leptic" could be applied to the Podzols, Luvisols, and Brunisols. The term (Andic) is used for those soils having a horizon containing greater than 60 per cent vitric volcanic ash, but may be less than 7 inches thick.

Relationships to the Canadian classification system are given below:

Canadian	7th Approximation
Humo-Ferric Podzol	Typic Cryorthod
Degraded Dystric Brunisol	Orthodic Cryochrept
Bisequa Gray Luvisol	(Andic) Orthodic Cryoboralf
Orthic Gray Luvisol	Typic Cryoboralf, Typic (Andic) Cryoboralf
Degraded Eutric Brunisol	Alfic (Andic) Cryochrept
Orthic Eutric Brunisol	(Eutric) Cryochrept
Orthic Regosol I	Typic Cryorthent, Typic Cryofluvent, Typic Cryopsammant
Orthic Regosol II	Arent
Orthic Regosol III	(Mollic) Cryopsamment, (Mollic) Cryothent
Orthic Regosol IV	(Mollic) Cryorthent, Typic Cryoboroll
Cumulic Regosol I	(Mollic) Cryorthent, Typic Cryoboroll Cryic Rendoll
Cumulic Regosol II	Typic Cryorthent
Gleyed Regosol	Aquic Cryorthent
Rego Gleysol	Typic Cryaquent
Ledge and Crevice Soils (Lithosols)	Lithic Cryic Entisols

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[1] Soil Survey Staff (1967)

APPENDIX C

Some Land Use Aspects

Forestry

Soil conditions indicate a poor to fair potential for forest production. The most severe limitation is the restriction or root penetration by the extremely calcareous nature of the materials and the compactness of the till.

Climate also imposes limitations on forest growth. The central valley areas in particular are quite dry and the strong valley winds impose special problems such as windthrow.

Mensuration data are limited and confined primarily to lower fan positions but reflect the soil and climatic limitations. These data indicate a slow growth rate of 0.23 - 0.3 inches in the last 10 years for trees attaining a DBH of 6 - 7 inches and a height of 45 - 50 feet in 70 years.

The majority of the area is presently covered by an immature pine forest approximately 70 years in age. The only commercial development to date has been a logging operation in the Corona Creek area where a 300 year old stand of limited aereal extent was harvested. As other areas mature, some logging may be beneficial, but the area does not appear suited to large scale commercial operations.

Wildlife

Many species of wildlife are present in the area. These include moose, elk, deer, sheep, bear, beaver, and many small animals and birds. The larger animals are relatively scarce although the non-forested fans are used as wintering grounds for elk and a few wild horses in the area. Hunting and fishing are limited within the confines of the project area, but the "plains" are extensively used as jumping-off points for pack trips into the "wilderness" areas.

Recreation

The greatest possibilities for the area appear to lie within the sphere of recreation. The creation of a lake behind the soon to be completed Big Horn Dam will augment the recreational potential of the region to include boating, as well as the present activities of hunting, fishing, camping, nature study, hiking, and pack trips. The completion of Highway No. 11 has resulted in a sharp increase in the flow of traffic through the area and future increases will require the development of camping and possibly commercial facilities. It is felt that some of the soils information gathered in this study might be of value in the future planning of the area. Some of the soil features which can be beneficially taken into account are: drainage, permeability, risk of flooding, surface texture, slope, stoniness or rockiness, and depth to bedrock (Montgomery and Edminster, 1966).

A discussion of the more pertinent soil characteristics is complemented by the accompanying map (Figure 18) in which the soil areas are rated for suitability for camping facilities.

Drainage: All of the soils have excellent surface drainage with the exception of a small area north of Whitegoat Lake.

Permeability: The outwash materials on the benches are very permeable but the till is quite compact and internal drainage somewhat impeded. This poses a moderate limitation to sewage disposal. The fans are rapidly drained and have no limitation in this regard.

Surface Texture: Most of the bench and fan surfaces are covered by a silt loam overlay which is poorly structured and soft. Traffic readily loosens this material and can result in extreme dustiness. Any area with anticipated moderate to heavy use would therefore have to safeguard against this, and planning should take into account the problems ensuing from intensive use. Where possible, maintenance of good groundcover would alleviate the problem. Also, trails and paths can erode quite rapidly exposing the gravelly materials underneath. Where traffic (vehicle or foot) is not excessive the overlay is an advantage in that it results in a smooth surface not possible with the very coarse underlying deposits.

Slope: The bench and fan landforms have slopes of generally less than 10 per cent and have no severe limitations for recreational facilities. Those of less than 5 per cent slope, such as found in the Kootenay Plains and local areas on the benches, are particularly suited to such facilities as playgrounds. Slopes of greater than 20 per cent (scarp faces and lower mountain slopes) are generally unsuited for camping but can be utilized for such outlets as hiking and climbing or possibly skiing. No limitation is considered for positions where snowslides or landslides may be encountered although these locations exist at the base of any steep mountain slope.

Stoniness and Rockiness: All the surficial deposits (excluding the loessial overlay) are very coarse and impose moderate limitations to any project requiring excavation, and to a lesser extent to camping facilities. As mentioned, much of the area has a loess capping which can be a bonus to surface use of the areas. The depth of finer textured (SiL-SL) material often increases near the toes of the less steeply sloping fans.

Depth to Bedrock: Where shallow, bedrock is a severe limitation. Areas affected are soil areas Id and portions of the Kootenay Plains on the Two O'clock Creek fan.

Erosion: Infiltration rates are generally high and erosion not a problem. Sloping roads with compacted grades, particularly in till, tend to erode because waters cannot infiltrate and surface wash results. The fine textured overlay has a high infiltration rate but if not protected, till erosion could become a problem in areas of intensive use. The lateral erosion of mountain streams is also a continuing problem requiring constant control.

A problem requiring close examination is that of fluctuating reservoir level. It will be low in the spring and probably into July as peak river flow does not occur until late June. The lower end of the lake will encroach upon fans of less than 10 per cent slope, so fluctuations of 50 or more feet in water level will greatly alter the shoreline (note Figure 18). Another problem which might be encountered is the building up of sediment at the point where the river enters the reservoir. The North Saskatchewan River carries a substantial load of suspended material and the area of sedimentation would coincide with the area exposed during low reservoir levels. Whether this is a serious problem depends upon the coarseness of the sediment.

It should be emphasized that this brief report does not take into account any influences that a camping public might have upon the natural environment. Areas such as the Kootenay Plains would be very susceptible to irreparable damage of vegetative communities through indiscriminate use of the areas.

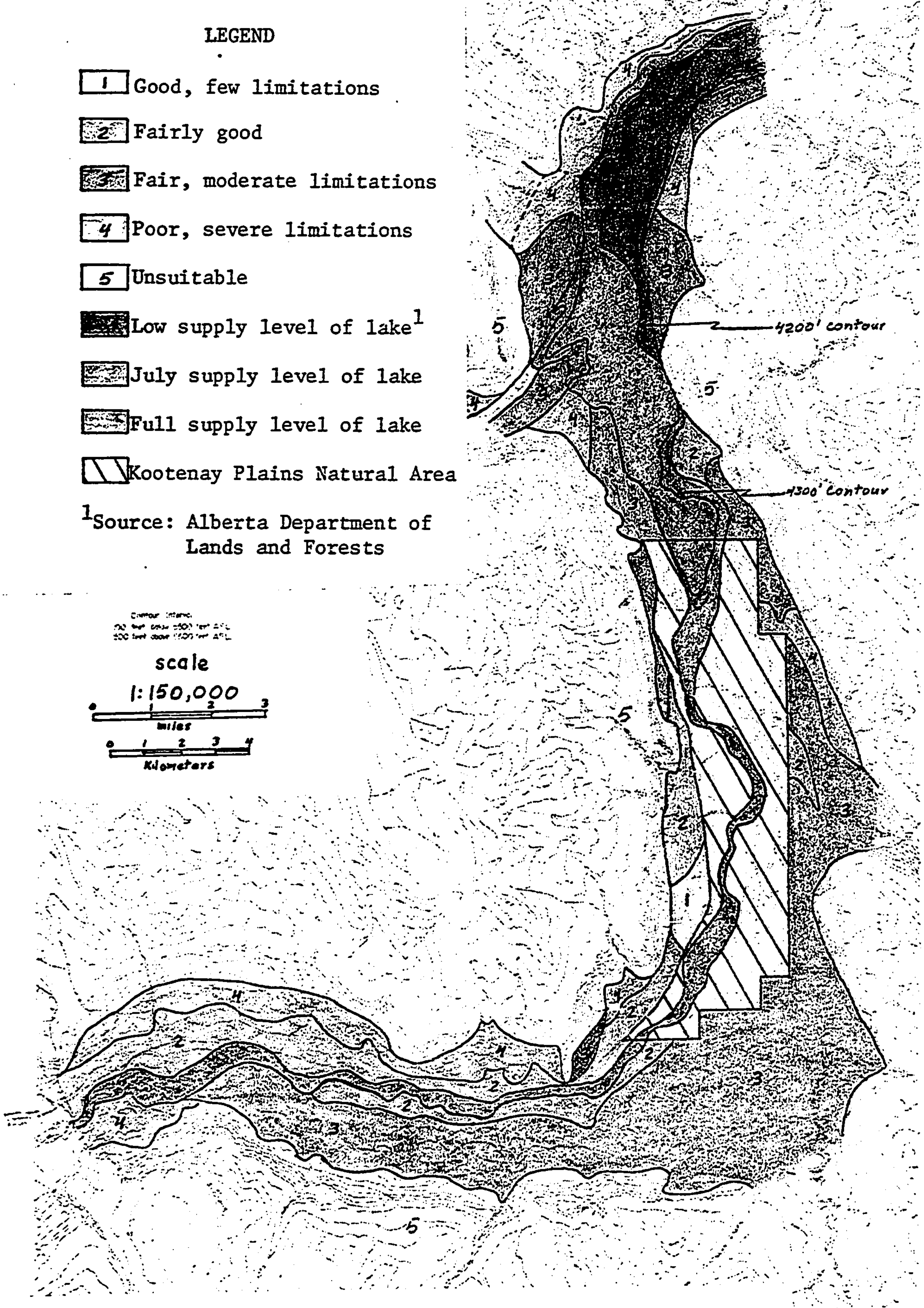


FIGURE 18: Soil rating map for camping facilities.

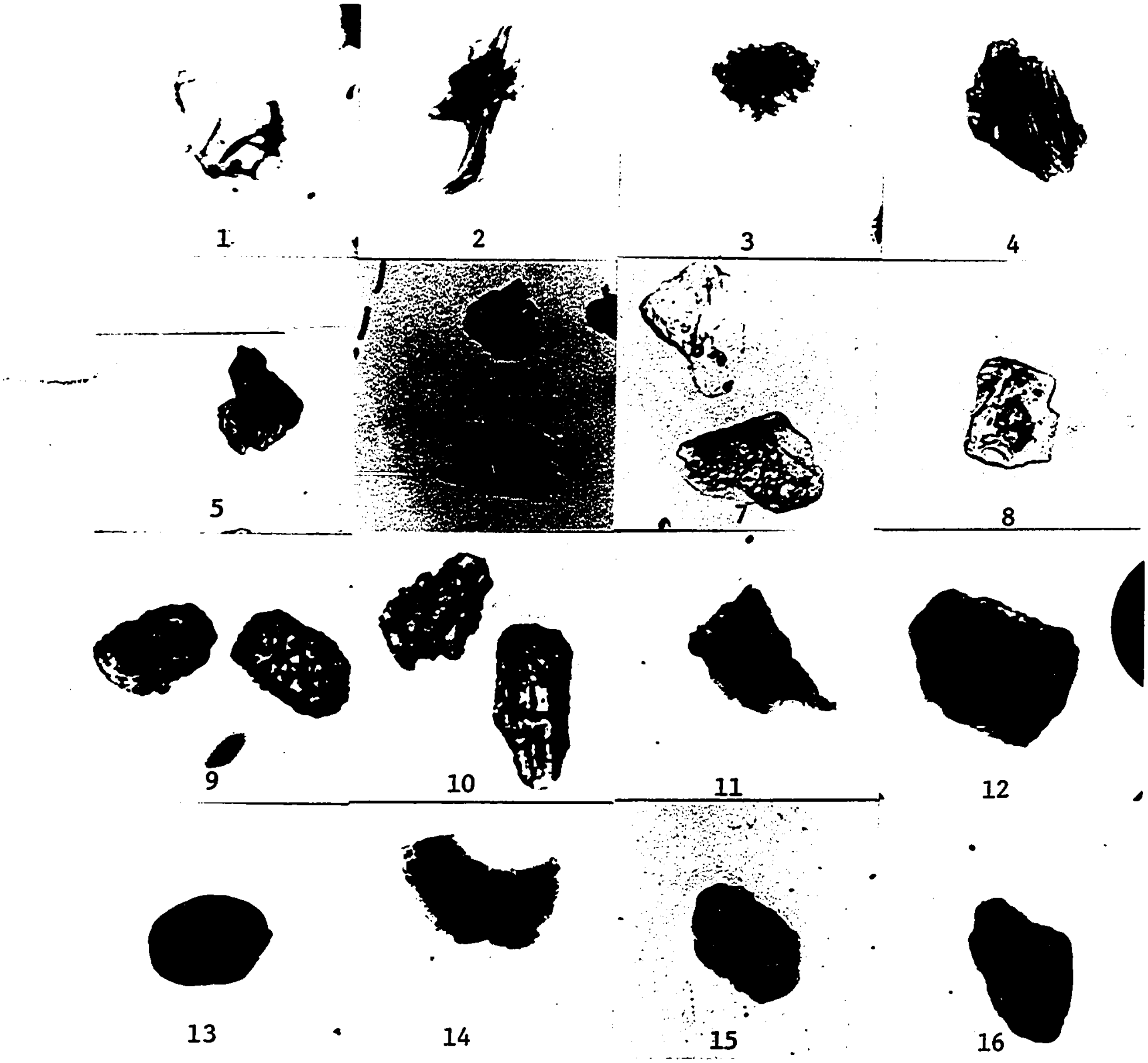
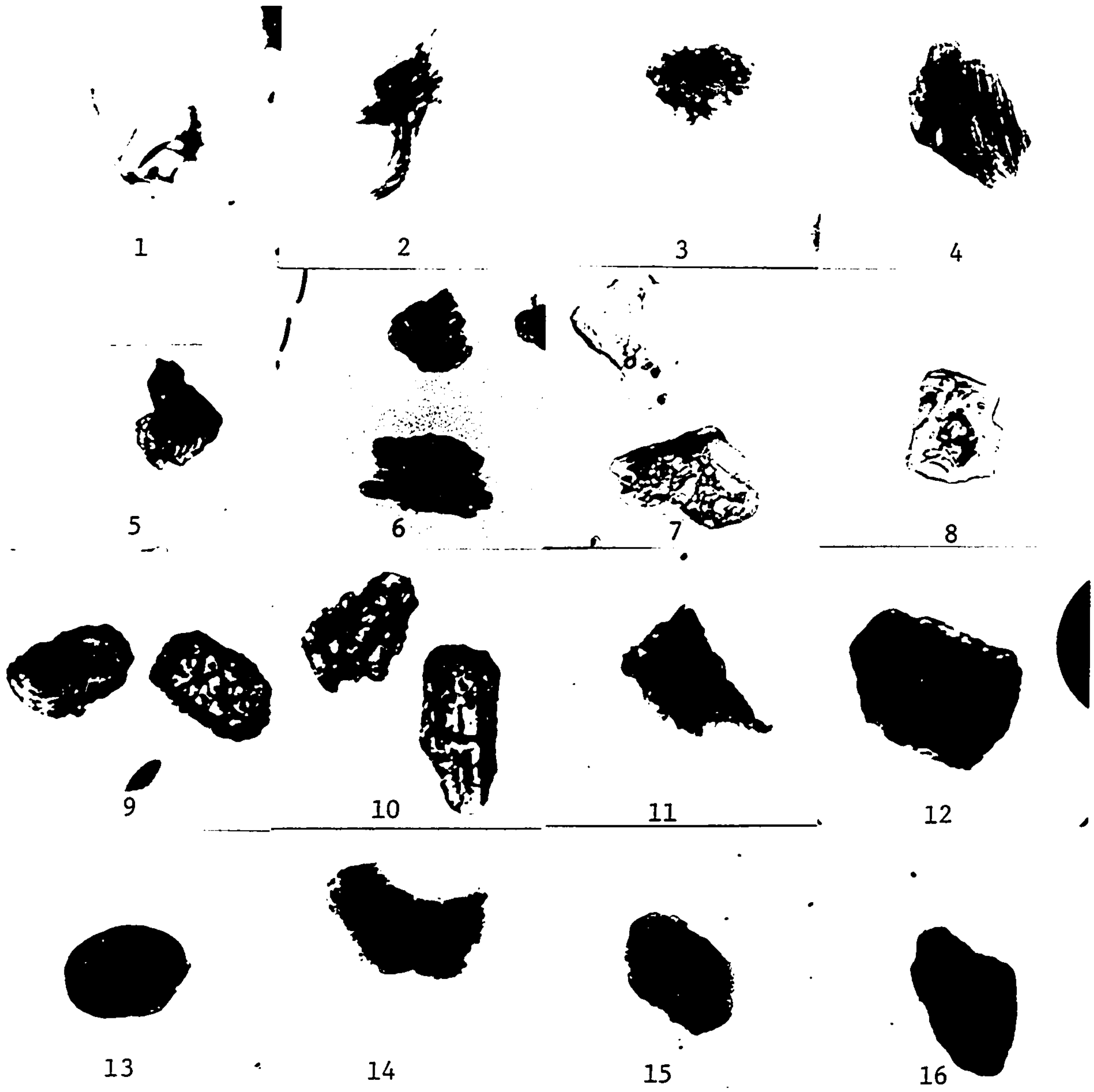


PLATE VIII. Fine Sand Grains of Volcanic Origin (x80).

1-6. Volcanic glass in S.G. < 2.50 fraction.
7-8. Glass encrusted quartz in S.G. 2.50-2.82 fraction.
9-10. Ortho-pyroxene in S.G. > 2.95 fraction.
11-12. Amphibole in S.G. > 2.95 fraction.
13-16. "Weathered volcanics" in S.G. > 2.95 fraction.



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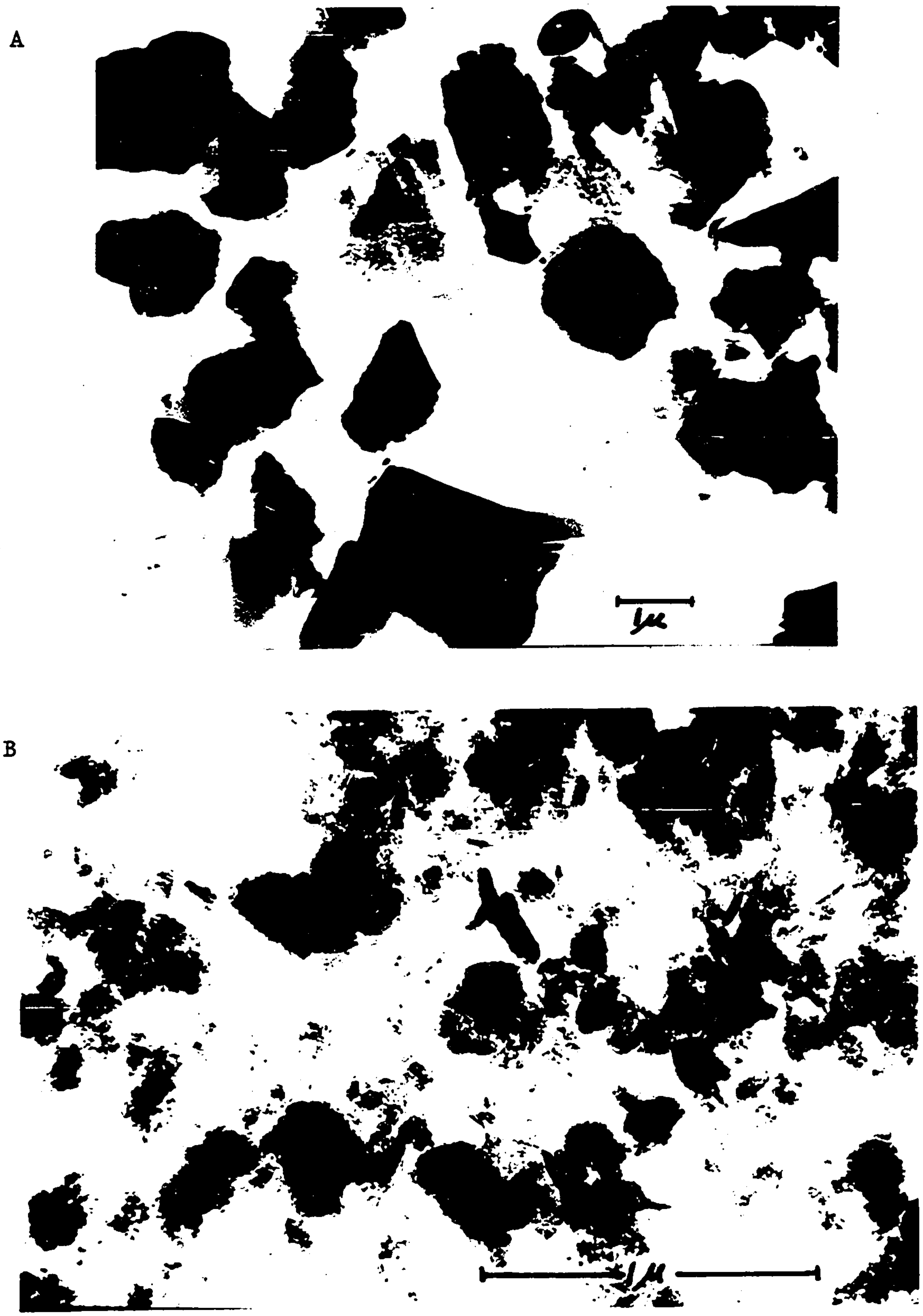
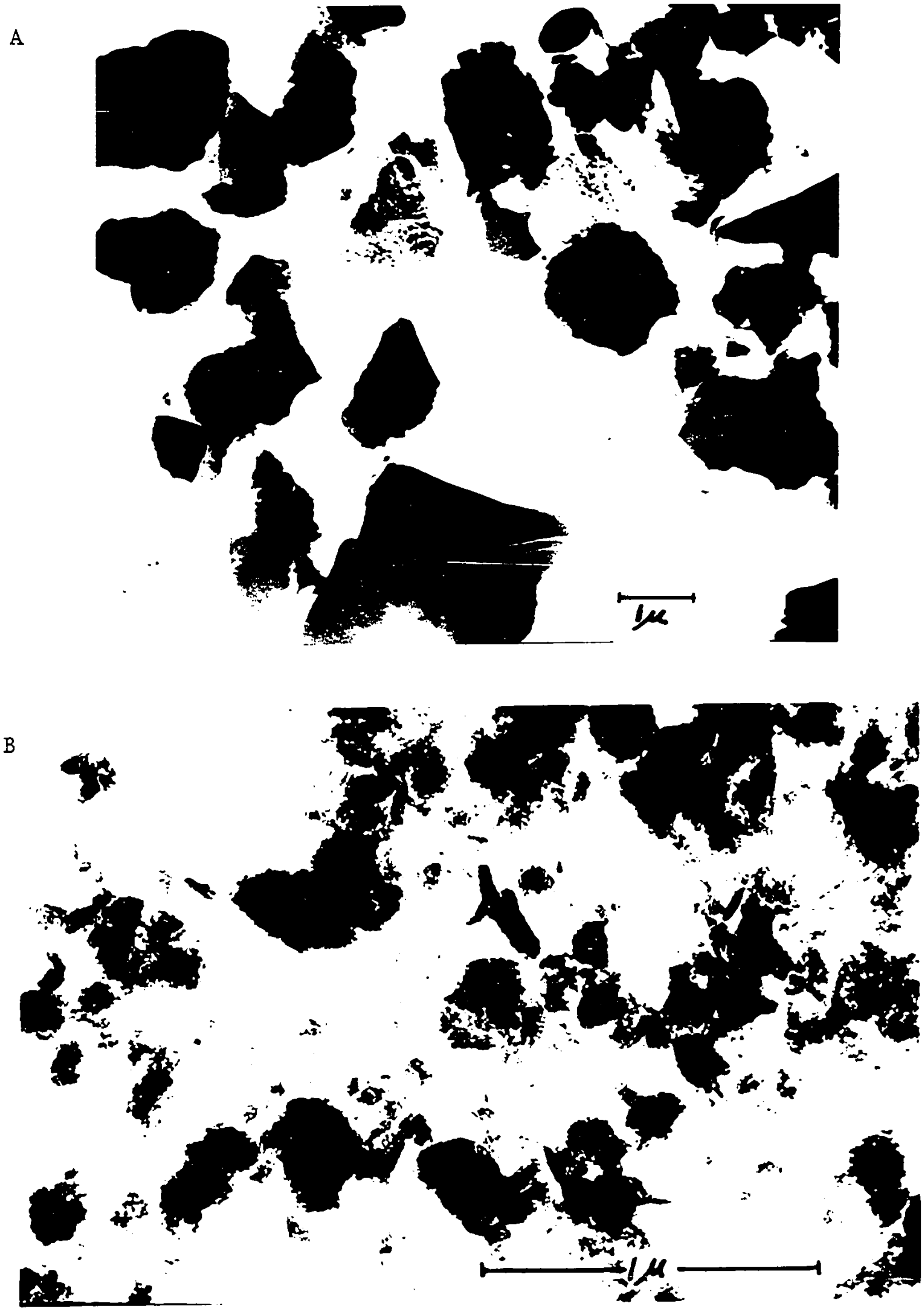


PLATE IX. Electron micrographs of coarse and fine clay separates.

A. 2–0.2µ clay from D6719 (x12,000).
B. <0.2µ clay from D6792 (x53,350).



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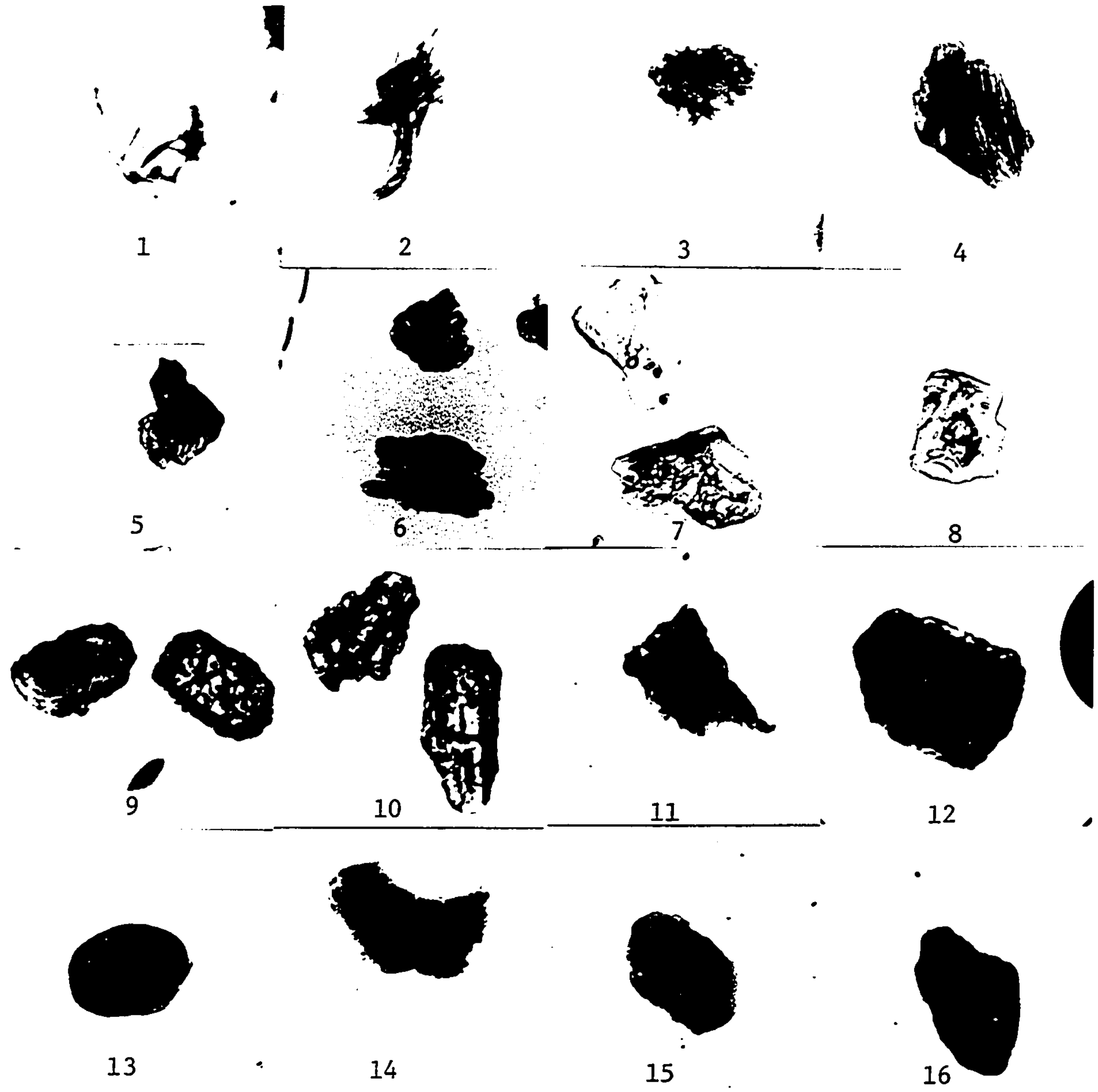

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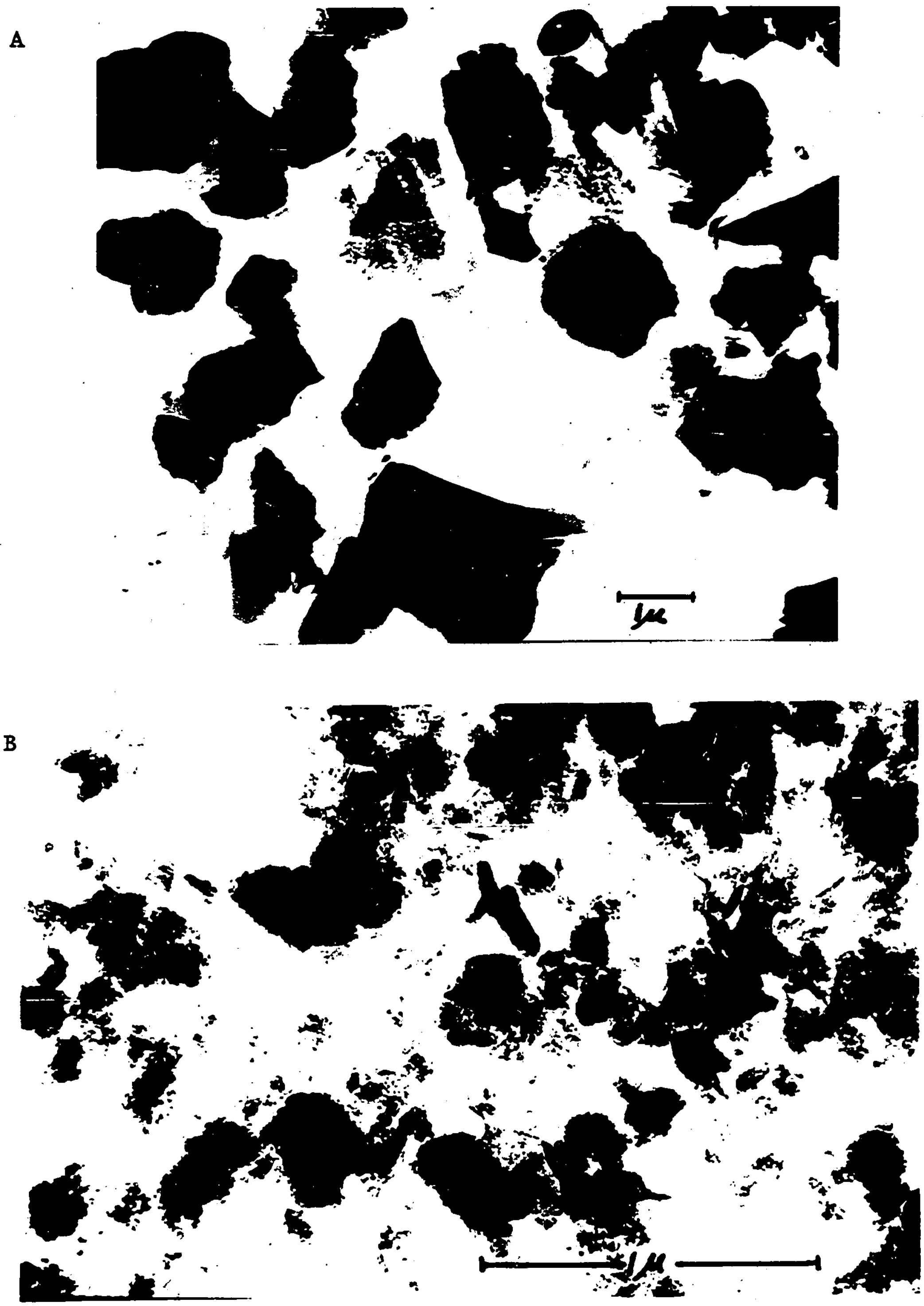

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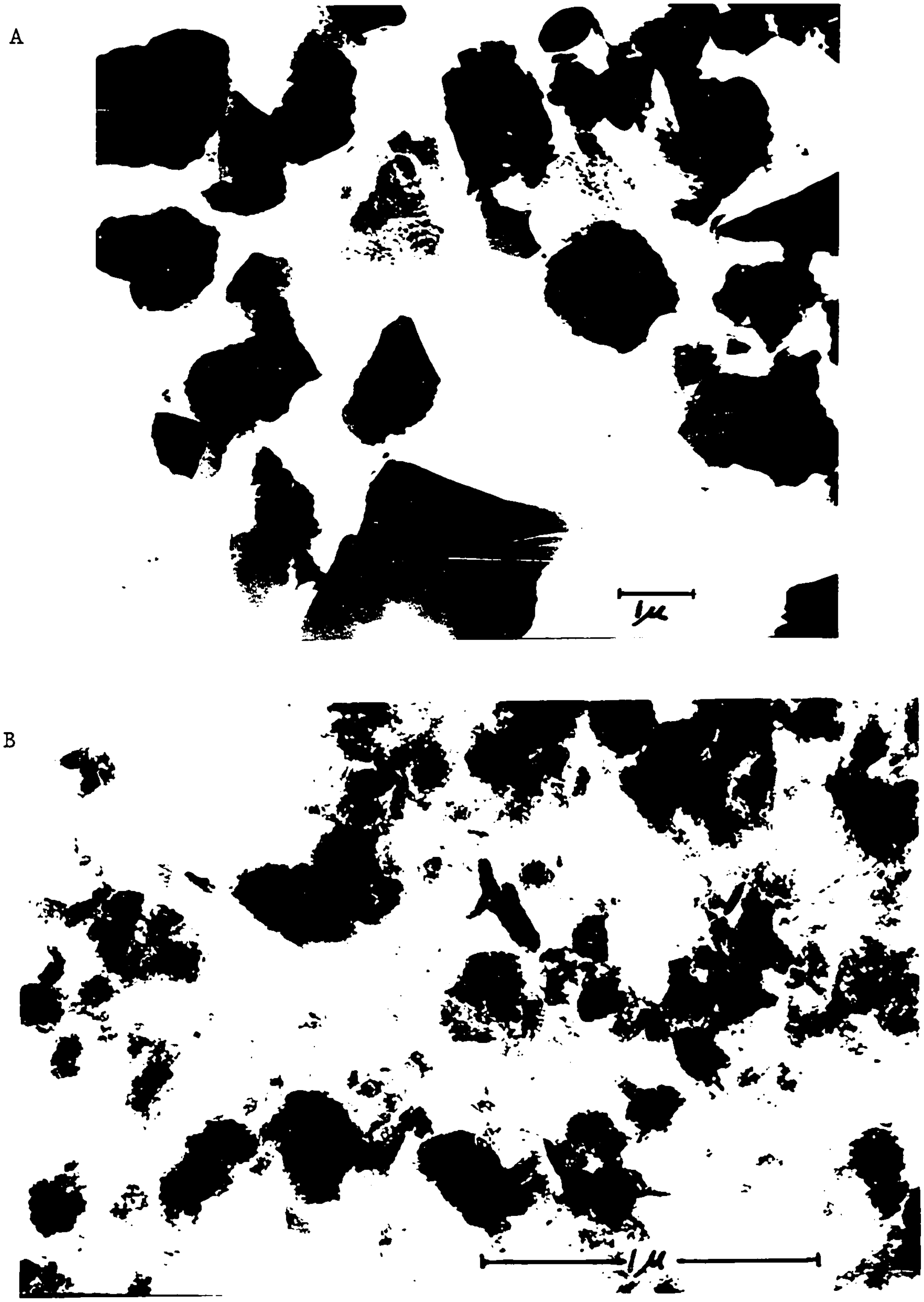

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B. < 0.2μ clay from D6792 (x53,350).

PLATE X. Stereotriplet illustrating valley features (for location see Figure 2 - section EF).

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Scale

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S O I L S M A P

of

ow Valley from Banff National Park east to Windy Point

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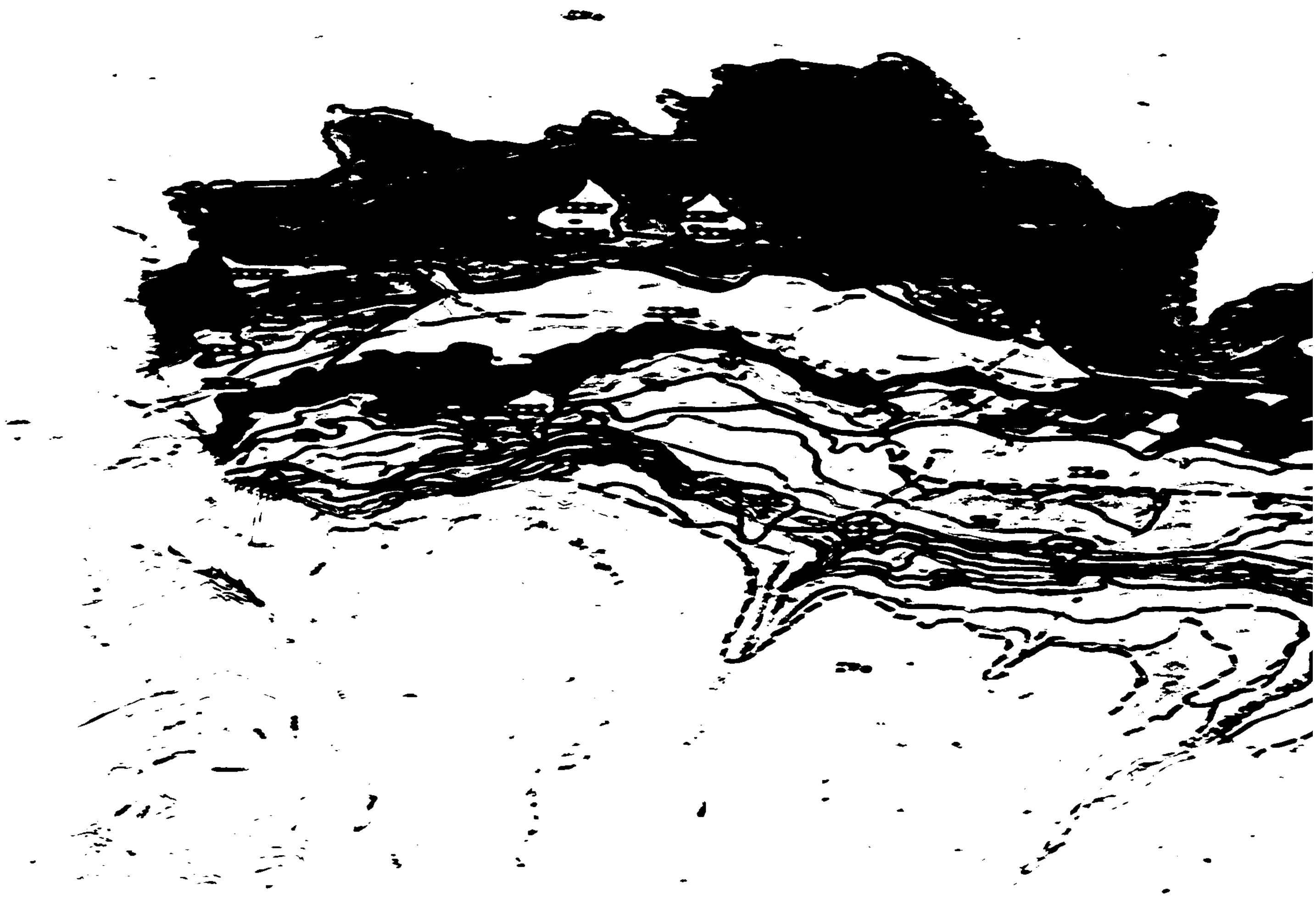


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Soils Map

of

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