RESEARCH COUNCIL OF ALBERTA

Preliminary Report 55-2

GLACIAL GEOLOGY
of an Area in East-Central Alberta

by

L. A. Bayrock

Price 50 cents

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Research Council of Alberta
University of Alberta
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ABSTRACT

The Coteau ice advance boundary was mapped in east-central Alberta. The terminal Coteau moraine was found to be located from 10 to 20 miles east of the terminal Coteau ice advance boundary.

Three tills were differentiated in the area: a basal Grey till, the Viking till, and the Coteau till. Mineralogical, mechanical and X-ray analyses performed on the Viking and Coteau tills indicated no major break in the composition of the two tills. The individual soil profiles of the two tills did not reveal any appreciable weathering of silicates in the upper soil horizons, and the depth of leaching of the carbonates appeared very similar and averaged 23 inches.

Based on the laboratory investigations of samples of the Viking and Coteau tills, the conclusion was reached that the time interval separating the two glaciations was quite short.

INTRODUCTION

General Statement

Under the general program of study by the Research Council of Alberta of the glacial deposits in various sections of Alberta, the author carried out a survey of the glacial deposits in an area in east-central Alberta with the following objectives:

(1) To outline the position of the Coteau ice advance in east-central Alberta,

(2) To study the glacial stratigraphy of the area, and

(3) To find out if there are any major mineralogical or mechanical differences in the composition of the surface tills.

There are two moraines present in the area -- the Viking moraine and the Coteau moraine. The Coteau moraine lies in the eastern part of the area and represents deposits from the last glacier to enter Alberta from the Keewatin center. The Viking moraine lies some 70 miles to the west of the Coteau moraine. The relative thickness of the till cover in the area is greatest in the morainic belts and thinnest between them. Three tills were recognized in the area studied: a basal Grey till, the Viking till, and the Coteau till.

The differentiation of drift sheets of different ages is accomplished by many methods. One method involves the amount of decomposition of tills belonging to the different glaciations. Decomposition proceeds along many lines, with leaching of carbonates representing one of the first factors to set in. Leaching depends on a number of variables such as:

(a) original composition of the parent material,
(b) annual and seasonal precipitation and evaporation,
(c) permeability of the parent material,
(d) type of vegetation cover,
(e) mean annual and seasonal temperature,
(f) erosion and topography,
(g) cultivation by man,
(h) ground-water table,
(i) surface and subsurface drainage.

Many other variables could be listed.

In certain restricted areas the depth of leaching may be used, with success, in outlining boundaries of glacial advances. If, however, the time interval between glaciations is short, no significant break in the depth of leaching of carbonates will be noted. Furthermore, with soils in arid climates the zone of lime accumulation approaches the surface and, consequently, it is doubtful whether this method can be applied in many of the western areas of North America. This fact is well illustrated in Alberta where soil profile boundaries do not parallel glacial boundaries but appear to follow climatic zones.

It is known that certain heavy minerals weather in the upper soil horizons. Hence, in some cases, a statistical analysis of the heavy minerals may be used in mapping drift sheets of different ages, especially in areas where the leaching tests are not significant.

Different lines of approach were applied in solving the problem of the position of the Coteau ice advance boundary. The banks of the North Saskatchewan river were inspected with the purpose of locating sections of glacial deposits. Determinations of the depth of leaching of carbonates were made in order to find a break between the Viking and the Coteau glaciations. Finally, aerial photographs, topographic maps, hand-specimen variations of the two tills, depth of till cover, drainage pattern, and many other features and properties were incorporated in mapping the Coteau ice advance boundary.

Mechanical, mineralogical and X-ray analyses were made on soil profiles from the Coteau glaciated region, the Viking glaciated region, and from the area between the Viking moraine and the Buffalo Lake moraine. The purpose of the laboratory tests was to determine whether there were any major differences in the two tills and to find out if there has been any significant breakdown of silicates in the soil horizons.

Location of the Area

The eastern boundary of the area under consideration is defined by the Alberta-Saskatchewan border, that is, 110° west longitude. The western boundary coincides approximately with the eastern margin of the Buffalo Lake moraine or 112°30' west longitude. The survey extended from about 15 miles north of the North Saskatchewan river (54° north latitude) to about 50 miles south of Highway No. 16 (53° north latitude). The general outline of the area is shown in Fig. 1. Most of the work was concentrated on the eastern half of the area.

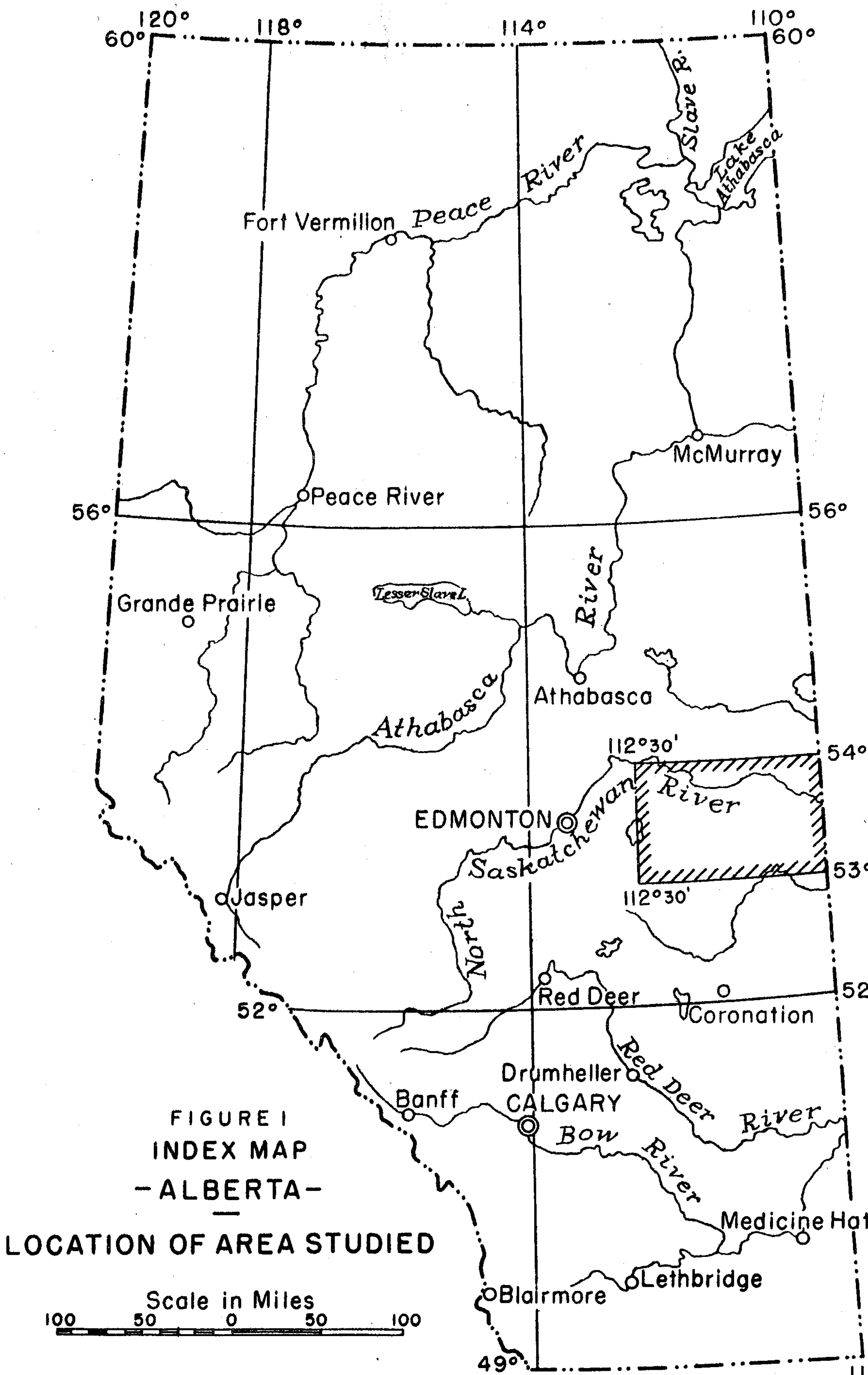


FIGURE I
INDEX MAP
— ALBERTA —
LOCATION OF AREA STUDIED

Previous Work

The fact that eastern Alberta has a cover of glacial material was noted by Tyrrell (1887), Dawson (1898), and Coleman (1909). Rutherford (1941) was the first to outline the western boundary of the Coteau ice advance in Alberta. Bretz (1943) disagreed with the position of the moraine as mapped by Rutherford and placed it farther to the west. The latest work on the area by Warren (1944) placed the Coteau moraine boundary in the same position as that shown by Rutherford, and the author's field mapping is in agreement with this.

The northern part of the Coteau moraine as mapped by Bretz (1943) coincides with the position of the Viking moraine as shown by Warren (1937, 1944). In the area studied by the author, Warren and Bretz agree only on the position of the southern part of the Viking moraine.

Acknowledgements

Thanks are extended to the members of the Department of Geology at the University of Alberta for assistance and guidance, particularly Dr. C. P. Gravenor under whose direction this paper was prepared. The author is also indebted to Dr. P. J. S. Byrne, Research Council of Alberta, who performed all the X-ray analyses, and to Mr. S. J. Groot for the drawings.

PHYSIOGRAPHY

The area studied may be divided into three major physiographic divisions:

(1) The area covered by the Coteau ice advance,

(2) An area of thin glacial material over bedrock in the vicinity of Vermilion, and

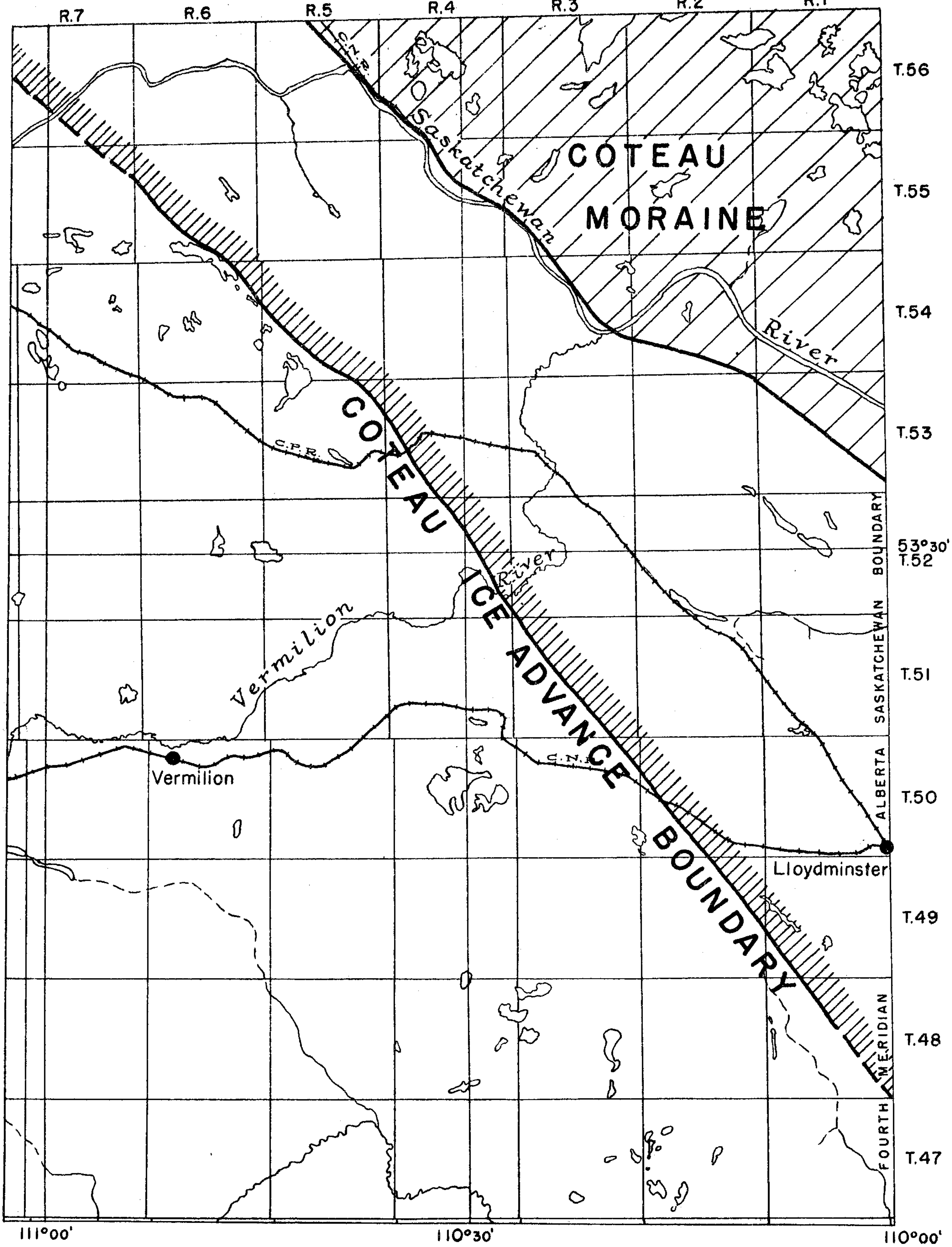
(3) The Viking moraine area.

Coteau Glaciated Region

The Coteau glaciated area can be subdivided into the Coteau moraine and the region between the terminal Coteau moraine and the terminal Coteau ice advance boundary (Fig. 2). In many areas of North America the outer terminus of an ice advance is not marked topographically by a moraine, but the moraine may be found behind the outer limit of the ice advance. This fact is well illustrated in Alberta by the nature of the Keewatin ice border in the vicinity of Edson, where the Keewatin till thins out to the west and the outer limit of the ice advance is not marked by a moraine. Similarly, the terminal Coteau ice advance boundary does not coincide with the terminal Coteau moraine, as the moraine is found about 10 to 20 miles east of the outer border of the ice advance. The portion of the Coteau glaciated country between the moraine and the terminal ice advance boundary shows many stagnant ice features, and is quite flat as compared to the typical morainic topography of the Coteau moraine itself.

The Coteau terminal moraine has an indefinite border on the west, and continues to the east beyond the fourth meridian into Saskatchewan. The topography of this area is hilly. The hills are nobby with steep sides, and sometimes have more than one peak. No definite trend to the hills was noted. Many undrained lakes occupy larger depressions, and are fed by small

FIGURE 2


R.7
R.6
R.5
R.4
R.3
R.2
R.1
T.56
T.55
T.54
T.53
53°30'
T.52
T.51
T.50
T.49
T.48
T.47
COTEAU
MORAINE
Saskatchewan
River
C.P.R.
C.N.R.
COTEAU ICE ADVANCE BOUNDARY
Vermilion
River
Vermilion
Lloydminster
SASKATCHEWAN BOUNDARY
ALBERTA
FOURTH MERIDIAN
111°00'
110°30'
110°00'

creeks which drain the surrounding country. The uneven skyline of the moraine can be easily observed.

The region between the terminal Coteau moraine and the terminal Coteau ice advance boundary has very little relief as compared with the Coteau moraine and the bedrock topography west of the boundary. The southern part of this region is characterized by the presence of a large number of northeasterly trending ridges, some of which have been interpreted by Allan (1944) as eskers. Essentially, they are composed of the same till as the surrounding country but are, perhaps, a little more sandy in places. No stratification or lamination has been observed in them. These ridges average from 15 to 25 feet in height, 50 to 80 feet in width, and a mile or more in length. Deane (1950) described similar ridges in the Lake Simcoe district, Ontario, and believed that they were ridges of till deposited between large stagnant ice blocks; he called them ice-block ridges. The author is in favor of calling the ridges of this area "ice-block ridges". West of this point, and approaching the border of the Coteau ice advance, the ridges become more obscure and numerous kettle holes take their place. The kettle holes first appear in numbers at the terminal ends of the ice-block ridges, and become more abundant to the west, forming a kame-like structure at the edge of the Coteau glacial advance boundary.

The northern part of the Coteau ice advance area has no ice-block ridges, but has broad flat ridges parallel to the Coteau moraine boundary which may mark short halts of the retreating Coteau glacier. It is difficult to observe these ridges from the ground, but they show up on aerial photographs and on topographic maps. They are up to a mile in width, several miles long, and 50 to 100 feet high. Coulees which occur between these ridges are also parallel to the Coteau ice advance boundary.

The western edge of the Coteau till is not marked topographically, and in some places cannot be recognized from the ground. The boundary of the Coteau glaciation north of the Vermilion river follows more or less the outcrop line of the Ribstone Creek and Brosseau sandstones. The Coteau ice advance area itself is located in the Lea Park outcrop area. The above-mentioned sandstone members presumably resisted glacial erosion and resulted in the surface bedrock expressions of the Vermilion area. On the other hand, the shale of the Lea Park formation was probably more susceptible to glacial erosion and hence was planed to form the flat country of the terminal Coteau glaciated region. South of the Vermilion river, the Ribstone Creek and the Brosseau sandstones outcrop in an approximate east-west direction. In this area there is no marked change of topography at the terminal Coteau ice advance boundary.

The trend of the terminal Coteau boundary is approximately N.40°E. in the area studied. The trend of the Viking moraine in the area is more or less north-south. These two trends are of assistance in distinguishing the two glaciations. Aerial photographs showing the margin of the Coteau glaciation help to illustrate the point.

The trends of the two glaciations influence the drainage pattern of the country. Warren (1944), in discussing the influence of glaciations on the drainage pattern in Alberta, stated that the north-south trend of the Viking glaciation turned the North Saskatchewan river from its northeasterly course to an easterly course and that the Coteau moraine undoubtedly was responsible for establishing a southeasterly direction for the North Saskatchewan river. The author agrees with this interpretation and would add that the trend of the North Saskatchewan river in the area of the terminal Coteau ice advance west of the moraine reflects short halts of the retreating Coteau glacier.

Vermilion Bedrock Expression Area

The eastern margin of this area is defined by the boundary of the Coteau ice advance. On the west the border of this area is not well defined, but grades into the Viking moraine. The general topography of this region is hilly, and these hills are quite different from those in the Coteau moraine. The hills of the Vermilion bedrock expression area have gentle slopes and do not have any sharp breaks. No trend to the hills was noted from the ground, but an east-west trend is evident from aerial photographs. Sloughs and lakes in this area are usually much larger than those found in the Coteau moraine.

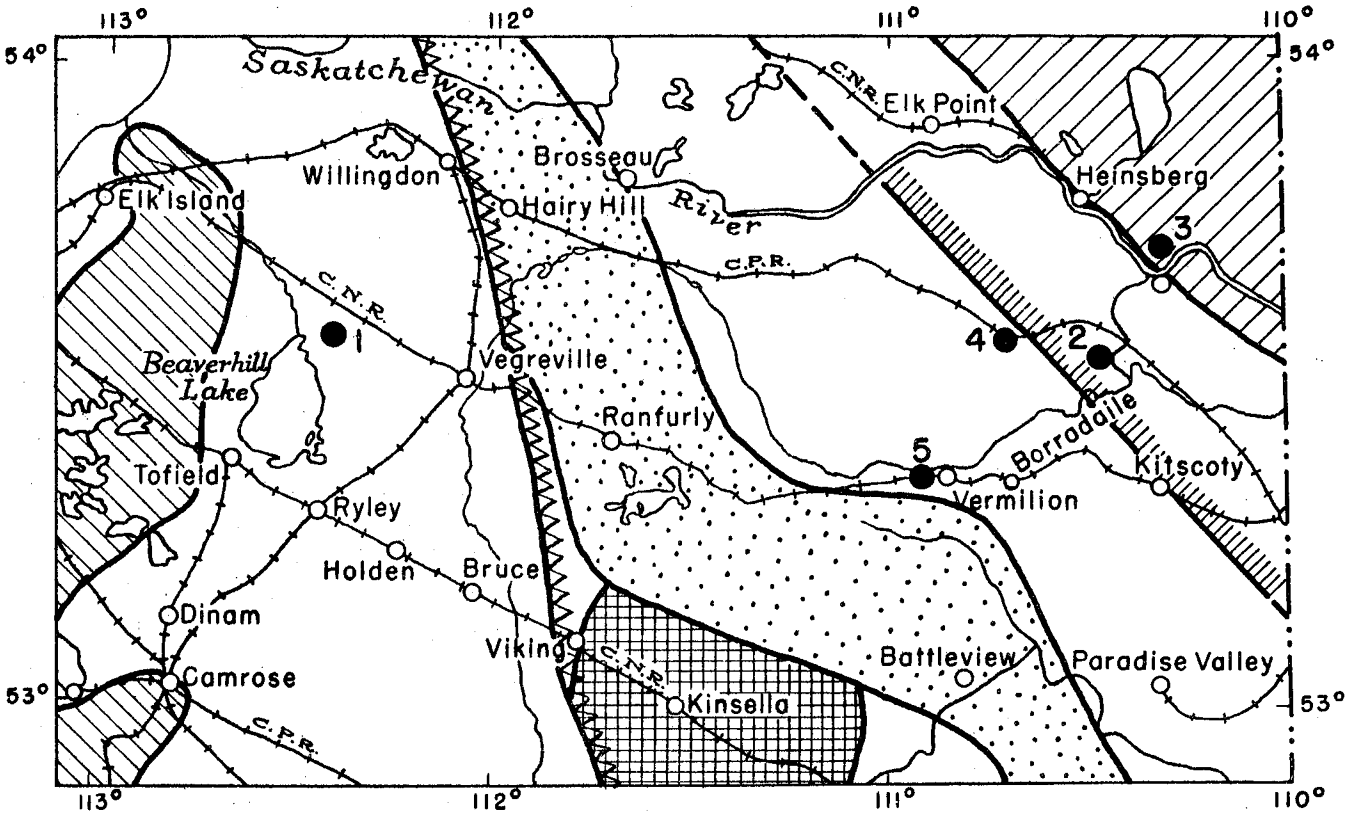
The till cover of this area is thin, and many road-cuts show exposures of bedrock covered with a thin layer of till. At a few localities severe contortions in the bedrock were observed, which probably were produced by the pressure of the overriding glacier. Hopkins (1923) and Slater (1927) observed similar structures in the area of the Mud Buttes in Alberta and postulated that they were the result of glacial pressure and shearing. Field observations indicated that only the clayey bedrock showed such contortions, and it is suggested that the topography of this region is controlled by bedrock expressions which have been modified by the overriding ice.

Viking Moraine Area

The outline of the Viking moraine as mapped by Warren (1937) is shown in Fig. 3. True morainic character is evident in some places but at other localities, where there are only broad hills, bedrock outcrops were noted in a number of road-cuts. Such bedrock outcrops were observed in some newly made road-cuts along Highway No. 16. It is evident from the above that the Viking moraine topography is partly controlled by bedrock expressions in certain areas, and that the moraine does not form a continuous belt. Many east-west trending spillways cut the Viking moraine in the Willingdon district. The western border of the Viking moraine is much better defined than the eastern boundary, and can be mapped more accurately.

FIGURE 3

POSITION OF MORAINES IN MAP AREA



L E G E N D

Buffalo Lake moraine (Bretz)........................

Viking moraine (Warren)........................

Coteau ice advance boundary (Bayrock)........

Coteau moraine (Bayrock)........................

Coteau moraine (Bretz)........................

Viking moraine (Bretz)........................

Location of sample profiles........................ 3

LITHOLOGY OF BEDROCK AND GLACIAL DEPOSITS

Bedrock

The bedrock of the area is composed of Upper Cretaceous sediments -- both marine and non-marine -- which are chiefly sandstones and shales. The bedrock is weakly consolidated; however, locally it is sufficiently lithified to form cliffs.

The composition of the tills is generally related to the nature of the underlying bedrock. Consequently, a full understanding of the lithology of the bedrock is necessary in order to make an intelligent appraisal of the variations in the tills of the area. Details are as follows:

Table of Formations

Recent: Windblown sand and loess; muck and bottom land.

Pleistocene
- Coteau till: Light brown to yellow-brown, sandy to clayey till.
- Viking till: Light brown to dark brown, clayey to sandy till.
- Grey till: Grey to dark grey, bentonitic till.

Unconformity

Upper Cretaceous Belly River formation members	Thickness, feet	Lithology
Oldman	0 to 100	Continental: brownish-grey sand and calcareous shale and silt.
Upper Birch Lake	55	Continental and marine: grey to yellow, medium-grained sand.
Mulga	40	Marine: grey shale with silt lenses and carbonaceous material.
Lower Birch Lake	120	Continental and marine: massive cross-bedded sandstone, buff-coloured, containing lenses of harder sandstone.
Grizzly Bear	40	Marine: dark grey-blue shale, containing iron and sandstone nodules.
Upper Ribstone Creek	40	Continental and marine: greenish-yellow, massive, soft sandstone at top; green carbonaceous shale, coal and light-grey sandstone at base.

Upper Cretaceous Belly River formation members	Thickness, feet	Lithology
Vanesti	80	Marine: grey shale, silty shale, clayey shale, and fine sand.
Lower Ribstone Creek	90	Continental and marine: massive yellow sandstone; fine-grained grey sandstone; grey silty shales; thin coal seams.
Shandro	70	Marine: dark grey shale with calcareous and arenaceous concretions; carbonaceous shale; brownish-grey silty shale.
Brosseau	95	Continental and marine: fine, grey calcareous sandstone; sandy brownish-grey shale.
Lea Park formation	560	Marine: grey silty shales with local intercalations of sandy shale, ironstone concretionary bands, and bentonite.
Colorado group		This group is not exposed in the map area, but underlies the above-mentioned formations.

The thicknesses and descriptions of bedrock are given according to the Imperial Kinsella Well No. 4, after Shaw and Harding (1949).

Description of Glacial Tills

Three different tills were found in the area. The oldest till is the Grey till which occurs sporadically in the region. The Viking till forms the surface cover over most of the area west of the Coteau ice advance boundary. Only one road-cut was found which showed the Grey till and the overlying Viking till undisturbed in one section (200 feet west of S.E. corner Sec.3,Tp.55,R.12,W.4th Mer.). The Coteau till is the youngest of the three tills and covers the country east of the terminal Coteau ice advance boundary (Fig. 2).

(1) The Grey Till

The Grey till is light grey to dark grey in colour, tough, bentonitic, and contains coal fragments picked up from the underlying bedrock.

Sometimes the Grey till grades from a bentonitic to a sandy variety without any apparent change in colour. The Grey till found in eastern parts of the province is a little lighter in colour than the Grey till found in the Big Bend section of the North Saskatchewan river west of Edmonton. No weathering or leaching of carbonates was observed on the upper portions of the Grey till in the region studied. A few sections on the banks of the North Saskatchewan river in the eastern part of the province show the Grey till but, unfortunately, all the sections examined were obscured by slumping and no definite conclusions could be reached. The author uses the term "Grey till" only to denote a till similar in hand-specimen to the Grey till at the Big Bend section west of Edmonton, without any attempt at correlation.

(2) The Viking Till

The Viking till is brown to dark brown in colour, loosely consolidated, and medium sandy in texture. It is composed of approximately equal amounts of sand, silt, and clay, with smaller amounts of gravel. Hand-specimens of the Viking till compare favourably with the Brown till of the Edmonton region. It is the author's opinion that in east-central Alberta the term Viking till should be used in preference to the term Brown till, because no conclusive evidence has been given that these tills were deposited by the same glaciation. Further, the Edmonton region is separated from the Viking moraine by the Buffalo Lake moraine and, at the present time, it is not known whether the Buffalo Lake moraine represents a terminal or a recessional moraine.

(3) The Coteau Till

The Coteau till is light brown to brown in colour, sandy in texture, and loosely consolidated. Generally, the Coteau till is more sandy in hand-specimen than the Viking till, and contains limestone pebbles in the unleached portions of the soil profiles. There is a striking difference between the

Coteau and the Viking tills at the Coteau ice advance boundary. East of the Coteau border, the Coteau till becomes darker in colour and looks more like the Brown or the Viking till. In the Coteau moraine itself the character of the Coteau till varies over small distances. Some hills have sandy light-brown to yellow till on the summits and brown to dark-brown till at the base. At a few places the two varieties of Coteau tills have been observed in a single road-cut. It is probable that the light-brown surface till represents superglacial or ablational till. The till in the area between the Coteau moraine and the Coteau ice advance boundary is generally more sandy than that in the Coteau moraine area.

Recent Deposits

The recent deposits of the area are comprised of windblown sand and loess which accumulated in some depressions. Muck and bottom land deposits of the area are also classified as recent. Generally, recent deposits are local in character and do not form any extensive accumulations.

Leaching of Carbonates

Field observations did not reveal any break in the depth of leaching of carbonates in the soil profiles developed on the Viking and Coteau tills. The average depth of leaching was found to be 23 inches. Deviations from this value are probably due to differences in the texture of the tills. It was observed that sandy phases have a deeper depth of leaching than clayey phases of the same till.

PLEISTOCENE HISTORY OF THE AREA

There were at least three major glaciations in the area studied. These glaciations are represented by the Grey till, the Viking till, and the Coteau till. It is difficult to correlate these glaciations with glaciations in other regions in Alberta because no Pleistocene mapping has been done in the adjacent areas. Probably the Viking till which covers much of the area mapped is of the same age as the Brown till found at the surface in other places in Alberta. However, until further mapping in the province shows that the Viking till is correlative with the Brown till, the author prefers to use the term Viking till to denote the surface till in the area west of the Coteau boundary and east of the Buffalo Lake moraine.

The Grey Till Stage

In many areas of Alberta sections of glacial deposits show a basal Grey till which rests on bedrock or on Saskatchewan sands and gravels. Although it is not known whether this till was deposited in all areas by the same glaciation, all the evidence to date would suggest that this was the case. Over much of the region studied the Grey till has been removed by subsequent glacial erosion and only a few patches of it are left in the east-central part of the province.

No interglacial or interstadial deposits were found separating the Grey and the Viking tills. Further, no evidence of soil formation or leaching was found at the top of the Grey till. It is difficult to determine the correlation of the Grey till from the above facts, and more investigational work will have to be done before any conclusions can be drawn.

The Viking Stage

The subsequent glaciation in the area is called the Viking glaciation. The Viking ice overrode the entire area and deposited the surface till covering west of the Coteau ice advance boundary. The Viking glacier removed most of the pre-existing Grey till cover and left only small isolated patches of this till in some depressions. In the Vermilion area the Viking glacier removed most of the pre-existing Grey till cover and left only small isolated patches of this till in some depressions. In the Vermilion area the Viking glacier must have been lacking in debris because it left only a thin till cover, 4 to 7 feet in thickness, over the bedrock. Another very significant feature of this glaciation is that it contorted the underlying soft bedrock.

After depositing the Viking moraine, this glacier retreated to the east beyond the Coteau boundary. The duration of the interval separating the retreat of the Viking ice and the oncoming Coteau advance is uncertain because there have been no exposures found of the Viking and the Coteau tills in one section. However, it is reasonable to assume that the Viking-Coteau interstadial was short. This can be supported by the fact that the area glaciated by the Viking glacier has retained such youthful features as well-preserved kettle holes, undrained lakes, steep-sided hills, in addition to many other characteristics of youthful glacial topography.

The Coteau Stage

After the retreat of the Viking ice, the Coteau glacier advanced up to the position outlined on Fig. 2. At this point the climate changed and the front of the glacier became stagnant. In the area of Lloydminster, ice-block ridges were produced between large stagnant ice blocks. At the edge of the glacier in that area some ice blocks were buried in glacial debris and, after melting, produced kettle holes. Farther to the north the ice retreated by back-wasting. Short halts of the retreating glacier are marked by the broad flat ridges mentioned earlier. Two major halts produced deflections in the North Saskatchewan and Vermilion rivers.

After the Coteau ice had retreated from 10 to 20 miles behind the outer advance limit, it stayed long enough in one location to deposit the Coteau moraine. At this time the North Saskatchewan river flowed along the front of the glacier, and retained this direction after the ice disappeared. The final stage of the Pleistocene history of the area was the retreat of the Coteau glacier.

Most writers agree that the age of the Coteau moraine is Wisconsin. Horberg (1952) mentioned the Coteau moraine in his article on the Lethbridge region, and assumed it to be Mankato in age. Johnson and Wickenden (1931) believed that the Coteau moraine marked the limit of a late Wisconsin ice advance. Bretz (1943) stated: "The Altamont (Coteau) moraine is accepted in the present study as terminal late Wisconsin equivalent to the Des Moines, Mankato and Port Huron moraines." Alden (1932) believed that the Coteau moraine is late Wisconsin and represented the last ice advance of the Keewatin glacier in western America. The author agrees that the Coteau glaciation is the last one in the area studied but feels that no definite age can be assigned to it since there has been insufficient work done to correlate this or any other Alberta glaciation with the Pleistocene stratigraphy of eastern America.

LABORATORY INVESTIGATIONS

The laboratory investigations included mechanical and mineralogical analyses of soil samples taken from the surface till coverings of the area studied. The results of the mechanical analyses were plotted as cumulative curves. The heavy minerals were separated, counted, and the percentages of the different mineral species determined.

Sampling

The samples for the laboratory analyses were collected from representative areas from each of the main glaciated regions. At each locality a hole was dug and samples were taken every 6 inches from the surface down to the line between the "B" and "B_{ca}" soil horizons. The "B_{ca}" soil horizon is the horizon representing the accumulation of $CaCO_3$. Then one sample was taken from the boundary separating the "B" and "B_{ca}" soil horizons, one from the "B_{ca}" soil horizon, and one from the "C" soil horizon. Tills having similar texture were used in this study.

The first digit of the sample number signifies the location of the sample. The second part of the sample number -- which is separated from the first by a hyphen -- is related to the depth at which the sample was taken; e.g.,for sample 5-2 (see Appendix A) the number 5 indicates the location of the sample and the number 2 indicates the depth from the surface at which the sample was taken (i.e., 12 inches).

Outline of the Mechanical Analysis Procedure

The following flowsheet shows the main steps involved in the mechanical analysis procedure:

(1) 150 grams of the dried sample was weighed out.

(2) Material above 2-mm. size was removed by wet sieving.

(3) Then the material finer than 0.062 mm. was removed by wet sieving.

(4) The fraction between 2 mm. and 0.062 mm. was dried and then sieved using the following screens:

18 mesh - 1.00 mm.
35 mesh - 0.50 mm.
60 mesh - 0.25 mm.
80 mesh - 0.177 mm.
120 mesh - 0.125 mm.
170 mesh - 0.088 mm.
230 mesh - 0.062 mm.

(5) Each sand fraction separated in step 4 was weighed, and the material finer than 0.062 mm. was added to the minus 0.062 mm. portion of the sample obtained in step 3.

(6) The material finer than 0.062 mm. from steps 3 and 5 was dried at 120°C. and weighed.

(7) Finally, 10 gm. of the dried material from step 6 was taken and sedimentation analysis carried out on it by the pipette method as outlined by Toogood and Peters (1953).

During the course of performing the mechanical analysis it was found that ordinary washing procedures did not remove all the silt and clay from the sand fraction. However, prolonged boiling in distilled water favoured a better separation. Best results were obtained by boiling the sample in about 750 to 1000 ml. of distilled water for about 60 minutes and repeating this procedure two additional times. The main objection to using the boiling procedure is that after the clays are oven-dried it is not always possible to fully redisperse them.

Results of the Mechanical Analysis

The results of the mechanical analysis were plotted as cumulative curves (Appendix B). The silt-clay break was taken at 2 microns and no size analysis was made on material below this size. The upper limit was set by the 2-mm. size, that is, the gravel-sand break. All samples of one profile were plotted on a single graph in order to make correlations easier.

The shapes of the cumulative curves show that sand, silt, and clay fractions are represented, on the average, in approximately equal amounts in all of the samples. The different profiles have different amounts of sand, silt, and clay, but the ratio is usually similar for all of the analyzed samples of a single profile. It is interesting to note that there is no major accumulation of clay within the soil profile. It is generally considered by soil scientists that clay and other colloids migrate downward from the "A" soil horizon and accumulate in the "B" horizon. This lack of secondary accumulation of clay in the soils studied might be explained by the small amount of downward percolating water in the region under study, and there is also the possibility that the soils did not have sufficient time to develop this characteristic.

Outline of the Heavy Mineral Analysis

The portion of sand between the 100-mesh and 200-mesh sizes was separated, weighed, and placed in tetrabromoethane (sp.gr.= 2.965); the heavy minerals were separated, dried, weighed, and the percentage of heavy minerals present in this sand fraction was calculated (see Appendix A). The heavy minerals were mounted in Aroclor (n = 1.66) and examined under the microscope. An average of 350 to 400 grains were counted from each slide, and the percentages of the individual minerals calculated (see Appendix C).

The general procedure was satisfactory and good results were obtained. The separations did not involve any major difficulties. The only drawback was in the actual mounting of the heavy minerals. It was noted that certain of the heavy minerals concentrated in one patch of the fraction and it was difficult to get a homogeneous mixture of a small fraction of the heavy minerals for mounting purposes. However, this was overcome to a large degree by mixing the whole heavy mineral fraction prior to mounting.

Description of the Heavy Minerals

Hornblende: The hornblende is fresh in appearance and shows no evidence of weathering in the samples examined. It is predominantly green to bluish-green, although some of the varieties are pleochroic from brown to green. Brown hornblende with an index of refraction higher than 1.66 was classified as basaltic hornblende. The green to bluish-green hornblende is considered to be of metamorphic origin. The black hornblende listed in the tables is a variety of the green hornblende; it is probably very rich in iron and, consequently, almost opaque in transmitted light. The majority of the hornblende particles examined showed well-defined cleavage outlines on the fragments. There was no evidence of weathering found on the hornblende throughout the individual soil profiles. Hornblende was the most abundant heavy mineral in all the samples, except for the samples of profile No. 1 where it made up only a little over 20 percent of the total heavy minerals counted.

Tremolite: The colourless varieties of amphiboles were counted as tremolite. Small amounts of this mineral were present in all the samples.

Pyroxenes: The pyroxenes were separated into monoclinic and orthorhombic types. Most of the grains showed no evidence of weathering.

Monoclinic Pyroxenes: The monoclinic pyroxenes usually predominated over the orthorhombic varieties. The monoclinic pyroxenes counted in the slides were for the most part colourless except for augite which showed green nonpleochroic colouration. Monoclinic pyroxenes averaged about two to three percent of the suites.

Orthorhombic Pyroxenes: Hypersthene generally showed marked pleochroism from bluish-green to red or to reddish-green. Enstatite occurred as colourless grains.

Epidote: The majority of the epidote had a distinct pleochroism from yellowish-green to white. Some of the altered epidote showed white in reflected light. This alteration probably took place prior to deposition. The number of altered grains is approximately the same in all of the samples examined. Most of the grains were irregular to subangular in outline.

Zoisite: Only traces of zoisite were noted in 18 out of the 30 samples examined. Most of the grains were colourless to grey in colour and fresh in appearance.

Garnet: Although most of the garnet was colourless, there were pink, red, yellow, and brown varieties also present. A typical grain may be described as being a fracture fragment showing well pronounced conchoidal fracture. All the grains were angular and no rounding was observed on any of the grains. The garnet showed no evidence of weathering. This mineral averaged 10 to 15 percent of the heavy mineral suite.

Magnetite: Magnetite and hematite are grouped together. The percentage of magnetite was found to approximately the same in all of the samples. It varied in amount from 10 to 15 percent of the heavy minerals.

Limonite: All opaque minerals having an earthy appearance and yellow to brown colour in reflected light were considered as limonite. The amount of limonite was about the same in the individual soil profiles, but varied in different locations. Profile No. 1 contained the largest amount -- 23 to 28 percent. All the other profiles had a much lower percentage of limonite, usually from 5 to 15 percent.

Apatite: Apatite occurred both as rounded and fractured grains. Some grains showing crystal outline were also observed. All the apatite noted was colourless. In the upper parts of the soil profiles this mineral showed a brownish colouration and uneven surface which may represent incipient weathering. The percentage of this mineral varied from 1 to 5 percent in the samples examined and showed some increase with depth in a few profiles.

Tourmaline: Brown, green, pink, bluish-grey, and brownish-black tourmaline grains were present in the samples. Some of the tourmaline showed rounded secondary overgrowths of a colourless variety of the mineral. The amount of tourmaline was never high and varied from traces up to 1.6 percent. About one-half of the tourmaline grains had good crystal outline.

Zircon: Zircon was found in all of the samples. The colourless variety predominated and the yellow variety was rare. Generally the grains showed good crystal outline, but quite a few rounded grains were observed. It was noted that the larger zircon grains showed better crystal outline.

Titanite: The titanite observed in the samples was generally colourless or yellow. The colourless grains had, on the average, a better crystal outline than the yellow varieties. The mineral occurred as traces on most of the slides and seldom attained a value higher than one percent.

Rutile: The colour of the rutile grains varied from deep reddish-brown to deep red. Only traces of this mineral were noted on the slides.

Topaz: Only traces of topaz were present in some of the samples. The grains of this mineral were colourless.

Staurolite: Very few grains of staurolite were observed in the samples. For the most part the mineral was golden-yellow in colour and had a very angular outline.

Andalusite: The andalusite occurred as irregular to subhedral grains, some of which had carbonaceous inclusions. The amount was usually small but sometimes attained a value higher than one percent. No marked alterations were observed on this mineral.

Monazite: The monazite was usually yellowish in colour and did not show crystal outline. It was present only in traces.

Sillimanite: Only traces of this mineral were noted in about one-half of the slides examined. Most of the grains were quite clear and fresh.

Chlorite: Some green to grey chlorite grains were observed in a few of the samples. The grains showed aggregate polarization in the majority of the fragments and only very few grains were single crystals. This mineral occurred only as traces in some of the samples and was absent in others.

Chloritoid: Chloritoid and serpentine are classified together. Only 7 samples contained traces of this mineral group. The grains were green in colour, irregular in outline, and showed aggregate polarization.

Leucoxene: Very few leucoxene grains were observed. They were usually irregular in outline and distinctly white in reflected light. It is possible that a few grains of this mineral might have been confused with limonite.

Anhydrite: A few colourless and brownish grains of anhydrite were observed in traces on a few slides.

Biotite: Brown, brownish-red, and green biotite flakes occurred in small amounts in almost all the samples.

Gold: Gold flakes were found in five of the thirty heavy mineral suites examined. Sample "5-4" showed three grains of gold in the heavy mineral count and 12 grains on the whole slide. The gold flakes were irregular in outline and comparatively thin.

Kyanite: Only 5 samples showed traces of kyanite. This mineral usually had good cleavage outline and was colourless.

Pyrite: Profile No. 1 contained a few grains of an opaque mineral which had a metallic lustre and was light yellow in colour. Tentatively, this mineral was considered to be pyrite.

Glaucophane: Only traces of glaucophane were observed in samples of profiles No. 1 and No. 2.

Altered Minerals Translucent at the Edges (Unidentified): Altered minerals which had unaltered borders were classified under this heading and were further subdivided into groups according to their colour in reflected light. The white-coloured group was the largest -- as is evident from the tables --and averaged from 1 to 4 percent.

Interpretation of the Heavy Mineral Analysis

All the samples analyzed showed similar heavy mineral suites. The suites were composed of stable, metastable, and unstable minerals. The percentages of the different minerals in the individual samples studied were quite similar. No appreciable weathering of the metastable and unstable minerals was noted in the soil profiles examined. The only exception was apatite which showed incipient weathering in the upper parts of the soil profiles; this weathering showed as a light-brown surface colouration of the grains and etching of their surfaces. Apatite grains from the lower soil horizons were usually clear and had a smooth surface. Further, the weathering of apatite was evident from the fact that it was present in smaller amounts in the upper portions of some of the profiles.

The fact that there is practically no weathering of the heavy minerals in the soil profiles analyzed suggests that the Coteau and the Viking tills are quite young and that the time interval separating them is relatively short. However, it should be pointed out that a cold climate and a low precipitation such as is found in this region might not produce much breakdown of the silicates over a long period of time. Nevertheless, since a shallow soil profile has developed on the Coteau till since late Wisconsin (?) times, it is not unreasonable to suppose that if there had been a long time interval between the deposition of the Viking and the Coteau tills, a deeper and better developed soil profile would now be found on the Viking till. As no distinct break in depth of soil profile, depth of leaching, or breakdown of silicates was found in these two tills, it is suggested they were deposited during the same major glacial stage. Thus, if the Coteau moraine is taken as late Wisconsin (?), it is possible that the Viking till is also Wisconsin in age.

Heavy mineral analysis on Athabasca sandstone by Mawdsley (1954) revealed the presence of a large number of tourmaline grains with secondary overgrowth. Similar tourmaline grains with rounded overgrowth were observed by the author in some of the till samples. It is believed that part of the tourmaline in the Viking till originally came from the Athabasca sandstone and that the overgrowth was rounded during transport. This means that the ice was moving in a southwesterly direction over northern Saskatchewan and Alberta. This direction agrees with striae and drumlins found in the region of Cree Lake, Saskatchewan, by Sproule (1939).

X-Ray Analysis of Clay Fractions

X-ray analysis of the clay fractions from the soil profiles were performed by Dr. P. J. S. Byrne, Research Council of Alberta. Only the first and last samples of each profile were analyzed, e.g.,"2-1" and "2-6". The analysis was performed on oriented aggregates both before and after treatment with ethylene glycol. In order to obtain quantitative results each sample was run through the X-ray spectrometer. The results thus obtained correspond to three different clay mineral groups -- montmorillonite, illite, and kaolinite or chamosite -- which have the following 001 "d" spacings in A° units respectively: 17 A° (after glycol treatment), 10 A°, and 7 A°. The following table gives the results in percent:

Sample No.*	17 A°	10 A°	7 A°
1 - 1	49%	23%	28%
1 - 6	49	22	29
2 - 1	54	24	22
2 - 6	41	30	29
3 - 1	17	49	34
3 - 6	42	22	35
4 - 1	75	6	19
4 - 6	71	6	23
5 - 1	7	40	53
5 - 6	43	17	40

*Sample No. 1 - 6 means sample No. 6 at profile location No. 1.

The percentage of the mineral characterized by the 7 A° spacing was calculated on the questionable assumption that its "form factor function" was equal to that of kaolinite. All measurements were made on the basis of the area below the curve rather than on the intensity of the peaks. The values were rounded off to one significant figure.

Only two of the profiles analyzed -- Nos. 3 and 5 -- showed an increase in illite over montmorillonite in the surface samples as compared to the "C" soil horizon. Profile No. 2 had more montmorillonite in the surface sample than in the parent material. Profiles Nos. 1 and 4 had constant values for the surface and parent materials.

A critical examination of the X-ray data leads to only one conclusion, namely, that there has been no major breakdown of the clay minerals in the soil profiles analyzed. This conclusion is in accordance with the results obtained from other analyses performed on the soil profiles.

ECONOMIC GEOLOGY

Sand and Gravel

The western border of the Coteau ice advance is marked by outwash deposits of sand and gravel. Field observations revealed that the best gravel pits are located at the Coteau advance border. At the present time the existing supplies do not satisfy the demand in the area, not only for general construction but also for road building. Prospecting might reveal new gravel and sand deposits of economic value along the Coteau ice advance border.

Water Supply

Generally, the terminal Coteau ice advance region is lacking in good water supplies. It was noted in the field that most of the drilling for water has been done in the Lea Park formation, which is a dense black shale deposit and does not contain any removable water. Some of the producing wells in the area are located in thick glacial till sections and yield satisfactory amounts of water. Further, most of the drilling has been done in depressions where the till cover is quite shallow and the bedrock is close to the surface. Such wells usually terminate in the Lea Park formation and are consequently dry. It is suggested that if wells were drilled on hilltops where there are thick glacial deposits, more producing wells might be obtained.

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APPENDIX A

Location of Sample Profiles

The sample profiles were collected at the following locations (see Fig. 3):

Profile location No.	Profile location
1	West of the Viking moraine and east of the Buffalo Lake moraine; N.E. corner of S.E.¼ Sec. 9, Tp. 53, R. 17, W. of 4th Mer.
2	The Coteau terminal ice advance region; 600 feet south of N.W. corner of Sec. 31, Tp. 52, R. 3, W. of 4th Mer.
3	The Coteau moraine itself; 0.1 miles west of N.E. corner of Sec. 36, Tp. 53, R. 3, W. of 4th Mer.
4	A few miles west of the Coteau ice advance boundary in the Vermilion area; N.W. corner Sec. 8, Tp. 53, R. 5, W. of 4th Mer.
5	West of Vermilion; N.W. corner Sec. 25, Tp. 50, R. 7, W. of 4th Mer.

POSITION OF SAMPLES IN THE PROFILES
(inches from surface)

Profile location No.	Position of sample in profile					
	1	2	3	4	5	6
1	6" - 7"	12" - 13"	18" - 19"	[illegible] - [illegible]	[illegible] - 31"	54" - 58"
2	6" - 7"	12" - 13"	18" - 19"	21.5" - 22.5"	28" - 29"	44" - 45"
3	6" - 7"	12" - 13"	18" - 19"	25" - 26"	31" - 32"	47" - 50"
4	6" - 7"	12" - 13"	18" - 19"	23.5" - 24.5"	29" - 30"	49" - 54"
5	6" - 7"	12" - 13"	18" - 19"	23.5" - 24.5"	29" - 30"	50" - 54"

DEPTH OF LEACHING OF CARBONATES AT THE SAMPLE PROFILE LOCATIONS

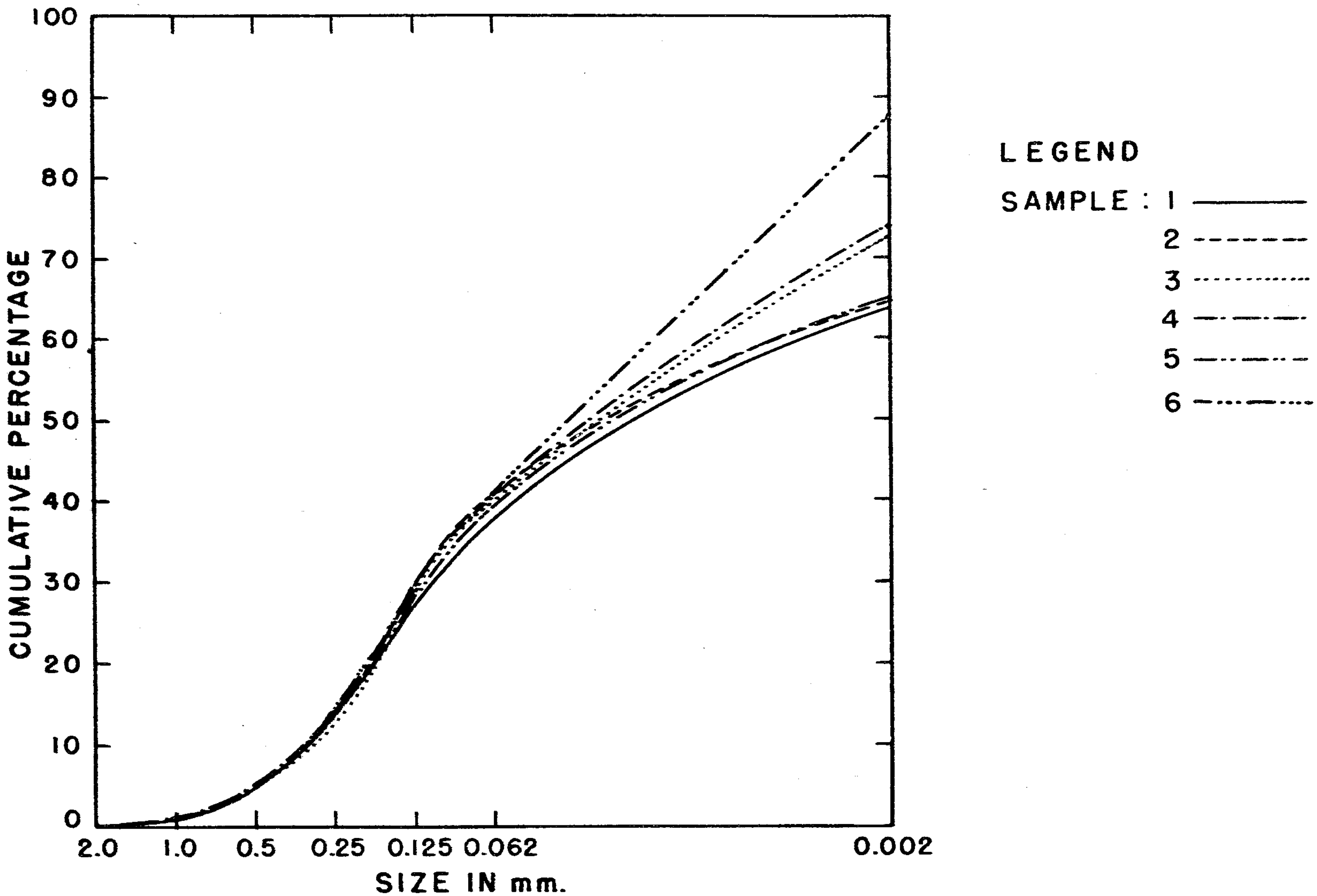
Profile location No.	Distance from surface, inches
1	24 to 25
2	21 to 23
3	25.5 to 26.5
4	23.4 to 24.5
5	23.5 to 24.5

HEAVY MINERAL FRACTION AS PERCENT
OF 100-MESH TO 200-MESH SAND FRACTION

Sample No.	Profile location No.				
	1	2	3	4	5
1	0.96	1.35	2.62	1.81	1.83
2	1.08	1.64	3.14	1.35	2.05
3	1.03	1.54	2.37	1.68	2.10
4	0.99	1.55	2.44	1.87	2.12
5	0.88	1.44	2.62	1.92	1.95
6	1.12	1.53	2.44	1.58	1.95

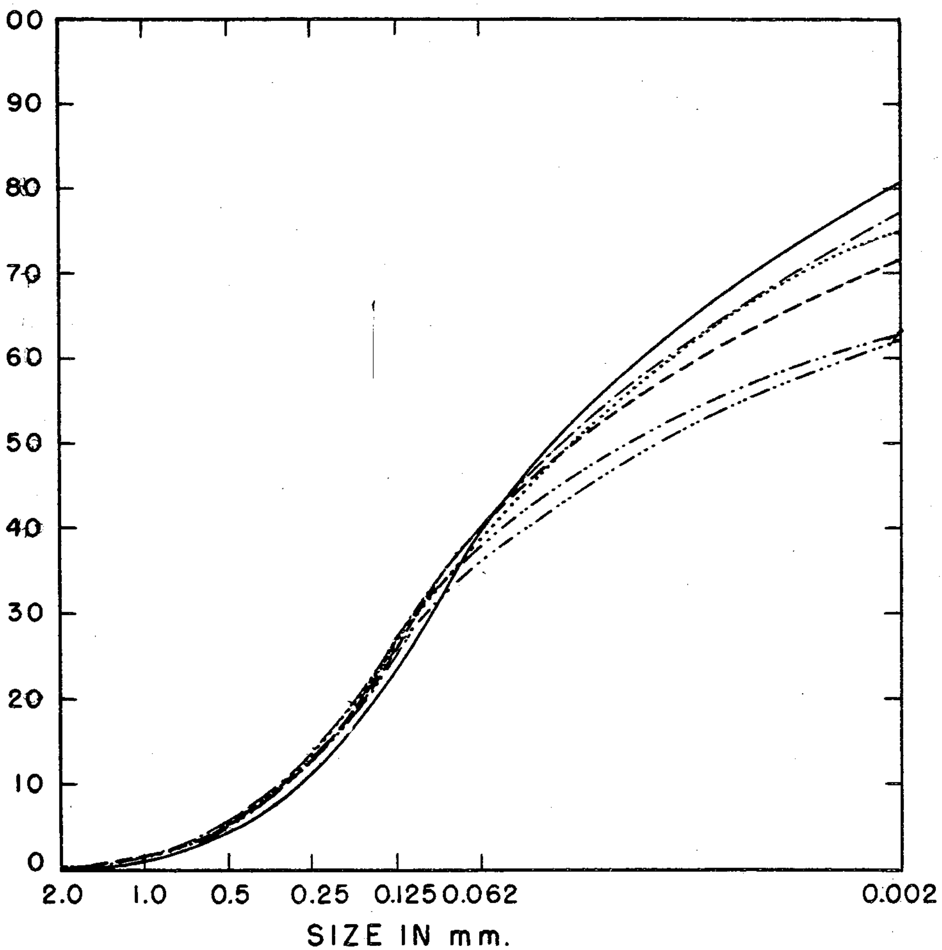
APPENDIX B
MECHANICAL ANALYSIS OF PROFILE SAMPLES

CUMULATIVE CURVES
PROFILE I

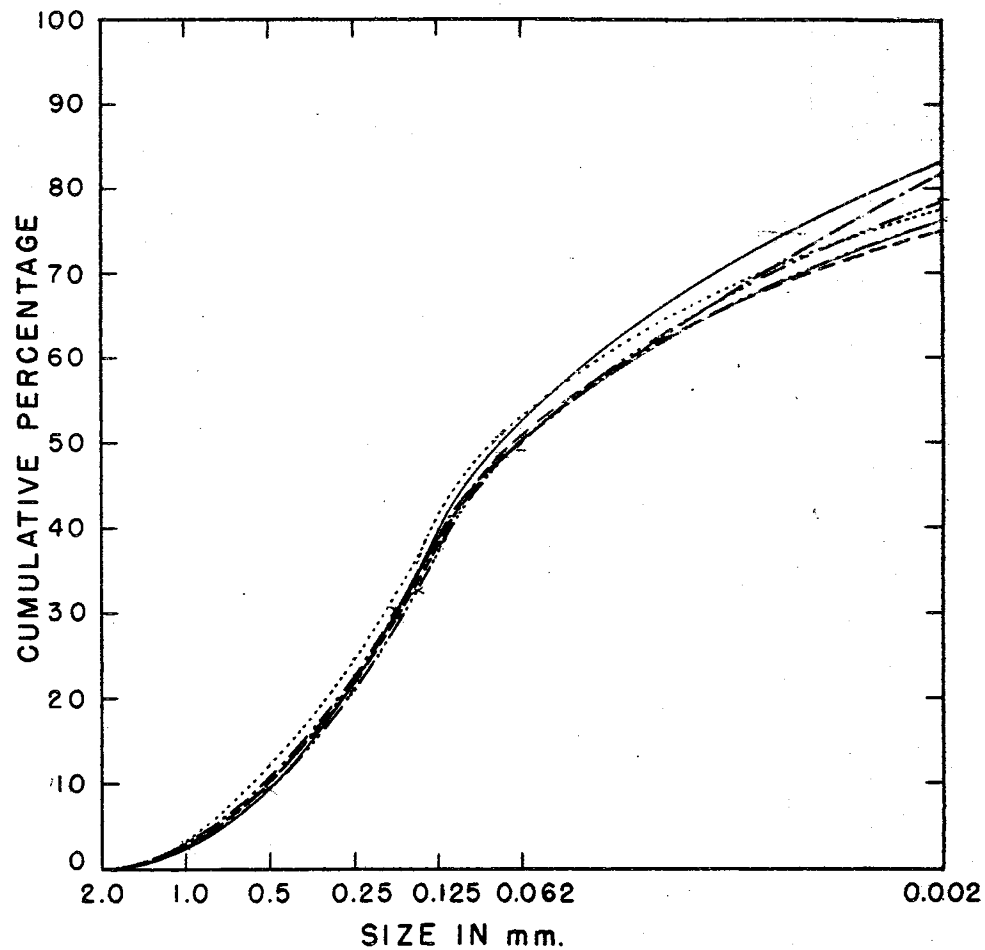


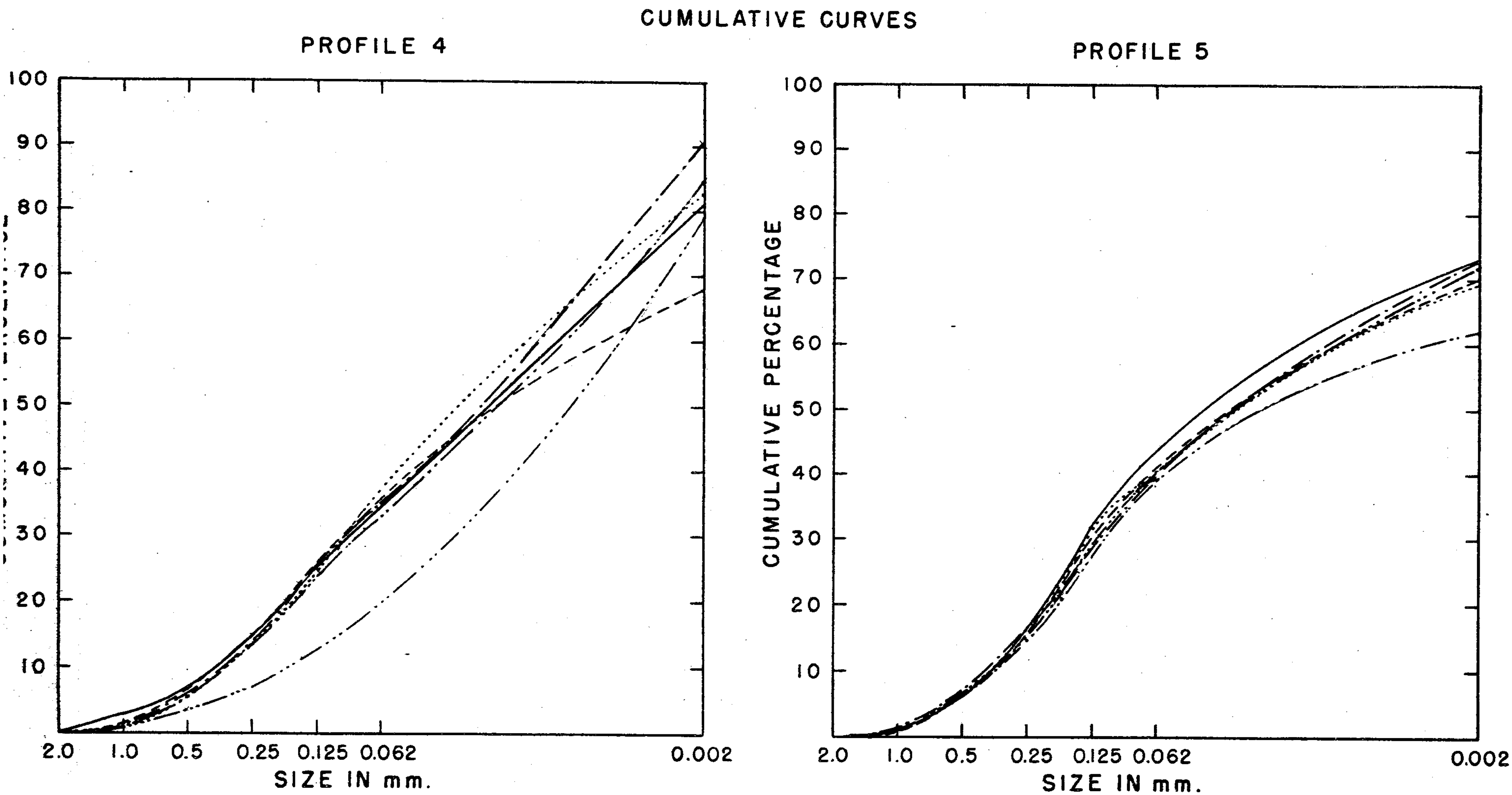
CUMULATIVE CURVES

PROFILE 2



PROFILE 3





CUMULATIVE CURVES
PROFILE 4
PROFILE 5
100
90
80
70
60
50
40
30
20
10
CUMULATIVE PERCENTAGE
2.0
1.0
0.5
0.25
0.125
0.062
0.002
SIZE IN mm.

APPENDIX C

Table I
HEAVY MINERAL ANALYSIS OF PROFILE No. 1
(Values shown are in percent; tr - denotes trace)

Mineral	Sample No. *					
	1-1	1-2	1-3	1-4	1-5	1-6**
Hornblende:						
metamorphic	21.5	24.8	20.3	22.2	22.4	19.6
basal	tr		tr	tr	tr	
black	tr	tr	tr	0.8	tr	0.8
altered	tr	1.8	1.6	1.3	1.2	1.9
Tremolite	tr	tr	tr	tr	tr	0.8
Pyroxenes (mono.):						
colourless	2.2	1.0	1.6	1.5	1.2	1.6
Augite	tr	tr	tr	tr	1.2	tr
Pyroxenes (ortho.):						
Hypersthene	1.6	1.0	1.9	1.3	2.1	1.6
Enstatite	tr	tr	1.4	1.5	tr	tr
Epidote	4.6	3.6	3.3	2.8	3.2	4.5
Zoisite	tr	tr	tr		tr	tr
Garnet:						
white	7.9	10.8	12.3	10.6	9.4	8.7
pink	tr	tr	1.4	tr	tr	tr
red		tr		tr		
brown			tr			tr
Magnetite	15.8	16.8	12.3	16.0	17.9	18.0
Limonite	28.0	23.7	24.7	22.7	23.8	24.9
Apatite	1.9	3.9	2.8	2.6	2.9	3.4
Tourmaline	1.6	0.8	1.1	1.0	tr	0.8
Zircon	tr	tr		1.5	2.6	0.8
Titanite	1.9	tr	0.8	0.8		0.8
Rutile		tr	tr	tr	tr	
Topaz		tr		tr		
Staurolite	1.1		tr		0.9	tr
Andalusite	0.8			tr	1.2	0.8
Monazite	0.8	tr	0.8	1.0		tr
Sillimanite	tr	tr				tr
Chlorite					tr	
Chloritoid				0.8		
Leucoxene			tr	1.5	tr	
Anhydrite		tr	tr			
Biotite	tr	tr	1.1	tr	0.9	1.6
Kyanite			tr			
Pyrite			tr	tr	0.9	
Glaucophane			tr			
Altered to:						
white	3.5	4.9	5.8	5.7	3.2	3.4
brown	2.2	1.0				1.1
black						tr
Unidentified	tr	tr	tr	tr	tr	0.8

* See Appendix A for location of profile and depth of sample.
** Sample No. 1-6 means sample No. 6 at profile location No. 1.

Table II
HEAVY MINERAL ANALYSIS OF PROFILE No. 2
(Values shown are in percent; tr - denotes trace)

Mineral	Sample No. *					
	2-1	2-2	2-3	2-4	2-5	2-6 **
Hornblende:						
metamorphic	48.9	42.6	42.8	33.6	35.8	34.5
basal	0.8	1.1	1.5	tr	tr	0.7
black	tr	0.8	0.8	1.0	0.8	0.7
altered	1.7	1.9	1.3	2.0	tr	1.5
Tremolite	0.8	tr		tr		1.5
Pyroxenes (mono.):						
colourless	1.4	1.1	2.1	2.1	1.7	0.7
Augite	1.1	tr		1.0	1.1	
Pyroxenes (ortho.):						
Hypersthene	1.4	1.9	1.8	4.9		tr
Enstatite	1.1		tr		tr	tr
Epidote	2.5	3.3	2.8	3.9	5.0	4.0
Zoisite	0.8		0.8	tr	0.7	tr
Garnet:						
white	8.7	9.0	10.2	8.8	14.3	11.5
pink	tr	tr		1.0		1.0
red	tr			tr		
brown	tr			tr		tr
Magnetite	8.7	11.5	10.2	14.9	15.7	13.2
Limonite	11.2	11.8	10.5	8.6	7.8	15.7
Apatite	2.2	2.5	2.1	3.9	5.0	3.2
Tourmaline	tr	tr	tr	tr	1.7	0.7
Zircon	tr	tr	tr	1.0	2.2	1.7
Titanite	1.1	0.8	0.8	0.8	tr	tr
Rutile	tr	tr	tr	0.8	tr	0.7
Topaz				tr	tr	tr
Staurolite		tr	tr	tr	tr	tr
Andalusite	tr	1.4	1.3	tr	tr	tr
Monazite		1.1		tr	tr	
Sillimanite	tr		tr	tr	tr	tr
Chlorite		tr				tr
Chloritoid	tr		tr	tr		
Leucoxene		tr		1.8	1.0	
Anhydrite						tr
Biotite		0.8		tr	1.1	tr
Gold					tr	tr
Kyanite		tr				
Glaucophane	tr					tr
Altered to:						
white	2.6	4.1	4.1	4.6	2.5	2.2
brown		tr	1.0			
black				tr		tr
Unidentified	tr	tr	1.0	tr	tr	tr

* See Appendix A for location of profile and depth of sample.
** Sample No. 2-6 means sample No. 6 at profile location No. 2.

Table III
HEAVY MINERAL ANALYSIS OF PROFILE No. 3
(Values shown are in percent; tr - denotes trace)

Mineral	Sample No. *					
	3-1	3-2	3-3	3-4	3-5	3-6**
Hornblende:						
metamorphic	41.6	47.2	49.6	44.4	38.7	40.2
basal	tr	tr		0.8	2.0	1.3
black	1.7	0.8	0.8	tr	tr	0.8
altered	0.8	1.1	1.1	1.3	1.5	0.8
Tremolite	1.4	0.8	1.9	1.0	1.8	tr
Pyroxenes (mono.):						
colourless	1.4	1.4	1.1	2.6	1.7	2.9
Augite	1.1	tr	1.3	1.3	1.5	tr
Pyroxenes (ortho.):						
Hypersthene	1.7	1.7	1.9	1.1	3.8	2.6
Enstatite	tr		tr	1.0	tr	tr
Epidote	0.8	1.7	1.1	1.3	1.7	2.6
Zoisite		tr			tr	
Garnet:						
white	15.6	17.9	16.6	12.6	14.7	14.6
pink	1.1	1.4	0.8	tr	tr	tr
red	1.4	tr		tr		
brown	1.1			tr	tr	0.8
Magnetite	16.7	9.6	10.2	11.3	11.4	15.4
Limonite	3.6	4.5	3.3	5.5	7.0	5.3
Apatite	1.9	2.5	3.0	4.5	4.0	4.8
Tourmaline		0.8	0.8	tr	1.0	tr
Zircon	tr	tr	1.1	tr	tr	1.3
Titanite	tr	0.8	0.8		tr	0.8
Rutile		0.8	tr	tr	0.8	
Topaz			tr		tr	tr
Staurolite	tr		tr	0.8	tr	tr
Andalusite	tr	1.1	tr	tr	tr	tr
Monazite	1.1	tr	tr	tr	tr	
Sillimanite				tr		
Chlorite	tr					
Chloritoid	tr	tr				
Anhydrite				tr		
Biotite					tr	tr
Gold						tr
Kyanite		tr	tr			
Altered to:						
white	2.5	1.7	2.5	3.4	3.4	1.6
brown		tr	tr			
black					0.8	
Unidentified	tr	tr	1.3	tr	tr	tr

* See Appendix A for location of profile and depth of sample.
** Sample No. 3-6 means sample No. 6 at profile location No. 3.

Table IV
HEAVY MINERAL ANALYSIS OF PROFILE No. 4
(Values shown are in percent; tr - denotes trace)

Mineral	Sample No. *					
	4-1	4-2	4-3	4-4	4-5	4-6**
Hornblende:						
metamorphic	30.1	29 5	37.1	33.9	39.5	34.6
basal	0 7	1.0	1.8	1.7	tr	1.1
black	2.5	1.3	0.8	3.4	1.3	tr
altered	1.9	tr	tr	tr	tr	tr
Tremolite	2.2	1.2	2.0	2.2	1.1	1.1
Pyroxenes (mono.):						
colourless	1.0	tr	0.8	1.4	0.8	1.9
Augite	1.0	tr	1.3	tr	2.2	tr
Pyroxenes (ortho.):						
Hypersthene	1.0	1.5	1.0	2.2	2.4	1.9
Enstatite	1.5	tr	1.0	1.0	tr	1.8
Epidote	3.7	3.9	5.9	2.9	2.4	3.5
Zoisite	tr		tr	tr	tr	
Garnet:						
white	13.9	28.3	11.0	11.5	15.2	11.4
pink	tr	0.7	1.3	tr	0.8	0.8
red		1.2		tr	tr	tr
brown		tr			tr	
Magnetite	10.9	11.5	14.3	13.0	15.9	16.0
Limonite	10.7	7.1	7.7	10.8	4.3	11.1
Apatite	2.9	2.7	3.1	2.6	2.9	2.7
Tourmaline	0.7	tr	1.0	0.7	1.3	1.3
Zircon	1.2	1.2	0.8	0.7	tr	tr
Titanite	tr	tr	tr	0.7	tr	tr
Rutile	tr		0.8		tr	tr
Topaz	tr		0.8		0.8	
Staurolite	tr	tr	tr	0.7	tr	tr
Andalusite	1.2	tr	tr		0.8	0.8
Monazite		tr	tr			tr
Sillimanite		tr	tr		tr	
Chlorite	tr	tr	tr	tr		
Chloritoid				tr	tr	
Leucoxene	0.7	tr	1.0	0.7		
Anhydrite				tr		
Biotite	2.7	tr		0.7	tr	tr
Kyanite			tr	tr		
Altered to:						
white	6.5	1.2	2.6	4.1	2.4	4.9
brown			tr	tr		
black		1.7	0.7	tr		1.3
Unidentified	tr	tr	0.8	1.2	0.8	tr

* See Appendix A for location of profile and depth of sample.
** Sample No. 4-6 means sample No. 6 at profile location No. 4.

Table V
HEAVY MINERAL ANALYSIS OF PROFILE No. 5
(Values shown are in percent; tr - denotes trace)

Mineral	Sample No. *					
	5-1	5-2	5-3	5-4	5-5	5-6 **
Hornblende:						
metamorphic	37.9	43.1	45.1	40.7	41.4	48.6
basal	tr		tr	1.2		1.0
black	2.0	tr	tr	0.7	tr	0.8
altered	3.1	tr	2.1	2.7	tr	0.8
Tremolite	tr	tr	0.8		0.8	1.5
Pyroxenes (mono.):						
colourless	1.8	2.2	1.6	2.0	1.7	3.3
Augite	0.8	1.9	tr	tr	1.4	0.8
Pyroxenes (ortho.):						
Hypersthene	1.5	1.9	2.1	3.7	0.8	tr
Enstatite		tr	0.8		tr	tr
Epidote	1.8	2.4	1.9	2.9	2.5	2.8
Zoisite	tr	tr			tr	
Garnet:						
white	14.6	13.8	15.1	14.3	14.9	9.4
pink	1.0	tr	1.0	tr	tr	1.0
red			0.8			
brown	tr	0.8	tr	tr	tr	
Magnetite	14.9	12.5	17.2	10.1	17.9	7.4
Ilmenite	8.4	8.7	4.0	6.4	4.4	9.7
Apatite	2.0	2.4	2.1	4.2	2.2	2.0
Tourmaline	tr	tr	tr	2.0	tr	tr
Zircon	0.8	tr	tr	1.0	2.2	tr
Titanite	tr	1.1		tr	0.8	1.0
Rutile			tr			tr
Topaz	tr			tr		tr
Staurolite	tr	tr		tr	tr	tr
Andalusite	tr		tr	0.7	tr	0.7
Monazite	tr	tr	tr	0.7		
Sillimanite		tr		0.7	tr	
Chlorite		tr		tr	tr	
Leucoxene			tr			tr
Anhydrite				tr		tr
Biotite		0.8		0.8		1.8
Gold		tr		0.7		
Altered to:						
white	3.8	1.9	2.1	1.7	2.2	2.0
black	tr	tr		tr	tr	0.8
Unidentified	tr	tr	tr	tr	tr	1.0

* See Appendix A for location of profile and depth of sample.
** Sample No. 5-6 means sample No. 6 at profile location No. 5.