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SOME CHARACTERISTICS AND PHYSICAL PROPERTIES OF ALBERTA TILLS

by

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ABSTRACT

Maps depicting the regional variation in the chemical and mineralogical composition, and physical properties of tills from throughout the plains region of Alberta were prepared by a computer with an attached plotter.

The chemical constituents and properties analyzed and discussed are: copper, zinc, manganese, calcium, boron, molybdenum, cobalt, pH, and soluble salts. The mineralogical components included are clay minerals and feldspars. The physical properties included are particle-size distribution, liquid limit and plastic limit, on the basis of which a number of additional engineering properties were calculated and discussed: plasticity number, plasticity, activity and corrosion potential.

Generally, the lithology of the till closely reflects that of the underlying bedrock. A noticeable exception is the distribution of soluble salts, the origin of which is more likely related to groundwater phenomena.

INTRODUCTION

Glacial till is by far the most significant parent material from which Alberta soils develop. Till deposits comprise approximately 70 per cent of the surficial deposits. They vary in thickness from less than 10 feet in much of the flat to gently rolling ground moraine, to more than a 100 feet in many buried preglacial river valleys and in regions of hummocky moraine.

By definition, glacial till is material deposited directly from glaciers without washing or sorting. The inherent characteristics vary widely and largely reflect the nature of the underlying bedrock. Information on the chemical, mineralogical, and physical composition of till is still limited, although variation in composition has been studied previously (Gravenor and Bayrock, 1961; Bayrock and Pawluk, 1966).

The composition of glacial till is of considerable significance in soil classification in that till contributes such inherent characteristics to the soil solum as color, texture, structure, mineralogical composition and the physico-chemical properties of major importance. It also provides criteria for distinguishing soils in the taxonomic classification at the "series" level of abstraction.

Soils are well known as reservoirs of plant nutrients. Some nutrient deficiencies in economically useful crops are known to be directly attributable to the lack of essential elements in the parent soil in forms that are available to plants. While considerable investigation has been conducted on the major nutrient distribution in Alberta soils, virtually nothing has been published on minor element distribution. Although the presence of certain elements in parent material does not of necessity ensure their availability to plants, a knowledge of their content may contribute a great deal to assessing areas of possible nutrient deficiencies. Similar studies conducted in unglaciated regions of the world provide data that not only coincides with nutrient deficiencies in plants but also relates to the incidence of certain human and animal disorders.

Physico-chemical properties, reflecting mineralogy and composition, profoundly influence the performance of glacial till as construction material.

In order to obtain a regional appraisal of parent material composition, glacial till samples were collected on a random basis over most of the accessible portions of Alberta. These samples were analyzed for twenty-two parameters considered to characterize the parent geologic materials from which soils form.

Other glacial deposits, such as lake clays and outwash, were not studied. These materials have originated from sorting of debris contained in or on a glacier, thus their composition not only reflects the nature of the glacial drift but also the degree of local sorting. Glacial tills of the Cordilleran region were not studied as the large local variation in composition does not lend itself to regional studies.

Bedrock Geology

Alberta can be divided into three major geologic "provinces" which correspond approximately to the major physiographic divisions of the province (Fig. 1). These are:

(1) Canadian Shield — a small area of Precambrian crystalline rocks in the northeastern corner of the province, adjacent to Lake Athabasca;

(2) Plains region — a relatively flat area underlain by gently dipping strata of Paleozoic, Cretaceous, and Tertiary ages; this constitutes most of the province; and

(3) Rocky Mountains and Foothills — a band of complexly folded and faulted sedimentary strata extending along the southwestern margin of the province.

The bulk of the till samples collected for this investigation come from the Plains region, which in turn is divisible on the basis of bedrock age and lithology into three areas:

(1) an area adjacent to the Canadian Shield in northeastern Alberta, underlain by carbonate and evaporite rocks of Devonian age;

(2) most of the northern, east-central, and southern Plains, underlain by interbedded marine and nonmarine Cretaceous sandstones and shales; and

(3) an arcuate portion of the west-central and southwestern Plains adjacent to the Foothills, underlain by nonmarine sandstones and shales of Cretaceous and early Tertiary age.

The Cretaceous and Tertiary rocks, which together underlie all but the northeastern part of the Plains, constitute a thick succession of interbedded marine and nonmarine strata, composed mainly of sandstone and silty shale with subordinate amounts of coal, bentonite, clay-ironstone and volcanic ash. Some general distinctions in lithology and composition can be made among these rock units, but in gross aspect the various sandstones and shales appear similar.

The marine beds that crop out extensively in northern Alberta, adjacent to the Peace and Athabasca River lowlands, are dominantly dark grey shale and siltstone, with lesser amounts of sandy detritus. In contrast, much of central and southern Alberta is underlain by mixed sandstone-shale formations of nonmarine origin, which contain a high proportion of sandy detritus. The late Cretaceous and Tertiary strata of west-central Alberta are entirely nonmarine and appear to differ from the underlying Cretaceous beds mainly in the details of mineral composition and lithology.

The main compositional features of the Cretaceous-Tertiary rocks of the Alberta Plains are:

(1) the presence of abundant montmorillonite in both sandy and shaly units; and

(2) the high proportion of unstable igneous (volcanic) detritus in the sand fraction.

These rocks are composed of essentially three mineral fractions:

(1) siliceous and micaceous detritus derived from a metasedimentary source area to the west of the present limits of outcrop;

(2) abundant volcanic (reworked and pyroclastic) detritus from the same source as (1) above; and

(3) a chemically precipitated fraction (siderite, calcite, clay minerals, zeolites) formed in the rocks after burial and deposition.

The ubiquitous montmorillonite content of these rocks is the result of the post-depositional alteration of unstable volcanic detritus, varying in amount from one formation to the next.

Glacial Geology

During late Pleistocene time a Keewatin-centered Continental ice sheet overran most of Alberta, advancing generally from the north-northeast. A Cordilleran ice sheet advancing eastward from the Rocky Mountains met the Continental ice in the Foothills area. The two ice sheets coalesced and flowed along the eastern margin of the Foothills in a south-southeasterly direction. The multitude of local ice-front fluctuations during retreat stage obscures the picture of the advance to some extent, but the major trends are evident (Gravenor and Bayrock, 1961). As a result of this glaciation, practically all Alberta is now covered by a veneer of glacial deposits ranging in thickness from a few inches to hundreds of feet. The common surficial deposit of the glaciers is till, an unsorted admixture of local bedrock and of "foreign" rock material from some distant source, such as the Canadian Shield. However, the bulk till material is locally derived, and therefore till composition largely reflects that of underlying or nearby strata.

The composition of the Continental and Cordilleran tills in Alberta differs in two main respects:

(1) the Cordilleran tills contain a high proportion of carbonate materials derived from the Paleozoic rocks of the Rocky Mountains; the Continental tills, except in the Paleozoic outcrop areas of northeastern Alberta, have low carbonate contents; and

(2) the Cordilleran tills are quite stony, containing a high proportion of gravel-size material; the Continental tills consist mainly of sand and clay-size materials.

Lacustrine sediments were deposited over large areas of Alberta where meltwaters were impounded in front of the glaciers during deglaciation. The main distinction between till and associated proglacial deposits is that the lacustrine, outwash, and aeolian materials are derived from till (and hence ultimately from local bedrock) through sorting of clayey and sandy constituents.

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Table 1. Summary of Analytical Procedures

CHEMICAL

(1) pH

(2) resistivity measurements:
  - (i) soluble-salt content
  - (ii) corrosivity

(3) elemental analyses specific for:
  - (i) cobalt
  - (ii) boron
  - (iii) copper
  - (iv) iron
  - (v) manganese
  - (vi) calcium
  - (vii) zinc
  - (viii) molybdenum
  - (ix) inorganic carbon in selected samples

MINERALOGICAL

(1) analyses performed on the clay fraction (<2 microns) of selected samples:
  - (i) elemental analyses
  - (ii) cation exchange
  - (iii) differential thermal
  - (iv) X-ray diffraction
  - (v) electronmicrographs
  - (vi) specific surface

(2) analyses performed on the clay fraction (<2 microns) of all samples:
  - (i) X-ray diffraction

(3) analyses performed on the light mineral fraction (S.G.<2.7) in the 0.10 to 0.15 mm size range:
  - (i) X-ray diffraction
  - (ii) elemental analyses

PHYSICAL

(1) particle-size distribution

(2) Atterberg limits:
  - (i) plastic limits
  - (ii) liquid limits
  - (iii) plasticity indexes

(3) from (1) and (2) activity number

SAMPLING AND ANALYTICAL PROCEDURES

Sampling was conducted through those parts of the province covered by the Continental Keewatin ice sheet. An arbitrary approach was necessary since access into many areas was limited. The northern portion of the province was sampled during the course of an exploratory soil survey conducted by helicopter during the years from 1958 to 1963, inclusive. Samples from the remainder of the province were obtained during the same period by through travel on roads. In addition, some samples were collected by Alberta Soil Survey staff during the course of their field work.

Samples were obtained from visually unaltered till from depths ranging from 2 to 8 feet and were free from the effects of soil-forming processes. A total of 475 samples were collected, representing an area of 170,000 square miles, or about 65 per cent of the area of Alberta. The sampling density is variable, the average being about one sample per ten townships (360 square miles). Locations of samples are shown in figure 2.

About one-third of the unsampled area, along the southwestern margin of the province, is covered by drift from the Rocky Mountains. The remainder of the unsampled area is of difficult access or is covered by surficial deposits other than till, as in the large areas of northern Alberta which are covered by lacustrine sediments. Boundaries of the major unsampled areas are shown by solid lines on all the illustrations.

Chemical Determinations

The pH of the till samples was determined by the soil paste method (Doughty, 1941). Soluble salt content was determined by resistivity measurements on extracts from 1 : 1, soil-water pastes. Elemental chemical determinations were performed on saturation extracts (U.S.D.A. Salinity Handbook #60, 1954).

A rapid powder-spark technique, using an emission spectograph, was employed for the analyses of cobalt, boron and copper. Iron, manganese and calcium were determined by X-ray fluorescence. A direct current arc rack-up technique was used for zinc and molybdenum. The results were checked by wet chemical analyses of spot samples. Inorganic carbon in selected samples was determined with the aid of a Leco carbon analyzer.

Mineralogical Analyses

Clay minerals were identified by X-ray diffraction methods. The X-ray diffraction powder patterns obtained for all samples were grouped into categories based on peak heights and areas under the peaks. Selective sampling provided 80 representative samples from all categories and on these 80 samples a number of subsequent determinations were performed: elemental analyses were conducted on samples pretreated with hot concentrated acid and subsequently dissolved with hydrofluoric acid; aluminum,

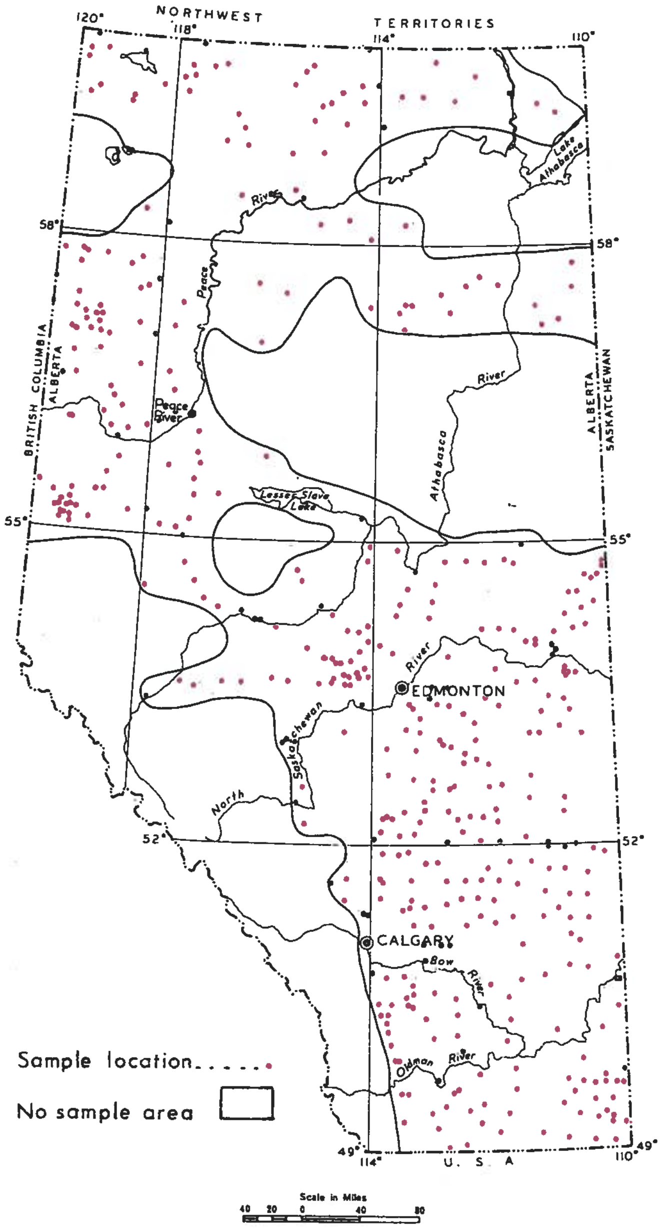

FIGURE 2. Sample location map.

magnesium, potassium and iron were determined with the aid of a Perkin-Elmer Model 303 atomic absorption unit; loss on ignition was determined by the standard procedure prior to dissolution (Atkinson *et al.*, 1958); cation exchange capacities were determined by saturating the clays with 1 Normal sodium acetate, washing with 80 per cent ethanol and displacing the exchangeable sodium ions by leaching with 1 Normal ammonium acetate; sodium was determined in the extract with the atomic absorption unit; differential thermal analyses were conducted on calcium-saturated clays with the aid of an Amino D.T.A. unit; specific surface areas were determined according to the procedure outlined by Heilman *et al.* (1966). Assignments for surface area and cation exchange capacity for clay components identified were as follows:

	Surface area (M^2/g)	C. E. C. (meq/100g)
Montmorillonite	980	90-100
Hydrous mica	10	18- 24
Kaolinite	10	7- 12
Chlorite	10	25- 30
Quartz	trace	trace

After establishment of a semi-quantitative base for the 80 samples, the X-ray diffraction patterns were used for regrouping the remainder of the samples within the established base, and for estimation of the clay mineral composition.

The light-mineral fraction, with a specific gravity of less than 2.75 and a size range of between 0.10 and 0.15 mm, was analyzed. The principal minerals present were identified by X-ray techniques, and quantitative estimates of potash feldspars and plagioclase feldspars were obtained by stoichiometric allocation following sample solution in hydrochloric and hydrofluoric acids and elemental determination with the atomic absorption unit.

Physical Determinations

Particle-size distribution was determined by a modified pipette technique (Toogood and Peters, 1953). Atterberg limits were determined according to ASTM Standard Methods D-423-66 and D-424-66 (ASTM, 1967).

Correlation Analysis and Map Preparation

Contour maps summarizing the analytical data were prepared by the procedure outlined in appendix A. Correlation coefficients (r-values) and scatter diagrams were obtained by computer for all measured parameters (See Appendices C, D).

CHEMICAL PROPERTIES OF GLACIAL TILLS

Analytical data were collected for ten parameters considered to be of significance for defining the geochemical properties of tills. These data were averaged according to the analytical technique outlined in appendix A, and the results presented in the form of contour maps (Figs. 3 - 12). Correlation analyses were conducted to determine if relationships existed among these properties (Appendices C, D). The most important relationships are:

(1) moderate positive correlations* among the contents of the elements: iron, boron, cobalt, copper, zinc and molybdenum;

(2) low negative correlations* of elements in (1) with calcium oxide content;

(3) low to moderate positive correlations* of elements in (1) with clay content; and

(4) moderate correlations* of calcium oxide with pH.

On the basis of these relationships, several conclusions may be drawn:

(1) the minor elements iron, boron, cobalt, copper, zinc and possibly molybdenum generally originated from a common source, and are principally associated with the clay-size fraction of the tills;

(2) calcium oxide content in the till reflects a relationship with silt-sized, calcitic and dolomitic material incorporated from Paleozoic strata; and

(3) the concentration of calcitic and dolomitic rock material has a significant influence upon the pH values.

Measured parameters for glacial tills vary systematically across the province and demonstrate a relevance to other characteristics of the regional geology. These variations and relationships are discussed in some detail in the following paragraphs.

Calcium Oxide and pH

Calcium oxide content in the glacial till samples ranges from 0.2 to 45.0 per cent across the province (Fig. 3; Appendix B). However, concentrations of more than 10 per cent calcium oxide are confined to limited areas adjacent to the Foothills region, and to the northeasterly part of the province, indicating a relationship to the source areas of limestone and

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* See appendix C for explanation of terms.

dolomite. Although sampling was limited ostensibly to Keewatin (Continental) till, three high calcium oxide values in west-central Alberta samples indicate that Cordilleran tills were in fact sampled. Other high calcium oxide values along the southwestern border of the sampling area possibly reflect incorporation into the tills of carbonate rocks from preglacial river gravels. A small area with high calcium oxide contents in the southeastern portion of the province coincides with a probable dolomite boulder train extending west from central Saskatchewan (Westgate, 1968).

The calcium oxide distribution in northern Alberta (Fig. 3) is of interest. Apart from the northeastern corner of Alberta, where Paleozoic dolomites and limestone are exposed, most of the area is underlain by Cretaceous shales and sandstones of low-lime content. However, high calcium oxide contents are found in tills west and south of the Caribou Mountains, whereas tills on top of these hills have low calcium oxide contents. The relatively sharp boundaries of the high calcium oxide areas, together with fluting directions and other glacial features, suggest that these high-lime tills represent a distinct late glacial phase or readvance. The interpretation made is that one ice lobe advanced around the east and south flanks of the Caribou Mountains while another advanced up the broad valley west of this upland region.

Relatively low concentrations of calcium oxide, from 0.2 to 2.0 per cent occur throughout the north-central region of the province, with extremely low quantities evident in the Clear Hills and adjacent areas and on top of the Birch Mountains. These values are representative of tills derived largely from the underlying Cretaceous shales and sandstone. Comparable low calcium oxide contents may be expected for other high-plain remnants of lesser extent in northern Alberta.

A comparison of data with results obtained for calcium carbonate-equivalent (determined as inorganic carbon) in a selected number of samples suggests a close correlation. These data, together with X-ray diffraction patterns, show a major portion of the calcium oxide to occur in the tills as dolomitic and limestone materials, and only a minor portion as silicate minerals such as feldspars.

The areas of higher calcium oxide contents in the central and southern regions of the province coincide closely with the areal distribution of Chernozemic soils. One of the diagnostic features in the taxonomic classification of these soils is the presence of an horizon of calcium carbonate accumulation in the soil profile. On the basis of calcium oxide distribution as depicted on figure 3, it may be expected that sufficient concentrations of calcium carbonate occur in the glacial tills of central and southern regions of Alberta for pedogenically developed Bca and Cca horizons to be formed. Furthermore, the presence of calcium carbonate in the glacial tills of these regions substantiates the fact that all Chernozemic soils developed on glacial tills of Alberta have calcareous parent materials and that they are properly designated as Ck horizons.

High-lime soils, mapped by the Alberta Soil Survey largely as calcareous and Rego Chernozemic soils, occur in abundance in regions where glacial tills have relatively high contents of calcium oxide. Calcareous soils are characterized by the presence of an Ah horizon underlain by a weakly developed calcareous B horizon, with an horizon of lime accumulation below. The B horizon is lacking in Rego Chernozemic soils. Genetically, the weak development or lack of a B horizon results from incomplete removal of the lime by leaching. This situation may be expected where the calcium carbonate content is sufficiently high that leaching has not yet moved the calcareous material into the lower sola and, on steep slopes, where precipitation tends to run off rather than infiltrate, and thus leaching is minimal. The former situation is prevalent throughout those areas of calcium oxide-rich glacial tills.

Luvisolic soils, principally the Grey Wooded and Dark Grey Wooded, are developed on till in better-drained topographic positions through the northern portion of the province. Although these soils are generally described as being developed on calcareous parent material, the low calcium oxide contents for much of the area suggest that this is not generally the case. In fact, in most instances no recognizable horizon of calcium carbonate accumulation exists in the soil sola nor is there evidence of limestone or dolomite deeper in the profile. Podzolic soils with well-developed horizons of lime accumulation and calcareous parent materials do, however, exist throughout the lowlands adjacent to the Caribou Mountains where high contents of calcium oxide are found in the glacial till.

A moderate correlation (N=473, r=0.49) exists between calcium oxide content and pH of the glacial tills. This relationship is to be expected since the major portion of calcium oxide occurs in the carbonate form which, upon hydrolysis, has a profound influence upon soil reaction. Glacial tills containing relatively high concentrations of calcium oxide range in pH from 7.5 to 8.5, those with intermediate concentrations range from 6.5 to 7.5 and those with relatively low concentrations range from 4.0 to 6.5.

Tills of highest acidity occur in the Clear Hills and Buffalo Head Hills (Fig. 4) and these presumably reflect the compositional influence of the iron-rich strata of the Cretaceous Smoky Group. Within this succession of marine shales with common pyrite, the Bad Heart Formation contains thin, lenticular, but widely distributed beds of oolitic, iron-rich sandstone. Among the sandstone components are variable quantities of siderite and amorphous ferrous opaline glass. Such components, bearing ferrous iron, readily oxidize and upon hydrolysis release protons to the surrounding media. The resulting low pH values thus reflect, to a large extent, the degree of oxidation that has occurred.

Responses to lime application for agronomic purposes have been reported for the acid soils in this region (Hennig *et al.*, 1967). However, for economic reasons, lime is not generally recommended as an amendment for all crops.

Iron

The content of iron in Alberta tills (Fig. 5; Appendix B) increases from less than 2 per cent in the northeast to more than 3.25 per cent in northwestern Alberta. Concentrations of more than 4 per cent occur at the intersection of the 57th parallel and the boundary of British Columbia. By comparing figures 1 and 4 it can be seen that the region with less than 2 per cent iron coincides with an area predominantly underlain by Devonian carbonates and evaporites.

Till in southern and central Alberta is characterized by iron values ranging from 2 to 3.25 per cent, and is correlative in composition with underlying upper Cretaceous and Paleocene nonmarine rocks. The general rise in iron content to the northwest reflects the increasing influence of the pyrite-bearing Cretaceous Smoky Group marine strata. Incorporation of iron-rich, oolitic material from the Bad Heart Formation into the tills doubtless accounts for the high iron contents in the Clear Hills area.

As 45 per cent of the variation in iron content can be accounted for by variation in the clay content (clay-size fraction), a substantial portion of the iron is found in this fraction (Table 5). Analytical data suggest that the composition of the various clay mineral groups varies across the province and that the iron present cannot be attributed to any specific clay mineral species. Lesser amounts of the iron are associated with the heavy mineral fraction (specific gravity > 3.0): principally hematite, magnetite and goethite in the Clear Hills region samples. Elsewhere, iron silicates such as biotite, amphiboles and pyroxenes as well as pyrite are more abundant. However, the heavy mineral fraction is generally less than 2 per cent, and in a majority of cases less than 1 per cent, of the total sand-size fraction of till samples.

The possibility of iron deficiencies, resulting from lime-induced chlorosis, in crops grown on Rego and calcareous Chernozemic soils developed from highly calcareous tills is unlikely for all but the more sensitive plants. Generally, sufficient quantities of iron silicates are present to release the required amounts for most crops.

Zinc

Although the distribution pattern of zinc in till is not as well defined as that of iron (Fig. 6; Appendix B), low values coincide, as for iron, with the northeastern Alberta Paleozoic region (50 ppm or less), medium values exist in southern and central Alberta (50-70 ppm), and the higher values again appear in northwestern Alberta.

Table 2. Zinc Contents of Cretaceous Bedrock Samples in Northwestern Alberta

Sample Number	Zinc (ppm)	Formation
BM-59-253	122	Wapiti
BM-59-261	67	Wapiti
BM-62-11	83	Puskwaskau
BM-59-200	109	Kaskapau
BM-62-16	58	Kaskapau
BM-62-33	216	Shaftesbury
BM-62-55	186	Shaftesbury
BM-62-44	96	Shaftesbury
CS-65-1	96	Shaftesbury
CS-65-2	168	Shaftesbury
CS-65-3	155	Shaftesbury
BM-59-444	131	Loon River
BM-62-68	178	Loon River

Analyses of thirteen bedrock samples from northwestern Alberta show an average zinc content of 128 ppm, with a range from 58 to 216 ppm (Table 2); the zinc contents of till in this area are thus a reflection of bedrock composition. According to Rankama and Sahama (1950) zinc content of clays and shales ranges between 80 to 1000 ppm. The zinc contents determined are thus not unusual for shales. Soils normally contain from 10 to

300 ppm of zinc, with average values of 30 to 100 ppm. Alberta tills are thus average in composition.

Although the quantities of zinc present in glacial tills are adequate for plant growth, deficiencies may result from a number of interacting factors related to clay mineral composition, alkalinity, organic matter content and microbial decomposition.

Copper

Copper is found in amounts ranging from 5 to 40 ppm (Fig. 7; Appendix B), and the distribution is similar to that of iron. In fact, 56 per cent of the variation in copper content can be accounted for by variation in iron content.

Three regions can again be distinguished: northeastern Alberta Precambrian and Paleozoic areas with tills containing less than 20 ppm copper; southern and central Alberta Cretaceous rock areas where the copper content ranges from 20 to 25 ppm; and the Clear Hills region in northwestern Alberta with more than 25 ppm copper. Four analyses of Bad Heart oolitic sandstone show an average copper content of 39 ppm and a range from 27 to 48 ppm. The copper content of till in the Clear Hills ranges from 35 to 39 ppm, substantiating the proposition that till is composed predominantly of local bedrock (Bayrock, 1962).

The usual content of copper in the soils is reported to be 2 to 100 ppm with an average of 20 ppm. Copper contents in excess of 100 ppm most commonly occur in soils near ore bodies, and this feature has served as a guide in geochemical prospecting (Swaine, 1955).

The chief function of copper in plants and soil is believed to be that of an oxidizing catalyst which affects both the health and yield of the plant. On the basis of the data obtained in this study it is unlikely that any major areas of copper deficiency occur in the study area, although it is still recognized that copper deficiencies in plants do not always correlate with low copper contents in the soil.

Manganese

Manganese content in the till samples varies from 0.008 to 0.055 per cent (Fig. 8; Appendix B). It is remarkably uniform throughout the southern half of the province, ranging from 0.030 to 0.045 per cent. A lower content, generally from 0.015 to 0.035, is more evident through the northern regions. Variation in manganese content shows no strong relationship to variation in other measured parameters.

The distribution of manganese in bedrock materials has not been studied, but nodules composed of iron and manganese oxides with a clay matrix are relatively common in southern Alberta, and rarer in northern Alberta. This general observation may be indicative of the over-all manganese content of bedrock, and thus of the distribution of manganese in tills.

The manganese content in most soils of the world ranges from 0.02 to 0.30 per cent, averaging 0.06 per cent (Swaine, 1955). Deficiencies usually occur in soils of high pH (6.7 or higher) and in the presence of considerable amounts of organic matter. On the basis of the foregoing it is unlikely that manganese deficiencies occur on a regional basis in Alberta.

Molybdenum

Molybdenum content is 1 ppm or less throughout most of Alberta south of latitude 55°, with contents of up to 3 ppm occuring in the north (Fig. 9; Appendix B).

Average values for total molybdenum in soils range up to 5 ppm, with 2 ppm as a mean. Molybdenum toxicity occurs in regions of the world where up to 100 ppm are reported, although small quantities are essential for normal plant growth. Molybdenum is not easily absorbed by plants from acid soils but rather from soils which contain free calcium carbonate and are alkaline in reaction.

Since the minimum values for molybdenum distribution in Alberta coincide with areas of high alkalinity, and also as the maximum values are not great, it is unlikely that any deficiencies or toxicity problems exist in the province.

Cobalt

The content of cobalt in glacial till samples is remarkably uniform throughout the province, generally ranging from 4 to 9 ppm, although a few samples contain as little as 2.5 or as much as 11 ppm (Fig. 10; Appendix B). The highest content occurs in the Clear Hills region.

Total cobalt content of soils usually ranges from 1 to 40 ppm, with values generally from 5 to 10 ppm. It is considered unlikely that any regional deficiencies of cobalt exist in the province.

No information is available on the distribution of cobalt in bedrock of Alberta.

Boron

Boron contents of tills vary from 13 to 70 ppm (Fig. 11; Appendix B). The lowest values are in the southeast quarter of the province, ranging from 20 to 30 ppm. Values of from 45 to 60 ppm are common for much of the Peace River region, and values exceeding 60 ppm occur in the Clear Hills and northern Peace River areas. In northern Alberta the boron contents of the tills decrease progressively eastward and northeastward to a low of 15 ppm adjacent to the Precambrian Shield.

Goldschmit and Peters (1932) have shown that boron is generally most abundant in marine argillaceous sediments and is present in only very small amounts in magmatic rocks. These conclusions are corroborated here in that the regions of high boron content are essentially coincident with those of clayey tills, and in that 37 per cent of the variation in boron is explicable by variation in the amount of clay-size material.

Total boron content for subsoils of the world varies from 2 to 100 ppm.

The incidence of boron deficiency in plants depends upon a number of factors including plant species, soil reaction and soil moisture. However, the boron contents of Alberta tills are much more favourable than those of areas where deficiency and toxicity problems are encountered.

The content of boron in bedrock of Alberta has not been studied and consequently no conclusions can be drawn on variations in boron content in till with respect to bedrock composition.

Water-Soluble Salts

Concentrations of water-soluble salts vary regionally from 0 to 50 milliequivalents per 100 grams of air-dried soil in glacial till materials of Alberta (Fig. 12; Appendix B). The presence of soluble salts coincides closely with the major regions of Solonetzic soils in the province.

The Peace River area is characterized by low to moderate soluble salt contents in till. The principal soils present fall within the Black Solod, Grey Solod, Solodic Black and Solodic Dark Grey subgroups. The soluble salts include large proportions of magnesium sulfate (Table 3).

According to accepted theories, Solods and Solodic soils represent an advanced stage in the sequence of Solonetzic soil development. They represent soils which were highly saline and from which sodium salts have been removed down the profile during pedogenic development. However, in the Peace River area, magnesium salts of lower solubility remain in the lower solum and are less rapidly removed. Many of the Solods and Solodic soils have well-preserved relic structure characteristic of Solonetzic soils. Therefore it is quite possible that the Peace River soils contained a much higher content of sodium salts in the solum at some period after the recession of the Pleistocene glacier. The presence of *Agropyron* forms, the chief vegetative community in a phytogeographic region associated with the saline tills, and the absence of *Festuca scabrella,* which is the expected

Table 3. Typical Composition of Salts in Till-Water Extracts

	Location					Cations			Anions				Total	
Sample No.	Sec.	Tp.	R.	West of Mer.	E C (mmhos/cm)	Ca++	Mg++ (meq/litre)	Na+	CO_3^{--}	HCO_3^- (meq/litre)	Cl-	SO_4^{--}	Cations (meq/litre)	Anions
74	36	35	14	4	6.0	22.0	2.0	57.0	—	1.9	0.5	81.0	81.0	83.4
62	24	33	13	4	6.5	21.0	2.0	68.0	—	3.9	0.5	90.0	91.0	94.4
60	12	29	15	4	4.8	18.0	12.0	31.0	—	3.9	0.2	60.0	61.0	64.1
46	16	27	9	4	7.5	22.0	4.0	78.0	—	1.9	0.5	101.0	104.0	103.4
44	33	29	6	4	10.3	30.0	90.0	96.0	—	3.9	2.7	210.0	216.0	216.6
41	3	27	4	4	5.2	31.0	82.8	2.2	—	1.9	0.2	114.0	116.0	116.1
57	20	33	10	4	1.7	2.0	3.0	16.0	tr	5.8	2.7	14.0	21.0	22.5
412	31	93	23	5	1.3	5.0	4.5	5.5	tr	1.9	n.d.	15.0	15.0	16.9
415	32	96	1	5	0.12	0.5	1.0	0.3	n.d.	n.d.	0.2	1.5	1.8	1.7
416	7	98	10	5	0.11	0.5	1.0	0.4	n.d.	n.d.	0.2	1.5	1.9	1.7
367	23	92	14	5	0.25	2.0	1.5	0.5	tr	1.9	0.2	0.9	4.0	3.0
390	26	98	2	6	0.10	2.0	0.5	0.3	n.d.	n.d.	0.2	1.4	2.8	1.6
376	8	86	5	6	4.3	22.0	33.8	4.6	n.d.	n.d.	n.d.	64.0	60.4	64.0
377	13	82	10	6	4.0	5.0	57.0	2.0	n.d.	0.9	0.2	63.0	64.0	64.1
111	28	59	11	4	1.2	6.0	17.0	0.9	n.d.	0.9	n.d.	22.0	23.9	22.9
101	6	62	3	4	0.24	1.0	8.0	0.7	n.d.	2.9	0.2	6.2	9.7	9.3
103	36	63	4	4	0.25	1.0	5.0	0.4	n.d.	1.9	n.d.	5.5	6.4	7.4
97	26	60	3	4	0.30	1.0	6.0	0.9	n.d.	1.9	0.2	5.6	7.9	7.7

edaphic climax vegetative type (Moss, 1955), further substantiates the opinion that the Peace River area was salinized with a high content of sodium salts at one time. *Agropyron* generally occurs as the dominant species in the salinized alluvial deposits in Wood Buffalo National Park, as well as in similar saline areas in southern Alberta where low to moderate amounts of sodium salts are present. As a result, *Agropyron,* which is relatively salt tolerant, probably became established when the area was salinized. Moderate levels of salinity prevented aspen poplar *(Populus tremuloides)* and willow *(Carex)* from becoming established, although they form the climatic climax vegetative type. With the slow downward removal of sodium salts the salinity decreased to a point where solodic soils developed over a major portion of the region, and gradual encroachment of the *Populus tremuloides-Carex* association onto the grassland is now well established.

The principal salt present in the till samples from southern and central Alberta is sodium sulfate, although a high content of magnesium sulfate is also evident in some samples (Table 3). Highest concentrations of salts are evident in the surficial layer, with lower concentrations in the underlying bedrock. The presence of gypsum crystals in rosettes to a considerable depth in the till suggests secondary recrystallization of salts; this more likely resulted from the upward movement of salts in regions of groundwater discharge rather than from downward leaching, as the latter would be inhibited by the extremely low permeability and by the restricted infiltration resulting from the low rainfall of this region.

Many of the soils developed from glacial till in this region show evidence of salt influence and fall within the Solonetz and Solod Great Soil Groups. However, it is not uncommon for associated Orthic or Solodic Chernozemic soils or both to occur on the hilltops and upper slopes, especially in areas having considerable local relief and where sufficient local groundwater recharge is taking place to bring about a rapid redistribution of salts.

Although the distribution of the soluble salts in tills in Alberta cannot be as yet explained in detail, it is evident that areas of high salt concentrations do not coincide with specific bedrock formations, and that there is no close relation between bedrock formations and salt content of till. It is also evident (Appendix C) that salt content shows no correlation with other chemical and mineralogical parameters of the tills. High salt concentration in the till is related to groundwater discharge; it does not reflect original composition of till but is a characteristic acquired by the sediment after deposition. The salt content is a function of both the climatic conditions and groundwater flow, and is also related to the poor integration of most of the surface drainage. Lastly, soluble salt distribution may also be related to the past climatic or groundwater conditions, or both, as illustrated in the Peace River area, and may not be explicable on the basis of present groundwater flow and climatic conditions.

Corrosion Potential

In measuring soil resistivity two major factors influence the readings: of lesser importance is soil moisture content and of greater significance is soil salinity, which in Alberta relates closely to sodium sulfate concentration in soil materials. Soil moisture supplies the electrolyte for corrosion of materials, since it constitutes the medium for ionic dissociation, therefore enhancing electro-chemical processes active in the corrosion process. However, since pure water is a poor conductor of electric current, it is the ions, largely from dissolved salts, that carry current and determine the electrical conductivity (measured as resistivity). Current transport varies with both the kind and concentration (more accurately activity) of ions in the electrolyte.

Glacial tills relatively free of soluble salts record resistivities of more than 2000 ohm-cm (conductivity less than 0.5 mmhos-cm^{-1}). Tills high in soluble salts in some cases have resistivities less than 125 ohm-cm (conductivity more than 8 mmhos-cm^{-1}) but generally average around 250 ohm-cm (conductivity 4 mmhos-cm^{-1}). Romanoff (1957) investigated the corrosion of steel in a number of selected soils. For the soils studied the least corrosive were found to have resistivities varying from 3,000 to 45,000 ohm-cm (conductivities 0.3 to 0.02 mmhos-cm^{-1}) and the most corrosive from 350 to 1,300 ohm-cm (conductivities 3 to 0.8 mmhos-cm^{-1}). Therefore, the major portion of the areas designated as having electrical conductivities in excess of 0.5 mmhos-cm^{-1} (Fig. 12) are expected to be potentially corrosive to steel.

Resistivities of less than 1,500 ohm-cm (electrical conductivity more than 0.67 mmhos-cm^{-1}) were obtained for 60 per cent of all samples collected from east central and southern Alberta in a recent survey by Alberta Government Telephones.* Materials with such conductivities are generally considered potentially corrosive to aluminum. As a major portion of the area sampled by Alberta Government Telephones coincides with areas of high salinity delineated in the present study, a corrosion hazard to aluminum less than 2000 ohm-cm are outlined (Fig. 12).

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* Personal Communication, R. Brown, Alberta Government Telephones, Edmonton

The U.S. Bureau of Standards (1966) has shown that dissolved sulfates of calcium, sodium, magnesium, potassium, aluminum and iron actively attack concrete by combining with cement to form compounds that have low solubilities, but which disrupt the concrete because their volume is greater than that of the cement paste from which they form. Positive attack from sulfate occurs in soils having concentrations ranging from 150 to 1,000 ppm sulfate. Considerable disintegration of concrete occurs in the range from 1,000 to 2,000 ppm and severe disintegration results where sulfate content exceeds 2,000 ppm.

Canadian Standards Association regulations for concrete exposed to sulfate in soils require special precautions to be taken where sulfate content exceeds 500 ppm. Sulfate-resistant concrete is recommended where concentrations of sulfate ranging from 5,000 to 20,000 ppm exist. Concentrations exceeding 20,000 ppm are considered to present special engineering problems.* Till-water extracts of ratio 1 : 1 may be expected to contain 500 ppm of sulfate if the tills contain 1 to 2 meq of soluble salts per 100 g, since the major anion in the extracts characteristically is sulfate (Table 3). This represents resistivities of approximately 50 to 100 ohm-cm (electrical conductivity 0.1 to 0.2 mmhos-cm^{-1}). The area where individual construction sites should be checked for the need to use sulfate-resistant concrete covers much of east-central and southern Alberta as well as some of the Peace River district. Since a few samples have salt contents exceeding 100 meq/100 g or electrical conductivities exceeding 8.0 mmhos-cm^{-1}, problem areas are likely to occur locally.

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* Personal Communication, B. P. McPhalen, Inland Cement Industries Ltd., Edmonton, Alberta

MINERALOGICAL CHARACTERISTICS

Mineralogical analyses were conducted only on the light-mineral portion (S. G. < 2.7) of the fine and very fine sand-size fractions and on the clay-size fraction (<2 microns). Composition is reported as a percentage of total fine and very fine sand-size fractions and of the total clay-size fraction, respectively.

Feldspars

Potash feldspars are a group of minerals with similar chemical composition but with differing crystal structures. The most common member of this group is microcline, of lesser importance is orthoclase. In view of the difficulty involved in distinguishing among these minerals quantitatively, they are grouped together as potash feldspars for this study.

Considerable variation in the potash feldspar content is found in the fine and very fine sand-size fractions in the tills of Alberta (Fig. 13; Appendix B). In general, the content varies from 3 to 10 per cent, but for most of the province it ranges from 6 to 8 per cent.

Soda-calcic feldspars generally make up from 8.5 to 17.0 per cent of the fine to very fine sand-size fraction (Fig. 14; Appendix B). Lowest quantities occur in northern and north-central Alberta where values range from 9.0 to 11.5 per cent. Somewhat higher quantities, from 11.5 to 16.5 per cent, occur in southern and south-central Alberta. Quantities in excess of 16.5 per cent are limited to two rather small areas.

Feldspar contents of some Cretaceous sandstones of northern Alberta (Table 4) have been determined by G. B. Mellon (personal communication) who utilized a staining technique on prepared impregnated thin sections where grain counts were made on the very fine to medium size ranges. Since grains in Cretaceous sandstones in Alberta seldom exceed 0.250 mm diameter (No. 60 U.S. Standard sieve), analyses conducted by Mellon and by the authors dealt essentially with the same sand-size ranges.

Variations in feldspar distribution in the sand-size fractions of bedrock are much more pronounced than those of the sand-size fractions of tills. Contribution to the till from disintegrated Precambrian rock is likely responsible for the "leveling out" effect.

Feldspar contents of the sand-size fractions of tills correspond only generally to those of the underlying bedrock. In the Peace River area, the bedrock consists of Cretaceous sandstones, siltstones and shales with a feldspar content of 1.6 to 17.0 per cent, whereas the content of the overlying till averages 17 per cent. Feldspar content exceeds 30 per cent in southern Alberta; no data are available for comparison with bedrock content but it is likely that some relationship exists. In central and western

Table 4. **Feldspar Content of Some Cretaceous Sandstones of Northern Alberta***

Formation	Na-Ca Feldspar (%)	K Feldspar (%)	Number of Samples
Pelican	2.0	0.2	4
Wapiti	20.0	5.0	2
Kaskapau	1.0	0.6	3
Dunvegan	8.5	8.5	8
Cadotte	1.0	4.0	6
Notikewin	23.0	9.0	5
Shaftesbury	1.0	4.0	8
Grand Rapids	10.0	4.0	8
Joli Fou	7.0	11.0	1
Clearwater	1.0	2.0	1

*data supplied by G. B. Mellon

Alberta, the till composition reflects the lower feldspar content of the Tertiary strata and the higher feldspar content of the nonmarine Cretaceous beds.

Montmorillonite

Montmorillonite content in the clay fraction of till varies from 20 to 60 per cent (Fig. 15; Appendix B), the highest quantities being found in areas where till is underlain by the Bearpaw, Edmonton and Belly River Formation strata. In these regions portions of the montmorillonite and hydrous mica occur as interlayered clays characterized by the presence of a very weak peak at 10.4Å (as described by Kodama and Brydon, 1966). On the basis of X-ray diffraction patterns, interlayering appears to be confined largely to the tills of southern and central Alberta. Outcrop samples of the Bearpaw Formation from southern Alberta contain common montmorillonite, and less illite (hydrous mica) and chlorite (Bryne and Farvolden, 1959).

On the basis of the clay mineralogy maps (Figs. 15 and 18) it appears that the Cretaceous strata in the northern regions of the province have low montmorillonite contents, as less than one-third of the clay-size fraction of the tills is composed of this mineral. Variation in montmorillonite content (as percentage of the whole sample) (Appendix C) accounts for 31 per cent of the variation in the amount of the clay-size fraction.

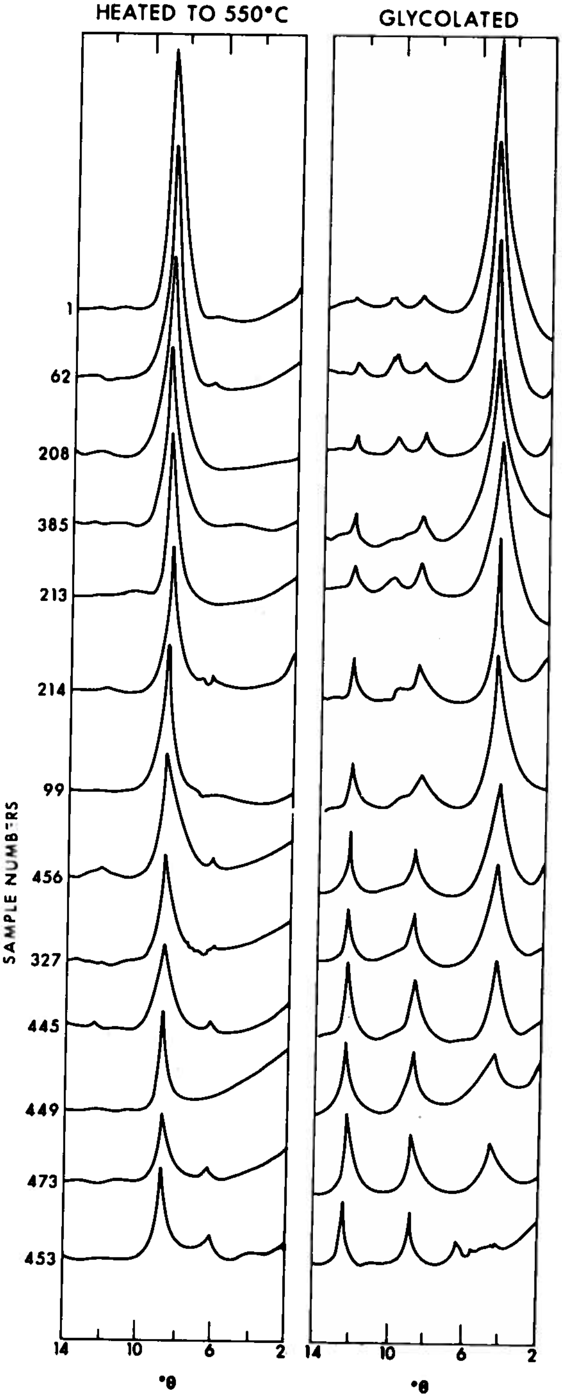

FIGURE 16. X-ray diffraction patterns for some representative clay samples from Alberta tills.

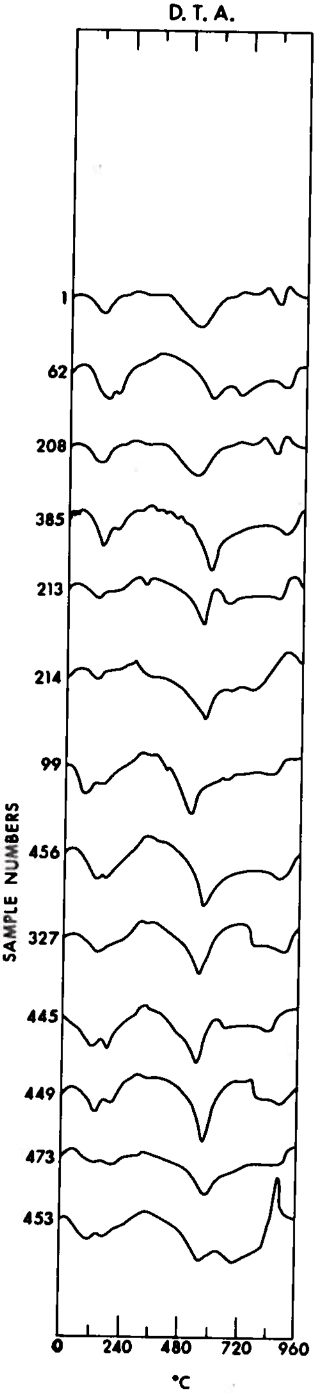

FIGURE 17. Differential thermal patterns for some representative clay samples from Alberta tills.

Table 5. Clay Mineral Composition of Typical Till Samples

Sample No.	Location Sec.	Tp.	R.	West of Mer.	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	K_2O (%)	C.E.C. (meq/100g)	Surface Area (M_2/g)	Hydrous Mica (%)	Montmorillonite (%)
1	6	2	2	4	23.1	9.2	2.9	2.0	68.5	615	20	59
62	24	33	13	4	23.6	7.9	1.9	1.7	65.8	604	17	58
208	26	38	17	4	22.1	9.1	3.1	2.5	66.9	568	25	54
399	31	92	10	6	24.8	8.1	1.9	2.3	60.1	502	23	48
213	1	42	19	4	23.4	10.4	2.1	2.1	59.9	439	21	42
214	32	41	19	4	23.4	9.0	2.9	3.1	44.9	389	31	37
99	19	59	6	4	20.5	8.5	2.7	3.0	49.6	385	30	37
456	35	126	21	5	21.6	9.1	2.0	3.1	45.4	345	31	33
327	1	71	7	6	23.6	9.1	2.3	3.2	34.5	302	32	29
445	36	124	9	6	22.3	8.5	2.6	3.3	35.9	281	33	27
449	3	117	16	5	22.8	7.3	2.0	3.5	28.5	191	35	18
473	32	117	23	5	17.3	5.3	2.0	2.9	23.2	186	29	18
453	5	124	18	5	22.5	8.5	4.2	4.8	36.7	173	48	16

X-ray diffraction and D.T.A. patterns (Figs. 16 and 17) suggest a variation in montmorillonite composition throughout the province. The relatively low content of MgO and the correspondingly high content of Fe_2O_3 suggest a general composition between that of beidellite and nontronite (Table 5). However, no significant correlation could be found between either Fe_2O_3 or MgO and percentage of montmorillonite in the clay-size fraction from 80 samples. The presence of variable amounts of chlorite, rich in both iron and magnesium (sample 453) at least in part may be responsible for the apparent lack of relationship. The presence of iron in the lattice structure of montmorillonite is verified by the absorption band evident at a frequency of 820 cm^{-1} in the infrared spectra.

Differential thermal analysis data show the characteristic 700°C peak, typical of most montmorillonites, for only a few samples in the southern part of the province. The loss of structural hydroxyls, for both the montmorillonite and hydrous mica, in most cases is at approximately 560°C, and this feature suggests the presence of a dioctahedral montmorillonite similar to "soil montmorillonites" (van der Marel, 1961) throughout most of central and northern Alberta. Electronmicrographs of clays high in "soil montmorillonite" (Plate 1) reveal a high content of flaky minerals that demonstrate a micaceous cleavage and that closely resemble beidellite in form. Only a very small portion of the clay minerals show a physical shape similar to ordinary montmorillonite, as illustrated in sample 62, with a "fluffy", well-dispersed form.

Hydrous Mica

Quantitative estimates of hydrous mica in the clay fraction were established on the basis of an assignment of 10 per cent K_2O content to this mineral (Jackson, 1956). X-ray diffraction patterns showed little or no evidence for the presence of fine-grained K-feldspars.

Hydrous mica content varies from 15 to 48 per cent, with the larger quantities occurring in tills from northern Alberta where this clay mineral comprises about 35 per cent of the clay-size fraction (Fig. 18; Appendix B). Lesser quantities are evident in central and southern Alberta where 20 to 25 per cent hydrous mica occurs throughout a major portion of the area.

X-ray diffraction peaks at 10Å spacing are well pronounced but generally not as intense as might be expected on the basis of K_2O content. This feature, especially for samples from the central and southern parts of the province, no doubt reflects the interstratification of hydrous mica with montmorillonite (Kodoma and Brydon, 1966).

Kaolinite, Chlorite and Quartz

Quantitative estimates for kaolinite, chlorite and fine-grained quartz have not been made, since these minerals occur in relatively low quantities in most samples. Chlorite minerals are characterized by the presence of a 14Å peak on X-ray diffraction patterns. These peaks remain unaffected by glycolation and are enhanced by heat treatment to 550° C. Since the 7Å peaks, characteristic of both chlorite and kaolinite, are destroyed by heating to 550° C, it is difficult to distinguish quantitatively between the two minerals. Sample 453 contains an unusually high content of chlorite that shows a strong exothermic peak at 870° C on D.T.A. patterns. This suggests the presence of prochlorite. The presence of prochlorite is further substantiated by the relatively higher content of magnesium oxide (Table 5) and this mineral group is readily distinguishable on electronmicrographs.

Absorption spectra from infrared analyses indicate the presence of a small but significant content of quartz in all samples, this content being generally less than 10 per cent.

Electronmicroscopic examination reveals a low but consistent amount of kaolinite in the samples examined. Irregularly shaped hexagonal crystals are confined entirely to the coarse fractions of the prepared clay specimens.

PHYSICAL PROPERTIES

The dependency of the results of the engineering soil classification tests upon the physical and mineralogical composition of till is readily apparent from the relationships found to exist among these characteristics (Appendix B). The most significant of these are:

(1) moderate to high correlation between the Atterberg limits and content of clay-size material;

(2) moderate correlation between the Atterberg limits and montmorillonite content (as percentage of whole sample); and

(3) low correlation between activity and percentage montmorillonite in the clay-size fraction.

It is evident from this study that both the content of clay-size material and the clay mineralogy influence the liquid limit as well as the plastic limit. These parameters are also reflected in the plasticity index. Activity, on the other hand, is largely influenced by the presence of expansible clay minerals (i.e. montmorillonite) and to a much lesser extent by content of clay-size material. This suggests that, where swelling clays are absent, the resulting activity values are low. Significant contents of soluble salts should be expected to have a depressing effect on activity, in which case a negative correlation should be expected. However, the low "r" value (Appendix C) indicates that any such relationship between soluble salt content and activity is obscured by other influences on soil activity.

A strong negative (inverse) correlation exists between sand and clay contents; the lack of correlation between these parameters and silt content are reflections of the low variability of silt content in many of the tills.

Particle-Size Distribution

Particle-size distribution, as differentiated into the three size-range groups—sand, silt and clay—closely reflects composition of the underlying bedrock strata (Figs. 19, 20, 21; Appendix B). Tills of high sand content (60 to 70 per cent) occur in northeastern Alberta and are derived principally from the adjacent Precambrian rocks. High clay contents occur primarily in northwestern Alberta, where quantities, in some instances exceeding 70 per cent, exist in tills derived principally from Cretaceous marine shales. Low contents of clay (10 to 20 per cent) occur in northeastern Alberta as well as in the Cypress Hills.

The major proportion of glacial tills in central and southern Alberta fall within the heavy loam, clay loam (sandy) and sandy clay loam textural classes. The major portion of the northeastern tills fall within the clay loam textural class, and fineness progressively increases westwards toward the Clear Hills area, which is characterized by heavy clay till.

Atterberg Limits

Plasticity is the property of a soil which allows rapid deformation without rupture and without noticeable volume change (see any text on introductory soil mechanics). The principal factors influencing plasticity are those that relate to water retention on colloidal surfaces. These are primarily clay-mineral content and size, clay-mineral composition, exchangeable cations and pH.

The plastic limit represents the moisture content (based on dry weight of soil) of soil material at which it changes from a friable to a plastic consistency. Plastic limits for tills in Alberta range from 12 to 28 per cent (Fig. 22; Appendix B). Plastic limits for medium-textured tills of southern and central Alberta range from 14 to 20 per cent. Values of 20 to 28 per cent are confined to the tills of high clay content of the Clear Hills area.

The liquid limit may be considered as that moisture content at which a soil exhibits a small but measureable shearing resistance. It is a measure of the moisture content at which water films become sufficiently thick that cohesion between particles decreases and the soil mass flows under a small applied stress. The liquid limit values vary from 15 to over 50 per cent (Fig. 23; Appendix B) with the general range for tills over much of the province being 25 to 35 per cent.

The plasticity index is the difference between the liquid limit and the plastic limit, and is an indirect measure of film tension or the force required to remold a soil. The values for plasticity index vary from 2 to 30 per cent (Fig. 24; Appendix B).

Plasticity in Alberta tills may be determined from data for liquid limit and plasticity index. The plasticity index and liquid limit must be combined in order to determine the degree of plasticity. This may be accomplished by graphically plotting plasticity index versus liquid limit.

A large proportion of the area mapped has plasticity indexes ranging from 10 to 20 per cent. When these are combined with the liquid limit values (Fig. 23) it is apparent that the majority of the tills may be classified as low to medium plastic soils in the engineering sense (Fig. 26).

Activity as applied to plastic soils is a measure of their propensity to undergo a volume change when the moisture content changes. The activity number "A" is determined by dividing the plasticity index by the percentage of clay-size material in the sample. With increasing soil activity, increasingly greater volume changes may be expected to take place when the moisture

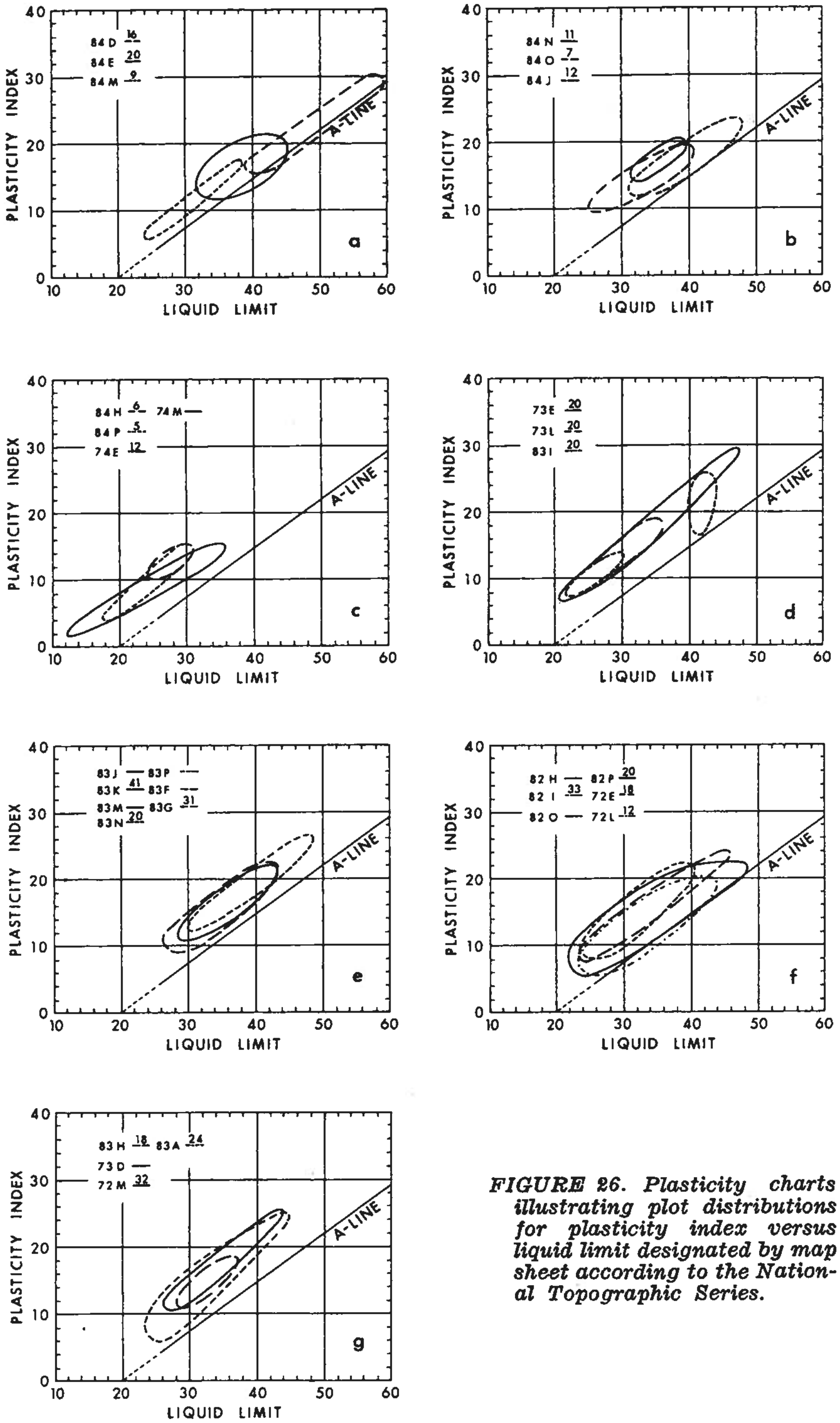

FIGURE 26. Plasticity charts illustrating plot distributions for plasticity index versus liquid limit designated by map sheet according to the National Topographic Series.

level of the material is altered. Tills for which the activity is less than 0.75 are considered relatively inactive. Those of normal activity range from 0.75 to 1.25 and highly active tills may be expected to have values exceeding 1.25 (Means *et al,* 1963).

On the basis of the present study, very few Alberta tills have activities greater than 1.0. The vast majority range from 0.2 to 0.8 (Fig. 25; Appendix B) and the geographic distribution closely reflects that of montmorillonite content in the clay fraction. Lowest activities are obtained for tills from the Clear Hills where montmorillonite content is lowest (Fig. 21), but where content of clay-size material is highest. Highest activities (generally from 0.7 to 0.9) occur in tills derived from the highly bentonitic shales in the south-central and eastern regions. The generally high salinity of these regions however, keeps the clays well flocculated, and therefore, should salt removal by leaching be facilitated during subgrade or foundation construction, the activity of the materials, hence their propensity for volume change, may increase substantially, as is typified in the pedogenically developed B horizons of Solonetzic soils.

Till samples with the highest plasticity index (14 to 30) and liquid limit (36 to 60) occur in and adjacent to the Clear Hills. The majority of samples are of medium to high plasticity. Limited scattering of values parallel to the "A" line on the plasticity chart (Fig. 26a) suggest uniformity in till lithology for the area. Although the tills contain a high clay content, the presence of only small quantities of montmorillonite and high contents of hydrous mica are considered largely responsible for the low activities.

Tills in the northern part of the province are generally of low to medium plasticity. The plasticity index (4 to 28) and the liquid limit (18 to 39) are lower than for tills of the Clear Hills region. However, the scatter of data points on the plasticity chart (Fig. 26b) suggests variable lithology in tills to the north of the Clear Hills. While the tills in the northwest corner of Alberta (NTS map-area 84 M) appear to be of uniform lithology, greater variability is apparent farther eastward towards the Caribou Mountains (NTS map-areas 84 N, 84 O). Variations largely reflect the content of the clay-size fraction, which varies from 20 per cent in the eastern to 40 per cent in the western sections of the area. Activity values are generally low, reflecting the low content of montmorillonite in the clay fraction throughout the entire region.

Generally sandy tills occur throughout the area adjacent to the Precambrian Shield and reflect a high content of granitic and metamorphic rock fragments, as well as of lower Cretaceous sandy material. Although the montmorillonite content of the clay-size fraction is higher than that of tills farther west, the low content of the clay-size fractions renders the materials either nonplastic or only slightly plastic (Fig. 26c). The liquid limit varies from 10 to 28 per cent, the plasticity index from 2 to 12 and the content of clay-size material from 0 to 20 per cent.

Tills in the area northeast of Edmonton (NTS map-area 83 I, 73 L) have liquid limits varying generally from 24 to 36 per cent and plasticity indexes from 8 to 20 per cent. The plasticity is somewhat lower than that for much of central and southern Alberta and somewhat higher than for regions to the north. The spread of points on the plasticity chart (Fig. 26d) suggests a heterogeneity in till lithology and probably reflects variability in bedrock composition.

Samples collected in the general area between Edmonton, Grande Prairie and Lesser Slave Lake have liquid limits varying from 26 to 48 per cent and are largely of medium plasticity (Fig. 26e). The plasticity index varies from 10 to 26 and generally is higher in regions of higher montmorillonite content. Considerable variation in lithology of tills is suggested only for the Swan Hills area.

Tills from southern and south-central Alberta have liquid limits varying from 22 to 48 per cent and plasticity indexes from 5 to 25. The wide spread of points on the plasticity charts (Fig. 26f) may be attributed largely to the variability of soluble salt content in the glacial till (Appendix B) although variability in clay-mineral distribution is also of significance. Activities are generally highest where tills have a high content of montmorillonite. However, the associated high soluble salt content and, to a lesser extent, a preponderance of coarse-grained particles result in normal activity for these southern Alberta tills.

Considerable heterogeneity in the point distribution on the plasticity charts results from grouping of data by the National Topographic Series sheet rather than by natural or rock-unit and petrographic boundaries of the variables that influence the Atterberg limits. However, the sampling density is not sufficient for regrouping by natural boundaries with reliable confidence.

SUMMARY AND CONCLUSIONS

On the basis of this study a number of conclusions appear warranted.

1. The minor elements iron, boron, cobalt, copper, zinc and molybdenum, present in tills of Alberta appear to have originated from a common source and are principally associated with the clay-size fraction.

Generally, values are highest in samples from the Clear Hills region and decrease in a southerly and easterly direction. In fact, the parameters were found to vary systematically across the province demonstrating a relevance to other characteristics of regional geology. Manganese content, on the other hand, is generally highest in the southern and lowest in the northern regions and shows no strong relation to other measured parameters. The decisive influence of minor changes in redox potential upon the mobility and secondary deposition of manganese dioxide suggests that the elemental distribution may be, at least in part, influenced by environmental and hydrological factors to a considerable depth below the soil surface.

The analytical data suggest considerable variability in the minor element distribution. However, it is unlikely that minor nutrient deficiencies for plant growth occur on a regional basis. Any deficiencies observed are likely of a local nature, reflecting factors that influence nutrient availability, such as, pH, lime content, clay mineralogy and so on.

2. Calcium oxide content relates to silt-sized calcitic and dolomitic material and is highly correlative with measured pH values. Lowest values for pH and calcium oxide content are found in the north-central regions of the province, as evident in, and adjacent to, the Clear Hills region. Values generally progressively increase in a southerly direction.

Calcium oxide distribution appears to be strongly influenced by the direction and mechanics of ice flow.

3. Occurrences of soluble salts closely relates to the distribution of Solonetzic soils of the province. Magnesium sulfate is generally the dominant salt present in the Peace River region while sodium sulfate is dominant in east-central and southeastern Alberta. Concentrations of salts in the tills do not coincide with the distribution of specific bedrock units and more likely relate to groundwater phenomena.

Areas of till having moderate to high salt concentrations are potentially corrosive to steel, aluminum and concrete. The salts constitute a hazard for construction of pipelines, buried telephone cables, cement foundations and so on.

4. Potash feldspars and soda-calcic feldspars comprise from 3 to 10 per cent and 8.5 to 17 per cent, respectively, of the fine and very fine sand fractions in the tills. Generally, content increases in a southerly direction through the province.

5. The clay fraction of the tills is comprised of variable amounts of montmorillonite, hydrous mica (illite), kaolinite, chlorite and fine grained quartz. Montmorillonite is the dominant clay mineral present in central and southern regions while hydrous mica generally dominates in many of the northern regions of the province. Some variations in mineral composition are also evident.

6. Analytical data for Atterberg limits suggest that Alberta tills are generally low to medium plastic and, when considered together with clay content, establish the tills to be relatively inactive to normally active. While highest plasticity is most evident in tills of high clay content, activity appears to be influenced by a complexity of physical, chemical and mineralogical manifestations inherent to the till.

7. Variability in the composition and physical properties of tills from the Plains physiographic region of Alberta was established from analyses of 475 samples. Although sampling density was variable, the average was about one sample per ten townships. On this basis, it is obvious that differences reported are only of regional significance and, as indicated in appendix B, data for individual sampling sites may not be representative for all tills in the immediate vicinity. As a rule tills are far from homogeneous over short distances (Bayrock, 1962).

8. Soils derived from tills generally have a few characteristics inherited from the parent material that have an adverse effect upon plant growth. These are low pH values, high lime content and moderate to high salinity.

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APPENDIX A.

TECHNIQUE FOR DERIVING CONTOUR MAPS FROM GEOLOGICAL DATA

Contour maps are frequently used to summarize geological data and, while it is usually reasonable to assume the accuracy of the measurements which determine a single piece of data, there are often geological considerations which make a datum value not truly representative of the location from which it was obtained. A geologist may use his experience to 'improve' the relevance of these values, but with large amounts of information this becomes impractical, and in this situation, the preparation of contour maps in which the isopleths are accurately and confidently located, presents a problem.

The technique used for this work consists essentially of defining the probability $P_i(x_{ij})$ that a datum value V_i could also have been found at a position j on the map, distance x_{ij} from the datum location i. Consequently, the most probable value which should be assigned to the location j is $\Sigma_i\ P_i(x_{ij}) . V / \Sigma_i\ P_i(x_{ij})$, where the summations are to be taken over all data values. Thus if the location j is chosen as all the intersections of a grid network placed over the map area then a grid of most probable values is obtained, and simple interpolation along the grid lines provides the locations of the isopleths. There are two qualifications to be added to this technique. First, that there should be a critical radius R_c such that $P_i(x_{ij}) = 0$ for $x_{ij} > R_c$. This sets a limit to the distance over which a reliable interpolation is assumed possible and it should be related to the average distance between data locations. Second, there should be a critical probability P_c such that, if the accumulated probability $\Sigma_i\ P_i\ (x_{ij})$, at any grid intersection is less than P_c, then no value will be assigned at that intersection. This sets a lower limit to the amount of information necessary before a prediction at a particular intersection is acceptable. Both of these qualifications are aimed at reducing distortion, due to imbalanced sampling, in areas where little data has been obtained.

For this work a grid of one hundred and eighty lines, each with one hundred points of intersection, was defined in the computer, an IBM 1620, so as to cover the entire map area, and at each intersection the sums $\Sigma_i\ P_i\ (x_{ij}). V_i$ and $\Sigma_i\ P_i\ (x_{ij})$ are initially set to zero. As each datum value, and its location, were entered into the computer these sums were correspondingly incremented at those intersections which lay within the critical radius R_c of the data location. After all data values had been entered, the grids of the two sums were amended by their deletion at those intersections for which $\Sigma_i\ P_i\ (x_{ij}) < P_c$ and then most probable values were calculated at all other intersections. From these values it was a simple matter to locate the desired isopleths between adjacent intersections. This was done automatically on a plotter connected to the computer. Because the computer was small the range of suitable probability functions $P_i(x_{ij})$ was limited. Ideally they should relate to the location and nature of the data, but after experimentation a step function which approximated $12/(x_{ij} + 1)$ was found to give good results with a critical radius R_c of 11 grid intervals, and a critical probability P_c of 4.

A more complete description of this technique (Newton, 1968) has been published separately.

APPENDIX B.

ANALYSES OF GLACIAL TILL SAMPLES

CHEMICAL ANALYSIS

MINERALOGICAL AND PHYSICAL ANALYSES

	Location																	Feldspar		Clay* Minerals				
Sample No.	Sec	Tp	R	West of Mer	pH	CaO %	Fe %	Zn ppm	Cu ppm	Mn ppm	Mo ppm	Co ppm	B ppm	Soluble Salts meq/100g	Plastic Limit	Liquid Limit	Plasticity Number	K %	Na-Ca %	M	I	Sand %	Silt %	Clay %
National Topographic Series Sheet 72E																								
1	6	2	2	4	7.9	3.8	2.7	100	21	400	1	5	25	26	20.73	34.62	13.89	10.2	20.8	IV	B	36	39	25
2	7	2	4	4	8.8	6.9	2.3	70	20	400	<1	6	22	100	-	-	-	9.9	18.7	I	B	31	49	20
3	20	4	2	4	7.4	2.0	2.9	95	24	250	1	7	39	26	20.53	39.57	19.04	11.2	22.5	III	B	27	35	38
4	12	4	1	4	8.1	3.4	2.3	85	18	350	<1	6	24	100	16.40	28.50	12.10	9.1	20.5	III	B	46	22	32
5	13	5	3	4	7.7	3.5	3.4	100	27	350	1	7	42	8	-	-	-	10.4	22.7	III	B	11	45	44
6	35	4	4	4	8.1	2.8	2.8	90	23	300	<1	7	28	18	-	-	-	20.9	23.1	III	B	36	22	42
7	20	2	7	4	8.1	7.6	2.3	55	16	450	<1	6	22	100	-	-	-	9.2	16.0	II	B	57	27	16
8	10	5	6	4	7.9	4.0	2.2	60	20	350	<1	6	23	62	15.83	24.55	8.72	9.0	18.0	II	B	47	29	24
9	28	6	4	4	7.4	4.5	2.2	65	14	250	1	5	21	8	15.80	31.58	15.78	10.8	24.4	III	B	44	36	20
10	33	6	2	4	8.1	6.9	2.7	75	18	350	<1	5	25	32	18.17	39.13	20.96	10.3	19.8	IV	B	35	36	29
11	27	8	1	4	7.5	6.2	2.6	75	17	450	1	5	23	<5	14.80	30.67	15.87	9.6	20.1	III	B	40	38	22
12	27	8	4	4	7.4	4.1	2.9	85	19	350	1	5	28	17	21.17	45.42	24.25	10.0	21.7	III	A	33	42	25
13	31	7	6	4	7.4	3.4	3.2	95	25	450	<1	7	27	32	22.13	45.70	23.57	9.7	21.7	II	B	21	46	33
14	13	6	8	4	7.4	4.6	2.4	75	21	400	1	6	24	54	13.97	28.30	14.33	8.5	17.9	II	C	46	30	24
15	4	3	10	4	7.5	5.5	2.8	80	22	500	1	6	23	18	18.40	37.40	19.00	10.0	20.8	III	B	38	38	24
16	3	9	7	4	7.9	4.4	2.4	65	16	300	<1	6	21	<5	18.80	26.06	7.26	11.1	33.0	III	B	60	27	13
17	32	8	5	4	7.7	7.0	2.7	65	23	450	<1	6	22	<5	16.43	36.88	20.45	10.5	27.2	III	A	36	36	28
18	25	9	3	4	7.3	5.5	2.7	75	15	350	1	5	23	59	16.33	32.15	15.82	10.2	18.8	IV	B	40	48	12
19	1	10	1	4	7.7	5.4	2.5	80	18	350	1	5	24	27	17.67	30.16	12.49	9.1	18.2	III	B	42	46	12

20	20	11	5	4	7.3	5.3	2.5	75	21	350	< 1	6	22	21	-	-	-	9.5	19.8		A	40	37	23
21	15	10	13	4	7.6	3.9	2.5	85	18	350	< 1	6	21	17	18.15	31.30	13.15	7.6	15.8	III	B	33	48	19
22	3	8	13	4	7.8	7.4	2.4	60	22	350	< 1	6	23	< 5	19.75	34.40	14.65	9.9	18.7	III	B	46	33	21
23	23	5	14	4	7.3	5.6	2.4	60	16	350	< 1	6	20	8	18.95	29.75	10.80	8.9	19.8	III	A	48	36	16
24	9	3	15	4	7.0	6.1	2.5	90	21	500	2	7	22	15	17.85	26.62	8.77	8.6	16.2	III	B	38	52	10
National Topographic Series Sheet 72 L																								
25	26	14	3	4	7.8	7.4	2.2	70	15	400	1	5	19	< 5	18.55	24.40	5.85	9.2	17.9	II	B	46	39	15
26	34	12	5	4	7.5	8.9	2.6	85	21	400	< 1	7	22	14	25.80	36.95	11.15	2.7	6.1	III	B	7	75	18
27	4	17	1	4	7.7	5.5	2.5	70	19	500	1	7	21	45	13.45	29.00	15.55	9.5	19.8	III	B	44	34	22
28	21	14	8	4	7.8	5.6	2.7	90	28	400	1	6	32	< 5	20.10	31.85	11.75	8.6	13.9	II	B	17	55	28
29	4	20	1	4	7.9	9.6	1.7	45	15	300	< 1	6	17	< 5	22.00	31.03	9.03	8.4	16.4	IV	A	59	31	10
30	4	20	1	4	8.1	9.6	1.7	40	15	300	< 1	5	16	< 5	22.15	28.14	5.99	-	-	III	B	58	34	8
31	27	22	1	4	8.4	5.2	2.0	70	14	350	< 1	6	21	< 5	-	-	-	8.8	18.9	III	A	68	22	10
32	20	21	4	4	7.7	10.4	2.3	60	19	400	< 1	6	24	11	15.05	23.55	8.50	-	-	II	B	51	31	18
33	31	21	6	4	8.2	7.8	2.0	60	13	350	1	5	19	10	19.70	27.35	7.65	10.5	18.5	II	B	46	42	12
34	33	20	9	4	7.6	4.5	3.3	110	16	500	1	5	21	45	24.60	44.12	19.52	8.5	17.1		B	10	63	27
35	11	20	12	4	8.2	6.2	2.6	75	25	350	< 1	6	24	< 5	24.75	36.75	12.00	8.2	15.9	II	B	36	38	26
36	18	18	13	4	7.8	3.9	2.5	85	15	400	1	6	22	31	18.70	31.50	12.80	8.8	18.9	III	A	42	38	20
37	32	15	13	4	7.2	1.1	2.1	55	16	350	< 1	6	21	< 5	-	-	-	9.6	18.6	III	B	72	13	15
38	23	13	14	4	8.1	3.1	2.8	75	23	350	1	6	28	< 5	18.60	38.10	19.50	9.2	19.0	III	B	34	41	25

* Montmorillonite (M) - where I = 10-25% II = 25-40% III = 40-55% IV = 55-70%
Illite (I) - where A = 10-20% B = 20-30% C = 30-40% D = 40-50%

	Location				CHEMICAL ANALYSIS										MINERALOGICAL AND PHYSICAL ANALYSES									
																		Feldspar		Clay* Minerals				
Sample No.	Sec	Tp	R	West of Mer	pH	CaO %	Fe %	Zn ppm	Cu ppm	Mn ppm	Mo ppm	Co ppm	B ppm	Soluble Salts meq/100g	Plastic Limit	Liquid Limit	Plasticity Number	K %	Na-Ca %	M	I	Sand %	Silt %	Clay %
National Topographic Series Sheet 72M																								
39	28	24	5	4	7.7	5.8	2.6	70	25	350	<1	7	27	19	19.60	34.80	15.20	10.2	17.2	IV		45	27	28
40	10	25	6	4	7.8	4.5	2.2	55	15	400	1	6	24	18	-	-	-	9.0	19.1	II	B	54	21	25
41	3	27	4	4	7.6	5.0	2.0	70	27	300	<1	6	31	30	15.30	28.20	12.90	9.5	19.4	III	B	45	27	28
42	4	27	6	4	7.7	4.8	2.4	60	22	350	2	5	30	12	-	-	-	10.2	19.3	IV	B	61	16	23
43	27	29	4	4	8.6	4.0	2.7	60	18	350	1	6	27	<5	13.27	41.65	28.38	9.0	15.2	III	B	48	25	27
44	33	29	6	4	7.9	3.5	2.3	50	18	350	<1	5	27	63	15.20	26.60	11.40	9.9	20.5	III	B	49	29	22
45	13	28	7	4	8.1	5.2	2.4	60	26	400	<1	6	30	<5	14.50	21.70	7.20	9.1	18.7	IV	B	50	21	29
46	16	27	9	4	7.8	6.8	2.2	55	24	250	1	6	28	45	18.30	39.45	21.15	9.9	-	IV	A	50	22	28
47	10	32	4	4	8.0	7.2	2.5	55	19	350	<1	7	29	<5	19.70	32.70	13.00	7.6	13.6	III	B	47	28	25
48	2	30	9	4	7.7	3.8	2.3	65	23	350	1	6	28	22	15.80	31.63	15.83	9.5	-	IV	A	49	26	25
49	12	24	12	4	7.6	2.9	3.1	80	27	450	1	6	32	13	16.50	37.15	20.65	9.9	-	III	B	44	26	30
50	7	27	12	4	7.5	2.9	2.8	65	26	450	1	6	27	18	-	-	-	10.5	-	IV	A	44	27	29
51	29	32	8	4	7.8	5.3	2.8	100	18	400	1	7	27	47	24.90	47.30	22.40	9.0	17.2	IV	A	36	28	36
52	30	32	6	4	7.8	5.4	2.4	60	17	350	<1	6	25	21	17.20	31.50	14.30	8.7	15.2	IV	A	50	25	25
53	15	34	2	4	7.9	16.0	1.6	60	25	200	1	7	21	<5	24.00	30.00	6.00	6.9	12.1	II	B	18	62	20
54	33	34	3	4	7.4	2.9	2.9	55	32	600	1	7	31	25	18.50	36.25	17.75	9.0	13.9	III	B	40	29	31
55	3	35	6	4	8.0	3.0	2.9	65	22	400	1	8	34	26	17.30	32.05	14.75	8.0	14.5	IV	B	49	25	26
56	8	35	8	4	7.7	3.6	2.5	65	20	350	1	7	28	35	19.10	30.12	11.02	10.2	20.9	IV	A	55	30	25
57	20	33	10	4	8.2	2.1	2.6	70	18	400	2	6	28	8	14.85	34.50	19.65	9.9	-	IV	B	52	28	20

Sample No.	Location				CHEMICAL ANALYSIS										MINERALOGICAL AND PHYSICAL ANALYSES									
																		Feldspar		Clay* Minerals				
	Sec	Tp	R	West of Mer	pH	CaO %	Fe %	Zn ppm	Cu ppm	Mn ppm	Mo ppm	Co ppm	B ppm	Soluble Salts meq/100g	Plastic Limit	Liquid Limit	Plasticity Number	K %	Na-Ca %	M	I	Sand %	Silt %	Clay %
79	1	48	9	4	7.4	2.6	3.3	80	27	450	1	6	23	<5	19.40	41.45	22.05	8.3	14.7	IV	A	34	33	33
80	1	48	10	4	7.4	3.9	2.1	60	18	300	1	6	27	<5	14.95	22.97	8.02	3.9	5.5	II	B	53	27	20
81	18	50	8	4	7.5	4.9	2.6	70	21	400	1	6	21	<5	14.60	28.83	14.23	7.2	18.7	II	B	42	34	24
82	6	52	7	4	7.4	3.8	2.5	75	19	350	1	5	29	7	14.97	30.50	15.53	5.7	10.6	III	B	40	47	13
83	32	54	4	4	7.8	2.4	2.7	85	18	400	1	5	25	<5	15.63	28.57	12.94	7.1	14.3	II	B	42	45	13
84	28	54	5	4	7.4	2.8	2.5	80	20	400	1	6	30	11	15.83	26.55	10.72	8.3	12.8	II	B	42	34	24
85	30	54	5	4	7.3	2.9	3.5	100	29	450	1	8	24	<5	19.55	47.08	27.53	10.3	13.4	III	B	31	36	33
86	30	54	5	4	7.4	3.8	2.6	75	18	420	1	5	23	7	-	-	-	9.0	16.4	II	B	42	32	26
87	18	55	5	4	7.6	2.3	2.6	75	20	380	<1	6	29	<5	11.75	28.55	16.80	8.5	14.1	II	B	43	35	22
88	35	56	9	4	7.7	5.2	2.5	60	24	400	<1	7	24	<5	16.00	28.58	12.58	8.3	18.2	II	B	40	34	26
89	33	53	11	4	7.7	5.2	2.8	75	22	400	<1	6	21	<5	17.85	34.77	16.92	8.5	16.7	II	B	35	35	30
90	1	57	7	4	7.5	3.0	2.8	70	24	400	<1	6	25	<5	-	-	-	7.5	13.0	II	A	44	31	25
91	7	57	6	4	7.1	2.4	2.1	55	22	350	<1	6	24	<5	13.30	20.50	7.20	7.9	12.6	II	B	60	24	16
92	1	58	7	4	8.4	3.7	2.2	40	20	350	<1	6	30	<5	12.80	24.05	11.25	7.8	11.8	III	B	54	22	24
93	1	58	9	4	7.9	3.1	2.7	35	28	400	<1	7	38	<5	16.73	31.27	14.55	7.0	12.6	II	B	40	26	34
94	36	56	12	4	7.3	9.8	2.4	80	21	450	2	6	26	5	20.43	32.41	11.98	3.6	6.1	II	B	42	38	20
95	8	55	13	4	7.8	4.4	2.5	70	19	400	<1	5	23	<5	14.05	27.02	12.97	-	-	II	B	40	34	26
96	4	51	13	4	7.8	3.0	2.7	85	22	450	<1	6	23	15	13.95	35.70	21.75	8.6	7.4	II	B	41	36	33

National Topographic Series Sheet 73L

97	26	60	3	4	7.7	4.9	2.8	70	30	350	2	7	37	<5	16.90	35.17	18.27	8.2	12.2	II	B	53	27	20
98	31	59	4	4	8.5	4.7	2.4	45	22	400	<1	6	29	<5	12.80	25.75	12.95	7.4	11.2	II	B	41	26	33
99	19	59	6	4	8.1	3.9	3.0	70	26	450	<1	7	35	<5	16.53	36.95	20.42	9.6	17.9	II	C	31	26	43
100	17	61	5	4	7.9	5.4	2.3	35	20	350	<1	5	29	<5	14.23	27.25	13.02	6.3	14.5	II	B	44	22	34
101	6	62	3	4	7.8	4.2	2.1	55	25	400	1	6	33	<5	15.03	31.45	16.42	7.0	12.6	II	B	41	27	32
102	35	62	2	4	8.2	3.8	2.6	50	24	450	<1	6	35	<5	14.60	28.22	13.62	7.7	11.9	II	B	44	28	28
103	36	63	4	4	7.8	5.2	2.7	50	28	450	1	7	33	<5	12.57	23.80	11.23	6.3	11.4	II	B	48	36	16
104	18	63	5	4	8.0	4.5	2.3	30	20	350	<1	6	30	<5	11.60	27.18	15.58	5.7	9.8	II	B	40	30	30
105	12	58	9	4	7.5	2.9	2.8	75	21	350	1	5	28	<5	20.10	33.00	12.90	7.5	12.9	II	B	37	36	27
106	11	58	10	4	7.9	4.2	2.5	50	21	400	1	6	28	<5	13.45	30.16	16.71	6.3	8.2	II	B	43	23	34
107	21	65	2	4	8.0	5.2	2.7	50	25	450	<1	7	31	<5	15.43	35.10	19.67	7.9	11.4	II	B	28	44	28
108	31	65	1	4	8.4	1.1	3.1	55	21	450	<1	5	23	<5	17.35	25.75	8.40	7.5	10.3	II	A	37	30	33
109	34	66	1	4	8.0	4.2	2.3	35	22	350	<1	6	29	<5	15.00	24.25	9.25	7.4	-	II	B	50	23	27
110	35	65	3	4	4.7	0.8	2.8	70	8	300	<1	5	20	<5	16.40	29.05	12.65	7.2	10.5	I	B	46	29	25
111	28	59	11	4	7.6	3.1	2.8	60	28	400	<1	8	39	6	20.00	35.35	15.35	7.3	12.8	II	B	34	26	40
112	36	59	13	4	7.5	3.2	2.6	50	26	350	1	7	35	<5	16.00	29.65	13.65	6.1	10.6	III	B	43	24	33
113	26	67	1	4	5.7	0.7	2.2	120	12	300	<1	7	18	<5	14.37	24.50	10.13	7.3	11.4	II	C	50	27	23
114	11	67	11	4	4.6	0.8	2.4	85	20	250	<1	6	31	<5	20.80	46.22	25.42	7.2	11.6	II	B	29	33	38
115	26	67	12	4	7.8	2.1	3.2	90	24	350	1	8	37	<5	17.27	45.91	28.64	6.6	10.8	III	C	28	39	33
116	23	69	10	4	4.6	0.8	3.3	110	23	350	1	7	26	<5	19.87	35.33	15.46	1.9	8.2	I	B	29	39	32

CHEMICAL ANALYSIS															MINERALOGICAL AND PHYSICAL ANALYSES									
	Location																	Feldspar		Clay* Minerals				
Sample No.	Sec	Tp	R	West of Mer	pH	CaO %	Fe %	Zn ppm	Cu ppm	Mn ppm	Mo ppm	Co ppm	B ppm	Soluble Salts meq/100g	Plastic Limit	Liquid Limit	Plasticity Number	K %	Na-Ca %	M	I	Sand %	Silt %	Clay %
National Topographic Series Sheet 74 E																								
117	22	95	4	4	4.8	0.4	1.9	85	11	200	<1	5	21	<5	14.00	17.06	3.06	2.3	4.6	III	A	65	24	11
118	22	95	4	4	7.7	6.3	1.1	20	8	100	<1	4	15	<5	10.43	11.96	1.53	2.8	2.9	I	D	66	29	5
119	6	95	6	4	5.5	0.6	2.6	90	16	250	1	6	24	<5	14.80	27.45	12.65	4.9	5.1		A	49	26	25
120	8	97	7	4	7.0	0.5	2.2	35	13	200	<1	6	26	<5	16.67	27.76	11.09	2.0	3.3	III	A	59	19	22
121	14	99	3	4	4.6	0.2	0.8	30	7	100	<1	4	15	<5	11.67	11.82	0.15	1.6	2.3	III	A	81	13	6
122	2	102	3	4	5.8	0.6	2.4	40	15	250	<1	7	25	<5	13.73	23.20	9.47	3.8	6.5	III	B	56	21	23
123	20	99	11	4	7.3	1.3	3.1	75	22	300	1	6	49	25	22.03	37.15	15.12	4.7	4.9	III	B	41	33	26
National Topographic Series Sheet 74 M																								
124	33	116	3	4	4.4	1.5	2.2	55	9	250	<1	6	15	<5	14.47	16.06	1.59	12.5	24.0	II	A	53	46	1
125	17	119	4	4	5.4	0.5	1.6	55	7	130	2	4	21	<5	-	-	-	9.6	10.7			28	68	4
126	18	120	6	4	6.7	1.2	3.5	80	21	350	<1	6	47	<5	34.00	-	-	13.8	15.0	III	C	4	25	71
127	21	121	9	4	8.0	9.4	2.7	90	24	400	1	7	28	<5	23.07	32.07	9.00	8.1	6.5	II	C	20	67	13
National Topographic Series Sheet 82 H																								
128	34	1	19	4	7.7	5.2	3.0	80	26	400	<1	7	27	<5	21.40	38.58	17.18	8.6	17.1	II	B	28	42	30
129	10	4	17	4	7.8	5.6	2.5	90	23	350	1	6	26	<5	17.30	27.38	10.08	-	-	III	B	37	46	17
130	24	6	17	4	7.8	4.4	2.5	65	17	350	<1	6	22	<5	15.65	27.97	12.32	-	-	II	B	46	34	20
131	32	5	18	4	8.3	6.0	2.9	90	19	400	1	5	21	100	20.15	42.04	21.89	9.5	22.4	III	B	21	46	33
132	25	3	22	4																				

133	8	6	21	4	7.9	7.6	2.7	95	24	400	1	7	21	<5	26.30	39.98	13.68	7.2	13.4	III	B	16	56	28
134	27	7	20	4	8.2	5.6	2.4	70	17	350	<1	6	19	<5	18.40	29.53	11.13	9.9	20.9	III	B	44	38	19
135	6	8	19	4	8.3	4.1	2.4	65	19	350	<1	6	24	<5	-	-	-	6.2	9.8	II	B	45	25	30
136	28	9	17	4	7.8	7.2	2.2	70	18	250	1	7	21	100	18.60	34.35	15.75	7.1	10.0	III	B	41	32	27
137	2	9	22	4	7.7	6.1	2.5	65	19	400	<1	6	22	<5	20.60	35.10	14.50	8.2	19.8	II	B	40	36	24
138	13	5	23	4	8.1	6.4	2.3	70	17	350	<1	6	22	28	15.43	26.35	10.92	7.6	13.2	II	B	34	29	37
139	23	4	26	4	8.3	7.0	2.6	85	19	350	<1	6	23	38	17.53	35.25	17.72	5.6	11.0	II	B	13	45	42
140	23	4	26	4	8.1	7.2	2.5	90	18	350	1	6	24	45	17.17	32.70	15.53	5.8	10.7	II	B	26	34	40
141	22	7	26	4	8.2	9.7	2.2	80	30	300	<1	5	13	<5	19.60	28.26	8.66	5.3	9.9	II	C	26	48	26
142	20	7	25	4	8.2	8.1	2.3	80	19	350	1	7	22	<5	-	-	-	6.3	10.6	II	B	33	54	13
143	11	11	21	4	8.3	12.8	2.0	95	15	350	<1	6	22	100	21.10	31.27	10.17	1.7	5.0	II	B	25	52	23
144	11	12	19	4	8.2	3.2	2.5	80	18	500	1	6	29	17	19.40	32.20	12.80	8.4	19.5	II	B	44	32	24
145	9	11	26	4	8.2	5.9	2.5	80	23	350	<1	6	22	<5	-	-	-	6.6	10.7	II	B	36	30	34
146	9	11	26	4	8.4	8.7	2.4	75	19	350	1	7	21	6	-	-	-	6.9	15.4	II	B	34	44	22
National Topographic Series Sheet 82I																								
147	6	14	19	4	7.8	4.1	2.5	70	27	400	1	8	28	<5	17.90	30.06	12.16	7.9	17.4		B	43	37	20
148	13	17	17	4	7.2	4.8	2.6	75	23	400	<1	7	25	40	17.30	39.70	22.40	9.5	19.0	IV	A	47	32	21
149	31	19	15	4	8.5	5.8	2.3	80	20	300	<1	7	28	51	23.50	38.20	14.70	10.4	21.5	IV		43	40	17
150	17	16	19	4	8.1	4.9	2.4	60	22	350	<1	6	27	<5	16.80	29.07	12.27	-	-	III	B	43	39	18
151	32	13	22	4	7.7	7.7	2.2	65	17	550	1	5	70	<5	22.65	32.95	10.30	14.6	17.1	II	A	48	36	16
152	6	18	19	4	8.0	5.2	2.2	70	16	350	1	6	18	12	-	-	-	5.8	9.9	II	B	42	36	22
153	35	15	23	4	8.0	11.6	2.0	55	21	300	<1	6	19	<5	22.40	30.07	7.67	9.1	17.1	III	B	41	42	17
154	36	18	22	4	7.9	4.8	2.6	80	23	400	<1	7	23	<5	18.80	33.90	15.10	8.8	19.5	III	A	34	45	21

					CHEMICAL ANALYSIS										MINERALOGICAL AND PHYSICAL ANALYSES									
	Location																	Feldspar		Clay* Minerals				
Sample No.	Sec	Tp	R	West of Mer	pH	CaO %	Fe %	Zn ppm	Cu ppm	Mn ppm	Mo ppm	Co ppm	B ppm	Soluble Salts meq/100g	Plastic Limit	Liquid Limit	Plasticity Number	K %	Na-Ca %	M	I	Sand %	Silt %	Clay %
155	8	17	24	4	8.2	4.6	2.5	75	17	450	1	6	21	<5	-	-	-	8.0	17.5	III	B	45	21	34
156	4	13	27	4	7.7	8.2	2.3	65	19	350	<1	6	19	<5	15.63	26.96	11.33	5.3	9.5	II	B	33	46	21
157	18	14	27	4	8.0	8.9	2.2	70	18	350	<1	7	21	<5	17.80	28.04	10.24	6.6	10.9	II	B	32	50	18
158	18	15	27	4	8.0	9.0	2.6	75	21	300	<1	7	26	<5	-	-	-	6.9	10.1	III	B	29	37	34
159	23	17	25	4	7.9	3.9	2.5	75	21	400	1	5	20	45	14.65	26.80	12.15	8.3	16.2	III	B	44	38	18
160	29	18	24	4	8.0	7.7	2.5	70	21	400	<1	7	25	<5	19.50	29.84	10.34	9.1	17.5	III	B	42	39	19
161	6	22	20	4	7.1	3.3	3.1	85	23	500	1	7	23	<5	22.15	39.87	17.72	8.0	16.4	III	B	23	49	28
162	33	19	24	4	7.9	8.8	2.6	55	24	450	<1	8	27	<5	21.43	29.25	7.82	9.6	20.8	IV	A	48	32	20
163	16	18	25	4	8.0	5.7	2.4	75	22	400	1	6	21	100	-	-	-	8.3	15.5	III	B	46	27	27
164	16	16	27	4	8.1	8.5	2.2	60	19	450	<1	7	18	<5	-	-	-	7.5	12.2	III	C	45	35	20
165	16	16	28	4	8.2	5.4	2.5	70	21	350	1	7	21	<5	-	-	-	6.9	13.6	III	C	40	39	21
166	28	17	27	4	8.3	2.9	2.9	70		400	1			<5	15.83	35.14	19.31	5.5	8.3	I	C	36	36	28
167	20	17	28	4	8.2	8.9	2.3	60	22	300	<1	8	19	<5	14.13	30.15	16.02	6.2	10.6	III	B	34	43	23
168	29	20	25	4	7.7	6.4	2.5	80	20	350	<1	7	14	<5	17.73	35.86	18.13	7.2	12.6	III	B	38	32	30
169	24	22	23	4	8.1	5.3	2.7	70	24	450	<1	7	21	8	21.65	39.55	17.90	8.4	18.3	II	B	23	53	24
170	20	20	27	4	7.8	7.4	2.5	75	22	350	<1	7	15	<5	15.77	33.98	18.21	6.6	13.2	II	B	37	30	33
171	2	21	29	4	8.5	9.0	1.6	60	15	300	<1	6	22	<5	12.43	16.10	3.67	5.2	5.5	II	B	47	46	7

National Topographic Series Sheet 82O

172	34	24	29	4	7.7	9.2	2.3	85	20	350	1	7	19	17	15.73	26.20	10.47	6.0	9.9	II	B	33	44	23
173	10	27	29	4	8.2	12.5	1.3	60	18	250	1	7	18	<5	16.37	18.21	1.24	5.8	10.3	I	C	45	45	10
174	26	27	1	5	7.8	11.7	2.1	80	19	300	1	7	17	<5	19.67	30.74	11.07	4.5	5.5	II	C	37	39	24
175	5	29	3	5	7.4	7.6	3.2	130	23	350	1	6	24	<5	26.80	47.30	20.50	8.1	6.1	III	B	75	9	34
176	22	31	3	5	7.2	8.8	2.4	70	22	400	1	7	26	<5	-	-	-	6.9	10.7	II	B	38	42	20
177	3	31	5	5	7.8	7.8	3.6	90	33	500	1	8	28	<5	-	-	-	9.2	23.5	II	B	3	12	85

National Topographic Series Sheet 82P

178	16	27	16	4	7.9	4.1	2.5	60	23	450	<1	7	22	<5	20.30	42.26	21.98	10.5	23.5	III	B	39	36	25
179	24	26	18	4	7.2	5.2	2.6	60	23	600	1	6	20	<5	16.90	32.95	16.05	-	-	IV	A	51	26	23
180	11	24	20	4	8.1	6.4	2.7	65	31	400	<1	7	21	<5	-	-	-	12.1	26.0	III	B	20	50	30
181	11	24	21	4	8.0	7.2	3.0	80	26	450	<1	8	26	<5	25.85	47.90	22.05	8.6	16.4	III	B	18	38	44
182	14	24	23	4	8.2	8.8	2.9	90	33	400	<1	8	28	<5	30.05	49.87	19.82	7.2	14.7	III	B	6	51	43
183	11	26	22	4	7.6	7.9	3.0	55	27	350	<1	7	25	<5	21.70	59.40	37.70	11.0	25.0	II	B	30	24	46
184	26	28	20	4	8.2	5.1	2.4	90	23	400	1	7	23	16	20.30	30.90	10.60	11.1	21.7	II	C	26	57	17
185	17	29	18	4	7.8	5.9	3.1	90	40	200	1	10	20	<5	25.65	44.85	19.20	16.2	26.8	III	B	18	49	33
186	18	29	16	4	8.5	6.1	2.6	55	23	500	1	7	19	22	18.05	50.30	32.25	10.5	26.4	IV	A	46	35	19
187	14	31	16	4	7.9	4.8	2.3	60	25	350	<1	7	30	<5	-	-	-	8.0	20.9	II	B	44	32	24
188	33	32	15	4	8.1	9.3	2.4	70	24	350	<1	6	27	6	-	-	-	8.0	10.3	II	B	27	39	34
189	13	31	18	4	6.1	1.1	2.9	60	24	500	<1	7	24	<5	-	-	-	10.1	22.5	III	A	48	22	30
190	12	31	20	4	7.7	5.3	3.0	80	34	500	<1	7	29	50	27.60	49.76	22.16	4.5	22.3	III	B	5	69	26
191	18	28	22	4	7.8	3.3	2.2	65	24	400	1	6	20	<5	-	-	-	-	-	III	B	51	39	10
192	15	26	24	4	8.2	6.3	2.1	50	20	350	<1	5	20	<5	15.80	22.67	6.87	8.3	17.0	III	B	56	29	15

					CHEMICAL ANALYSIS										MINERALOGICAL AND PHYSICAL ANALYSES									
	Location																	Feldspar		Clay* Minerals				
Sample No.	Sec	Tp	R	West of Mer	pH	CaO %	Fe %	Zn ppm	Cu ppm	Mn ppm	Mo ppm	Co ppm	B ppm	Soluble Salts meq/100g	Plastic Limit	Liquid Limit	Plasticity Number	K %	Na-Ca %	M	I	Sand %	Silt %	Clay %
193	8	28	25	4	8.1	15.3	1.7	55	21	250	<1	6	19	<5	23.40	34.02	10.62	5.8	12.6	II	B	30	45	25
194	8	28	24	4	8.0	6.4	1.5	55	15	300	<1	5	19	<5	-	-	-	6.9	11.0	III	B	47	48	5
195	10	29	24	4	7.8	5.0	2.4	65	27	450	1	7	24	<5	17.60	29.00	11.40	9.1	18.6	III	B	48	35	17
196	14	31	24	4	7.7	5.3	2.5	65	24	400	1	6	24	<5	15.70	28.36	12.66	8.0	19.4	III	B	40	37	23
197	16	33	22	4	7.7	3.5	2.6	65	28	400	1	7	24	<5	15.80	32.18	16.38	8.3	18.5	IV	B	46	32	22
198	13	33	21	4	7.8	3.6	2.6	60	21	400	1	6	28	<5	18.00	34.87	16.87	6.6	11.0	II	B	36	34	30
199	20	34	24	4	7.7	5.3	2.4	50	19	400	<1	6	26	<5	14.90	27.86	12.96	7.9	27.7	II	B	44	34	22
200	8	34	25	4	7.6	4.0	2.6	60	23	450	1	6	36	6	17.20	32.00	14.80	6.3	12.0	III	B	40	38	22
201	16	34	27	4	7.7	6.0	2.3	60	21	350	1	6	22	<5	17.30	29.47	12.17	8.7	18.2	III	B	44	32	24
202	19	31	27	4	7.4	4.2	4.2	110	29	400	1	6	32	17	-	-	-	-	-			3	15	82
203	18	31	27	4	7.9	10.8	2.3	85	26	350	1	6	28	<5	19.50	35.08	15.58	7.2	19.4	I	C	22	47	31
204	18	29	27	4	8.0	5.0	2.6	70	15	500	<1	5	22	<5	14.60	25.95	11.35	6.9	12.9	III	B	49	33	18
National Topographic Series Sheet 83A																								
205	36	35	16	4	8.1	5.1	2.4	60	27	650	<1	6	24	27	23.70	45.10	21.40	12.1	25.5	IV	B	15	60	25
206	36	36	18	4	7.8	3.1	2.7	75	29	400	1	6	24	35	-	-	-	-	-	III	D	33	41	26
207	19	38	15	4	7.7	5.2	2.5	55	23	400	1	6	23	100	-	-	-	10.5	17.5	III	B	52	31	17
208	26	38	17	4	7.3	1.0	2.6	50	18	400	<1	5	15	<5	-	-	-	10.5	28.9	III	A	56	21	23
209	8	38	18	4	7.6	1.5	2.8	55	27	350	1	6	27	27	-	-	-	7.3	14.0	II		54	26	20
210	36	35	20	4	8.1	3.5	2.4	50	19	400	1	5	23	<5	12.35	25.92	-	8.8	19.6	II	B	50	29	21

211	6	39	19	4	7.9	6.3	2.3	55	19	350	< 1	7	18	22	20.15	45.07	24.92	9.6	19.8	II	B	54	28	18
212	1	42	15	4	7.6	0.8	2.9	65	30	400	< 1	8	32	< 5	-	-	-	8.8	19.4		B	42	32	26
213	1	42	19	4	7.6	2.0	2.7	75	22	500	1	6	22	< 5	-	-	-	9.6	17.7	III	A	44	31	25
214	32	41	19	4	8.1	4.2	3.0	75	27	450	1	7	37	< 5	-	-	-	6.9	12.5	II	C	15	47	38
215	10	39	22	4	7.8	5.5	2.6	50	24	450	< 1	7	27	< 5	15.27	34.20	18.93	8.0	15.5	III	B	43	29	28
216	36	37	23	4	8.2	4.9	2.1	45	19	300	1	6	28	< 5	-	-	-	5.2	12.1	II	B	49	29	22
217	20	36	23	4	7.9	6.0	2.3	50	17	300	1	6	24	< 5	15.35	27.68	12.33	8.2	24.9	II	B	54	35	11
218	22	36	25	4	7.9	2.4	2.4	55	28	350	1	7	37	< 5	14.75	28.76	14.01	6.9	29.0	II	B	44	22	34
219	21	40	22	4	7.6	4.1	2.3	55	23	360	< 1	6	29	< 5	14.05	25.65	11.60	5.8	17.5	III	B	44	33	23
220	29	41	21	4	7.7	10.5	1.9	45	18	350	1	5	18	< 5	21.30	29.87	8.57	7.6	16.4	II	B	41	40	19
221	21	42	21	4	7.9	2.8	3.0	100	28	550	1	7	28	< 5	24.25	44.90	20.65	9.5	21.1	III	B	10	58	32
222	19	44	17	4	8.1	4.1	2.5	95	20	400	1	6	21		19.50	33.00	13.50	7.9	16.0		A	44	37	19
223	24	44	15	4	7.8	3.7	2.4	110	20	350	1	7	25	55	18.55	33.59	15.04	8.9	16.1	IV	A	45	35	20
224	3	45	16	4	8.1	3.0	2.6	80	18	350	1	5	25	85	16.15	35.13	18.98	7.9	14.3	IV	B	40	35	25
225	29	45	17	4	8.0	2.8	2.7	80	24	400	1	6	24	39	18.35	34.81	16.46	9.2	19.8	III		41	34	25
226	14	46	19	4	8.0	2.8	2.7	80	22	400	< 1	5	22	55	13.10	43.75	30.65	9.7	17.4	III	B	40	36	24
227	32	42	23	4	5.7	1.0	2.8	75	26	400	< 1	6	27	< 5	19.25	31.72	12.47	8.3	16.2	III	A	47	34	19
228	5	39	24	4	7.7	6.2	2.3	70	27	400	< 1	6	22	< 5	16.80	29.36	12.56	8.2	17.1	III	B	44	37	19
229	14	38	26	4	6.5	1.1	3.0	60	26	500	< 1	7	22	< 5	-	-	-	9.1	18.1	III	A	39	35	26
230	2	36	28	4	7.5	3.9	2.0	55	18	350	< 1	6	20	< 5	17.40	18.88	1.48	-	-	III	B	59	29	12
231	33	36	27	4	7.9	7.9	1.9	35	17	300	< 1	5	17	< 5	15.00	25.80	10.80	8.2	17.7	II	B	47	35	18
232	14	38	27	4	7.6	10.6	1.9	45	21	300	< 1	7	17	< 5	22.20	35.90	13.70	8.3	18.9	IV	A	46	34	20
233	19	38	26	4	7.6	5.3	2.7	65	25	450	1	7	23	< 5	15.55	29.00	13.45	8.6	19.0	III	B	43	34	23
234	10	43	26	4	7.5	2.3	2.3	60	17	350	< 1	6	24	< 5	15.60	23.60	8.00	7.8	15.8	II	B	42	47	11

					CHEMICAL ANALYSIS										MINERALOGICAL AND PHYSICAL ANALYSES									
	Location																	Feldspar		Clay* Minerals				
Sample No.	Sec	Tp	R	West of Mer	pH	CaO %	Fe %	Zn ppm	Cu ppm	Mn ppm	Mo ppm	Co ppm	B ppm	Soluble Salts meq/100g	Plastic Limit	Liquid Limit	Plasticity Number	K %	Na-Ca %	M	I	Sand %	Silt %	Clay %
235	9	46	26	4	5.2	0.8	2.9	55	22	150	< 1	5	22	<5	21.70	38.50	16.80	7.1	13.7	III	A	39	31	30
236	2	46	23	4	7.8	4.6	2.5	80	23	400	1	7	21	<5	14.40	31.25	16.85	12.8	20.1	I	B	41	39	20
237	25	46	20	4	7.5	2.9	2.6	80	26	400	< 1	6	21	20	19.60	36.11	16.51	10.7	18.7		A	39	34	27
238	27	37	8	5	7.7	7.7	2.6	100	-	450	2	-	-	<5	-	-	-	8.5	19.1	III		41	40	19
239	2	40	9	5	7.7	4.6	3.2	120	30	300	1	8	38	<5	22.13	30.75	8.62	9.5	10.3	II	B	22	51	27
240	32	41	8	5	7.8	7.0	2.6	65	25	500	< 1	7	18	<5	19.60	25.75	6.15	11.3	24.6	II	B	51	35	14
National Topographic Series Sheet 83F																								
241	16	53	15	5	7.8	44.4	3.0	65	29	450	1	8	28	<5	17.25	40.65	23.40	7.6	15.4	III	B	29	43	28
242	18	53	17	5	7.8	4.7	3.2	60	28	450	1	8	16	<5	19.85	31.20	11.35	11.7	25.3	IV	A	40	45	15
243	32	52	20	5	7.9	5.9	2.8	60	27	400	1	7	16	<5	17.45	28.63	11.18	11.1	22.7	IV	B	41	45	14
244	9	53	22	5	7.4	11.0	2.7	65	23	400	1	7	20	<5	20.85	39.40	19.65	8.6	15.2	I	C	17	39	44
245	13	51	25	5	7.9	12.1	1.7	45	18	250	1	6	17	<5	13.45	17.18	4.73	5.1	9.4	I	D	52	40	8
National Topographic Series Sheet 83G																								
246	6	48	3	5	5.6	1.4	3.0	80	20	550	< 1	6	19	<5	18.10	29.56	11.46	9.9	22.9	II	B	31	34	35
247	7	51	1	5	7.1	4.1	2.6	80	25	400	1	7	23	<5	19.55	28.57	9.02	9.1	21.7	IV	A	47	35	18
248	13	54	1	5	7.5	3.5	2.6	65	27	400	< 1	7	22	<5	15.75	32.25	16.50	9.0	18.2	III	A	41	35	24
249	15	54	2	5	7.4	1.5	2.8	55	26	350	1	6	31	<5	20.00	36.20	16.20	5.9	11.6	III	A	35	36	29
250	12	53	3	5	5.3	0.9	2.8	55	25	350	1	7	27	<5	16.10	26.75	10.65	6.8	11.6	III	B	48	27	25
251	12	53	3	5	5.1	0.7	3.3	50	31	100	2	4	44	<5	21.40	38.00	16.60	3.9	5.2	III	B	24	40	36

252	18	53	3	5	6.2	1.0	3.2	80	29	500	1	7	32	<5	19.15	34.95	15.80	7.0	11.8	III	A	33	33	34
253	10	54	3	5	7.1	3.2	2.4	65	21	300	2	6	32	<5	13.60	23.67	10.07	3.2	5.7	II	B	54	27	19
254	27	54	2	5	7.1	2.4	2.9	65	27	450	1	7	31	<5	17.35	33.35	16.00	6.9	11.9	III	B	27	47	26
255	9	55	1	5	6.9	2.6	2.7	55	24	400	1	6	30	<5	17.45	31.15	13.70	5.9	11.3	III	B	45	26	29
256	18	54	3	5	7.5	2.3	2.8	60	33	400	2	6	29	<5	16.30	35.45	19.15	6.0	10.7	IV	A	39	37	24
257	1	54	5	5	7.5	2.7	2.7	75	20	350	1	5	30	<5	17.75	31.40	13.65	6.0	9.9	III	B	41	34	25
258	22	53	5	5	7.6	2.4	2.5	60	25	400	1	7	29	<5	13.95	28.35	14.40	5.3	9.4	III	B	42	37	21
259	19	53	6	5	7.6	3.2	2.7	55	27	300	1	7	33	16	16.95	36.75	19.80	6.6	10.6	III	B	37	39	24
260	34	55	4	5	7.4	3.8	2.7	65	26	350	1	7	30	<5	18.50	33.40	14.90	6.1	10.7	III	A	39	34	27
261	1	56	3	5	6.1	1.0	3.1	85	25	400	1	6	31	<5	19.00	39.00	20.00	6.6	11.7		A	36	48	16
262	31	55	4	5	7.6	3.3	2.7	65	22	400	1	6	30	<5	15.95	33.60	17.65	6.4	22.7	III	A	38	36	26
263	14	56	5	5	7.1	1.0	2.7	40	19	350	1	5	32	<5	14.45	27.87	13.42	4.9	5.2	II	A	48	28	24
264	13	56	6	5	5.4	0.7	3.6	75	33	400	1	8	43	<5	23.20	44.44	21.24	4.2	6.1	II	B	23	32	45
265	4	47	9	5	7.8	2.6	3.2	85	26	600	1	7	28	<5	19.90	39.43	19.53	7.2	13.2	III	A	50	29	21
266	7	47	10	5	7.6	4.0	2.9	70	23	400	1	7	24	9	15.10	35.92	20.82	9.3	18.2	II	B	37	35	28
267	7	47	10	5	7.9	3.7	3.0	90	24	400	1	7	35	<5	17.83	38.33	20.50	6.0	12.8	II	B	29	36	35
268	7	47	10	5																				
269	7	47	10	5																				
270	27	53	10	5	7.7	3.1	3.0	60	28	400	1	7	27	<5	18.85	39.90	21.05	6.6	12.9	III	B	31	43	26
271	36	53	12	5	7.7	3.0	2.9	55	27	450	1	7	35	<5	17.20	38.94	21.74	6.9	13.6	III	B	36	39	25
272	13	57	8	5	7.7	3.0	2.6	90	23	350	1	7	31	<5	17.10	31.72	14.62	6.0	11.0	II	B	40	34	26
273	1	47	2	5	5.6	0.9	3.0	70	27	350	1	6	31	<5	19.35	39.98	20.63	6.9	11.7	IV	B	36	31	33

					CHEMICAL ANALYSIS										MINERALOGICAL AND PHYSICAL ANALYSES									
	Location																	Feldspar		Clay* Minerals				
Sample No.	Sec	Tp	R	West of Mer	pH	CaO %	Fe %	Zn ppm	Cu ppm	Mn ppm	Mo ppm	Co ppm	B ppm	Soluble Salts meq/100g	Plastic Limit	Liquid Limit	Plasticity Number	K %	Na-Ca %	M	I	Sand %	Silt %	Clay %
National Topographic Series Sheet 83H																								
274	3	47	16	4	7.8	4.8	2.5	70	24	350	1	7	27	6	17.85	32.28	14.43	8.2	13.9	III	B	44	33	23
275	3	49	16	4	8.2	4.5	2.4	60	24	350	<1	7	28	46	17.10	27.65	10.55	7.9	13.4	IV	B	49	31	20
276	29	45	17	4	7.8	1.0	2.8	70	32	500	1	9	42	11	16.57	30.95	14.38	6.6	8.2	III	A	40	35	25
277	14	46	19	4	7.8	2.6	2.6	50	30	400	<1	8	32	45	15.83	34.25	18.42	8.9	15.5	III	B	44	31	25
278	5	50	17	4	8.0	4.8	2.4	60	24	350	1	6	26	80	18.20	33.03	14.83	7.6	14.4	III	B	45	32	23
279	10	47	20	4	7.6	3.5	2.6	90	23	450	1	6	22	16	20.25	36.20	15.95	9.7	18.5	IV	A	51	26	23
280	4	48	22	4	7.1	2.0	3.2	75	31	450	2	8	29	<5	-	-	-	10.1	18.2	II	B	24	43	33
281	1	51	19	4	8.0	3.4	2.5	70	28	350	1	8	28	<5	17.30	30.68	13.38	9.9	16.7	II	A	40	40	20
282	11	53	17	4	8.4	3.8	2.5	60	26	350	1	8	24	100	17.30	30.05	12.75	8.2	14.7	III	B	49	33	18
283	11	53	19	4	-	3.7	2.5	55	27	450	1	10	21	-	18.30	30.93	12.63	9.5	17.7	IV	A	48	33	19
284	15	51	20	4	7.7	3.0	2.8	70	23	350	1	5	28	<5	16.30	33.28	16.98	6.6	11.9	III	B	43	31	26
285	28	49	22	4	7.6	3.8	2.6	70	27	350	1	7	30	<5	15.95	32.60	16.65	6.6	13.2	III	A	43	31	26
286	13	48	24	4	5.5	1.0	2.8	75	33	400	1	7	26	<5	16.75	32.25	15.50	8.2	9.9	IV	A	42	32	26
287	26	50	23	4	7.6	3.4	2.7	65	25	500	1	7	30	17	18.60	34.35	15.75	6.6	13.2	III	B	41	32	27
288	3	52	21	4	7.4	3.9	2.6	80	24	500	1	8	29	7	16.55	32.92	16.37	6.6	10.9	II	C	45	20	35
289	8	51	23	4	7.4	2.7	2.7	75	23	400	<1	7	22	<5	16.90	30.89	13.99	8.9	15.4	III	A	44	35	21
290	12	53	21	4	7.8	7.5	2.7	60	27	400	1	8	30	<5	18.15	36.05	17.90	7.2	11.9	III	B	29	45	26
291	25	56	19	4	7.3	3.6	2.7	60	21	400	<1	6	22	<5	15.50	25.45	9.95	7.5	12.9	II	B	52	31	17
292	3	57	25	4	7.5	1.8	2.9	75	28	450	1	7	25	<5	19.35	37.32	17.97	8.3	15.2		B	42	24	34

293	3	57	26	4	6.5	1.3	2.7	85	28	400	1	7	23	<5	20.05	36.20	16.15	9.3	16.2	IV	B	37	36	27

National Topographic Series Sheet 83I

294	36	59	15	4	7.8	3.7	2.3	40	20	350	1	7	28	<5	14.10	26.25	12.15	6.1	8.2	III	B	50	18	32
295	1	61	21	4	7.5	5.2	2.4	55	22	350	1	7	28	<5	16.15	29.27	13.22	6.0	14.1	IV	A	44	36	20
296	32	62	20	4	5.2	0.9	3.0	65	30	400	1	6	28	<5	18.60	43.20	24.60	6.9	13.2	III	B	42	17	41
297	35	64	20	4	7.4	4.2	2.6	65	20	400	<1	6	26	<5	16.35	27.61	11.26	7.7	16.6	III	B	47	36	17
298	15	67	14	4	4.8	0.8	3.9	85	33	450	1	7	47	<5	-	-	-	-	-	III	B	1	57	42
299	29	67	16	4	5.6	0.8	2.9	60	26	300	1	6	36	7	20.50	31.28	10.78	5.8	16.0	III	B	38	34	28
300	24	67	19	4	-	0.7	3.6	95	37	450	1	8	52	5	25.95	43.80	17.85	5.3	9.9	III	B	12	53	35
301	16	66	22	4	7.9	2.7	3.8	80	37	600	1	8	25	<5	25.25	46.91	21.66	8.3	14.8	IV	A	27	44	29
302	10	64	23	4	7.3	2.8	3.2	75	31	450	1	7	38	<5	20.30	46.02	25.72	5.9	9.9	III	B	26	38	36
303	22	62	24	4	7.0	1.0	2.4	55	23	300	<1	7	23	<5	15.05	22.10	7.05	7.3	13.9	III	B	62	23	15
304	7	61	24	4	7.4	1.7	2.6	60	23	400	<1	7	26	6	15.75	24.63	8.88	7.9	13.6	III	B	49	31	20
305	27	68	24	4	7.5	2.1	2.5	70	23	350	1	8	33	<5	14.95	26.85	11.90	5.3	7.9	III	B	39	39	22

National Topographic Series Sheet 83J

306	11	58	1	5	7.8	2.1	2.7	60	20	400	1	5	30	<5	15.80	28.08	12.28	5.6	10.1	III	B	43	35	22
307	2	59	2	5	7.5	4.1	2.9	80	23	450	1	5	22	<5	22.70	41.58	18.88	10.5	20.1	II	B	34	36	30
308	2	60	1	5	7.8	4.9	2.7	70	31	400	1	8	31	<5	20.40	41.12	20.72	6.9	13.9	III	A	30	38	32
309	28	59	3	5	7.8	1.1	2.9	40	27	350	<1	9	29	<5	14.85	37.62	22.77	7.6	12.4	IV	A	42	32	26
310	14	61	5	5	7.6	4.0	3.0	85	27	400	1	7	30	<5	25.35	43.00	19.65	6.6	11.8	IV	B	33	34	33
311	17	62	6	5	7.7	4.1	2.6	65	24	450	1	7	23	<5	19.35	29.98	10.63	7.5	13.6	III	A	43	34	23
312	29	59	11	5	7.5	7.3	3.0	85	28	350	1	7	28	<5	24.45	43.50	19.05	7.9	11.6	III	B	22	42	36
313	20	60	13	5														8.3	13.2	III	B	42	21	37

					CHEMICAL ANALYSIS										MINERALOGICAL AND PHYSICAL ANALYSES									
	Location																	Feldspar		Clay* Minerals				
Sample No.	Sec	Tp	R	West of Mer	pH	CaO %	Fe %	Zn ppm	Cu ppm	Mn ppm	Mo ppm	Co ppm	B ppm	Soluble Salts meq/100g	Plastic Limit	Liquid Limit	Plasticity Number	K %	Na-Ca %	M	I	Sand %	Silt %	Clay %
314	6	65	8	5	7.6	3.1	3.0	80	28	400	1	8	35	<5	19.70	37.42	17.72	6.6	12.9	III	B	33	40	27
315	16	67	1	5	7.7	4.1	2.7	60	25	500	1	7	32	<5	17.40	35.00	17.60	6.2	11.7	III	B	42	32	26
316	2	69	1	5	7.3	1.4	2.9	70	24	450	1	8	33	<5	17.55	32.37	14.82	6.6	11.0	III	B	43	31	26
317	3	66	9	5	5.2	1.0	3.2	80	29	400	1	7	28	<5	20.90	37.80	16.90	7.3	14.5	IV	A	32	35	33
318	25	60	14	5	6.4	1.6	3.8	80	31	500	1	7	19	<5	19.10	46.85	27.75	11.4	19.1	IV	A	13	56	31
National Topographic Series Sheet 83K																								
319	21	61	15	5	7.6	3.8	3.2	80	30	450	1	7	23	<5	24.40	37.35	12.95	8.5	18.5	IV	A	31	37	32
320	36	61	18	5	7.3	3.0	2.9	95	27	350	1	10	37	15	21.15	37.00	15.93	8.1	16.3	III	B	33	37	30
321	31	62	19	5	5.0	0.9	3.6	65	24	300	<1	6	29	<5	24.40	43.85	19.45	6.9	14.8	III	A	14	49	37
322	36	64	21	5	5.4	1.0	3.2	55	33	400	1	8	30	<5	20.40	37.08	16.68	7.2	14.3	IV	A	36	37	27
323	36	66	22	5	7.6	3.4	2.9	90	25	300	1	6	36	<5	16.65	31.65	15.00	6.1	9.4	II	B	35	38	27
324	10	63	26	5	4.8	0.7	3.4	65	18	300	1	8	30	<5	22.17	38.00	15.90	7.1	11.8	II	B	32	33	35
325	27	69	22	5	7.4	3.5	2.9	90	26	450	1	7	26	<5	25.85	40.05	14.20	9.6	21.7	IV	A	33	35	32
National Topographic Series Sheet 83M																								
326	7	72	2	6	7.6	3.0	3.3	80	32	400	2	7	47	<5	19.60	39.25	19.65	6.6	10.1	II	B	22	56	22
327	1	71	7	6	7.5	3.1	3.2	65	29	400	2	7	43	35	21.35	43.28	11.93	6.6	11.6	II	C	22	39	39
328	15	70	9	6	8.2	5.0	2.7	110	30	350	2	7	40	19		34.50		7.9	11.5					
329	10	71	9	6	7.7	2.8	3.1	95	34	450	1	9	44	<5	20.93	37.45	16.52	9.1	19.8	III	B	30	34	36
330	4	72	9	6	7.4	2.9	2.9	80	27	450	1	7	24	<5	18.20	31.93	13.73	10.0	18.2	III	A	37	38	25

331	14	72	9	6	7.8	4.1	3.2	120	32	400	1	8	46	23				9.2	16.8	I	B	20	30	50
332	5	72	8	6	7.8	1.8	3.7	110	34	350	1	7	56	<5				8.3	13.1	II	B	9	31	60
333	14	71	10	6	7.6	4.3	2.7	65	24	400	<1	6	30	<5	17.60	34.17	16.58	8.2	14.1	II	B	40	33	27
334	15	71	10	6	7.6	2.2	3.6	105	38	400	1	7	48	12				8.2	11.9	II	C	12	36	52
335	33	70	10	6	7.8	6.1	3.0	100	31	400	<1	8	37	9				10.3	21.0	II	C	26	37	37
336	17	72	10	6	7.5	4.8	3.2	70	30	400	<1	8	36	<5				8.5	16.8	III	B	31	37	32
337	17	72	10	6	7.6	4.4	2.7	80	27	350	<1	7	35	<5				8.5	16.8	II	B	41	31	28
338	34	72	10	6	7.3	3.5	2.5	85	32	400	1	8	44	<5	20.97	36.95	15.98	8.5	17.7	III	B	24	39	37
339	9	73	9	6	7.5	5.4	2.9	65	26	350	1	7	40	<5	18.33	38.90	20.57	6.6	12.3	II	B	30	33	37
340	6	74	6	6	7.4	3.9	3.1	60	28	450	1	8	35	24	24.10	43.47	19.37	7.9	14.8	II	B	28	35	37
341	18	74	5	6	8.0	4.5	2.5	65	21	350	1	6	31	<5	15.70	25.00	9.30	4.9	7.2	II	B	48	39	13
342	16	76	5	6	7.7	3.4	2.7	65	23	350	1	7	39	23	19.05	29.55	10.50	5.3	7.2	II	C	36	40	24
343	15	74	9	6	7.6	3.9	2.6	75	21	350	1	7	40	16	23.20	42.10	18.90	9.2	19.4	III	B	24	40	36
344	34	73	11	6	8.0	3.5	3.0	80	28	450	1	8	30	26	20.95	33.61	12.66	9.5	20.0	III		26	49	25
345	36	74	13	6	7.7	3.4	3.2	85	27	550	1	8	25	<5	18.00	30.80	12.80	9.2	11.9			31	40	29
346	10	78	4	6	7.2	2.7	3.3	80	29	400	1	9	46	18	17.60	31.70	14.10	7.2	9.9	I		29	45	26
347	21	80	4	5	7.4	2.8	3.2	110	25	350	1	7	53	35	20.65	42.86	22.21	6.0	9.6	I	C	18	47	35

National Topographic Series Sheet 83 N

348	28	74	18	5	7.5	5.2	3.1	100	27	350	2	8	33	<5	18.75	39.60	20.85	7.3	14.8	III	B	25	43	32
349	30	71	21	5	7.4	2.7	3.4	100	31	350	1	8	47	21	23.35	45.30	21.95	7.3	13.9	II	C	16	44	40
350	23	74	21	5	7.5	2.0	3.1	100	32	250	2	7	54	17	21.60	40.50	18.90	5.6	8.7	I	C	22	42	36
351	23	70	23	5	6.4	0.8	4.2	110	35	400	1	7	47	11	31.60	59.20	27.60	6.9	10.5	III	B	8	34	58
352	12	76	21	5	7.4	3.6	3.1	95	31	350	2	6	53	<5	19.60	37.87	18.27	6.6	10.2	II	B	27	43	30

Sample No.	Location				CHEMICAL ANALYSIS										MINERALOGICAL AND PHYSICAL ANALYSES									
																		Feldspar		Clay* Minerals				
	Sec	Tp	R	West of Mer	pH	CaO %	Fe %	Zn ppm	Cu ppm	Mn ppm	Mo ppm	Co ppm	B ppm	Soluble Salts meq/100g	Plastic Limit	Liquid Limit	Plasticity Number	K %	Na-Ca %	M	I	Sand %	Silt %	Clay %
353	35	70	25	5	7.6	4.2	2.9	90	31	350	1	7	43	<5	19.10	34.82	15.72	6.6	11.3	III	B	28	46	26
354	4	78	20	5	6.4	0.7	3.7	60	33	500	1	7	45	8	21.60	48.05	26.45	5.7	8.6	II	B	17	41	42
355	7	79	20	5	7.4	3.0	3.3	100	37	350	1	8	62	23	23.15	43.19	20.04	6.0	7.9	I	C	21	39	40
356	25	77	24	5	7.4	2.7	3.1	75	30	350	1	7	39	<5	19.25	38.75	19.50	6.0	10.7	III	B	28	42	30
357	8	72	26	5	7.5	2.5	3.4	110	30	450	1	8	37	27	25.35	48.61	23.26	9.9	22.7	III	B	23	41	36
National Topographic Series Sheet 83 O																								
358	28	72	2	5	7.4	1.6	2.8	60	24	350	1	6	27	<5	15.20	30.27	15.07	6.3	10.2	IV	B	43	26	21
359	20	73	8	5	7.4	3.3	3.8	60	30	30	2	7	33	6	19.40	40.89	21.49	7.3	14.5	III	B	29	41	30
360	17	79	12	5	7.9	2.9	2.8	80	30	400	<1	7	36	<5	18.07	35.53	17.46	9.2	13.2	I	C	36	32	32
National Topographic Series Sheet 83 P																								
361	10	80	26	4	4.8	0.6	2.7	55	17	250	<1	7	28	<5	15.73	30.77	15.04	5.2	6.0	II	B	42	34	24
National Topographic Series Sheet 84C																								
362	31	81	20	5	7.6	2.0	3.3	120	32	350	1	8	48	7	19.25	35.38	16.13	5.3	9.0	II	C	29	42	29
363	20	83	21	5	7.7	3.5	3.3	95	33	350	1	8	55	41	21.65	47.63	26.98			II		7	57	36
364	34	83	23	5	7.6	3.6	3.1	90	29	350	1	7	43	16	22.50	33.18	10.68	8.6	10.7	II	B	21	45	25
365	28	82	25	5	7.5	1.3	3.6	110	24	450	2	8	47	<5	22.70	37.16	14.46	8.1	11.3	II	B	22	49	29
366	7	86	23	5	6.9	1.1	3.8	110	38	500	1	8	42	34	21.00	44.73	23.73	6.0	11.7	II	B	16	45	39
367	23	92	14	5	7.3	3.1	3.2	90	32	350	2	8	48	<5				6.6	12.8	II	C	30	35	35
368	13	88	24	5	5.4	0.7	3.6	110	36	300	2	6	45	<5	21.15	40.87	19.72	6.6	12.6	II	B	34	30	36

APPENDIX C.

CORRELATION BETWEEN SOME CHARACTERISTICS OF ALBERTA TILLS

					CHEMICAL ANALYSIS										MINERALOGICAL AND PHYSICAL ANALYSES									
	Location																	Feldspar		Clay* Minerals				
Sample No.	Sec	Tp	R	West of Mer	pH	CaO %	Fe %	Zn ppm	Cu ppm	Mn ppm	Mo ppm	Co ppm	B ppm	Soluble Salts meq/100g	Plastic Limit	Liquid Limit	Plasticity Number	K %	Na-Ca %	M	I	Sand %	Silt %	Clay %
390	26	98	2	6	5.4	0.8	3.8	110	35	350	2	7	42	<5	19.20	33.26	14.03	7.3	6.0	II		30	34	36
391	27	97	3	6	4.5	0.6	4.0	75	30	300	<1	7	47	<5	-	-	-	5.9	6.6	II	C	20	34	46
392	17	93	7	6	4.1	0.5	3.7	70	36	250	1	7	38	<5	21.70	40.25	18.55	8.3	6.0	II	A - B	28	34	38
393	22	94	7	6	4.1	0.5	4.7	85	29	250	1	8	53	<5	26.90	42.00	15.10	9.6	14.2	I	C	16	39	45
394	24	94	8	6	4.0	0.5	4.2	95	38	250	1	8	49	<5	24.80	46.30	21.50	8.3	20.8	II	C	10	42	48
395	7	95	7	6	4.3	0.7	4.2	110	34	350	2	9	48	<5	22.90	41.75	18.85	6.9	10.9	II	C	20	35	45
396	29	92	8	6	4.2	0.6	3.8	55	29	200	1	5	36	<5	25.10	50.65	25.55	9.2	-	III	B	20	34	46
397	23	93	9	6	4.8	0.8	3.5	80	28	250	1	10	47	<5	21.30	41.60	20.30	7.5	-	II	C	15	39	46
398	27	94	9	6	4.6	0.5	3.8	70	26	400	1	8	45	<5	-	-	-	5.6	7.3	II	C	27	41	32
399	31	92	10	6	4.3	0.3	4.7	80	34	150	2	7	59	<5	28.60	44.40	15.80	6.6	-	I	C	13	39	48
400	4	95	10	6	7.2	1.7	3.4	70	33	350	1	6	51	<5	18.50	36.30	17.80	6.6	10.2	II	C	28	34	38
401	21	100	4	6	4.5	0.6	3.5	70	39	400	1	8	48	<5	18.25	32.90	14.65	9.9	11.9	II	B	29	36	35
402	11	101	3	6	4.7	0.6	4.0	95	33	200	2	6	54	<5	24.60	42.35	17.75	6.6	7.0	II	C	17	41	42
403	15	101	7	6	7.1	1.2	3.6	55	24	400	1	7	48	<5	-	-	-	8.6	13.1	II		30	33	37
404	26	96	10	6	4.7	0.6	3.7	80	36	400	1	7	46	<5	23.90	36.36	12.46	8.6	-	II	B	25	33	42
405	12	95	13	6	6.5	0.9	3.5	75	32	400	1	6	48	<5	19.50	35.10	15.60	6.6	7.9	II	B	25	35	40
406	10	100	10	6	4.4	0.8	3.7	85	30	300	1	8	50	<5	22.20	34.87	12.67	6.9	12.2	II	C	20	44	36
407	36	101	9	6	6.9	0.8	3.4	95	29	450	2	8	43	<5	-	-	-	6.6	8.2	II	C	26	40	34
408	18	101	9	6	4.3	0.4	3.6	75	30	450	1	9	46	<5	22.90	36.48	13.58	10.7	11.9	II	B	23	37	40
409	22	101	12	6	5.6	0.7	3.4	95	37	400	1	7	44	<5	18.10	31.90	13.80	8.3	8.2	II	B	33	34	33

410	13	98	13	6	6.8	1.0	3.6	80	34	400	1	8	45	<5	20.70	33.60	12.90	10.9	16.5	I	C	28	40	32
National Topographic Series Sheet 84F																								
411	5	99	14	5	4.2	0.6	3.8	100	31	300	3	7	47	<5	24.60	40.15	15.55	10.2		II	B	24	45	31
412	31	93	23	5										6				9.7		II	C	30	35	35
413	20	96	22	5	7.6	2.8	3.2	100	31	400	1	8	44	<5	16.20	31.60	15.40	10.6	13.6	II	B-C	41	29	30
414	20	96	22	5														7.6	12.6	II	C	23	39	38
National Topographic Series Sheet 84G																								
415	32	96	1	5														8.9		II	B	25	37	38
416	7	98	10	5	4.9	0.7	3.5	100	31	300	2	6	42	<5				6.6	8.2	III	B	35	27	38
National Topographic Series Sheet 84H																								
417	10	96	17	4	4.6	0.5	2.9	50	20	200	1	6	30	<5								51	22	27
418	17	99	15	4	5.0	0.5	2.6	60	20	250	<1	6	33	<5			12.87	4.1	3.7	II	C	43	27	30
419	29	100	13	4	4.7	0.5	2.8	75	19	300	1	9	29	<5	15.03	27.90	11.05	3.5	4.7	II	B	45	25	30
420	11	98	18	4	4.7	0.6	3.0	85	19	250	2	6	33	<5	15.83	26.88	11.55	4.5	5.9	II	B	37	17	46
421	16	97	21	4	5.1	0.6	2.9	75	21	300	1	6	35	<5	15.90	27.45	13.85	3.9	5.6	II	B	41	38	21
422	17	97	22	4	5.3	0.7	2.9	80	25	350	1	8	36	<5	13.43	27.28	12.62	4.2	6.4	I	B	38	32	30
423	10	96	23	4	5.6	0.8	2.9	65	19	350	<1	6	31	<5	16.73	29.35	15.47	4.5	6.3	III	B	40	26	34
424	3	94	22	4											14.53	30.00						35	31	34
National Topographic Series Sheet 84I																								
425	23	106	21	4	7.6	8.2	3.0	70	21	300	<1	7	44	<5	21.35	43.40	22.05	2.0	6.3	I	C	20	39	41

					CHEMICAL ANALYSIS										MINERALOGICAL AND PHYSICAL ANALYSES									
	Location																	Feldspar		Clay* Minerals				
Sample No.	Sec	Tp	R	West of Mer	pH	CaO %	Fe %	Zn ppm	Cu ppm	Mn ppm	Mo ppm	Co ppm	B ppm	Soluble Salts meq/100g	Plastic Limit	Liquid Limit	Plasticity Number	K %	Na-Ca %	M	I	Sand %	Silt %	Clay %
National Topographic Series Sheet 84 J																								
426	31	104	1	5	8.0	13.1	2.1	40	21	400	<1	7	53	<5	20.90	36.65	15.75	3.7	5.3	I	C	29	41	30
427	3	107	3	5	7.8	6.5	3.2	80	31	350	2	7	42	<5	25.30	46.90	21.60	7.3	10.7	II	B	22	44	34
428	4	106	7	5	8.0	12.4	2.2	50	16	250	<1	6	40	<5	17.70	31.20	13.50	4.0	8.0	I	D	28	42	30
429	9	109	9	5	8.6	13.5	1.7	25	11	200	<1	5	28	7	19.20	33.05	13.85	5.3	9.0	I	C	39	26	35
430	14	110	8	5	4.6	0.6	3.7	100	36	350	3	10	44	<5	22.10	42.25	20.15	6.1	9.0	II	B-C	22	36	42
431	24	109	12	5	7.7	4.3	3.0	80	26	250	<1	6	63	11	25.37	41.64	16.27	7.3	9.2	I	C	19	25	56
432	24	109	12	5	7.9	3.7	2.5	50	17	250	<1	6	57	14	20.27	43.55	23.28	3.7	6.4	I	C	19	26	55
433	15	114	7	5	7.0	1.9	3.6	90	37	350	<1	8	52	<5	27.60	50.00	22.40	8.5	11.1	II	B	17	37	46
434	34	114	10	5	7.4	1.3	3.4	90	24	250	2	6	40	<5	21.53	39.52	17.99	8.3	10.8	I	C	24	36	40
National Topographic Series Sheet 84 K																								
435	31	59	4	5	8.5	4.7	2.4	45	22	400	<1	6	29	<5	20.60	36.27	15.67	5.2	10.8	I	C	35	34	31
436	27	105	24	5	7.6	5.8	2.9	70	27	300	<1	6	55	<5	20.80	37.42	16.62	4.7	6.9	I	C	21	38	41
National Topographic Series Sheet 84 L																								
437	11	107	3	6	4.7	0.6	3.8	110	39	300	2	8	47	<5	20.62	39.00	18.38	6.6	9.9	II	B	25	37	38
438	10	114	6	6	4.6	0.6	3.7	65	36	300	3	8	53	<5	22.33	48.80	26.47	9.1	10.8	I	C	18	35	47

National Topographic Series Sheet 84M

439	6	119	5	6	7.1	1.0	3.8	90	34	400	2	7	35	<5	21.65	37.58	15.93	8.2	10.3	III	B	30	30	40
440	39	119	5	6	7.6	2.5	3.2	85	28	400	2	7	35	<5	18.10	31.70	13.60	7.9	11.0	II	B	33	35	32
441	3	121	2	6	7.3	1.9	3.3	90	27	350	1	6	32	<5	19.57	37.31	17.74	8.2	10.3	II	B	32	32	36
442	21	119	10	6	7.3	3.1	4.0	110	28	600	3	6	31	<5	19.93	32.05	12.12	8.8	12.2	II	B	40	38	22
443	26	120	9	6	7.6	2.4	3.5	100	30	350	1	8	37	<5	20.03	36.33	16.30	9.8	10.8	II	B	25	40	35
444	33	124	4	6	7.7	8.5	2.8	70	19	300	1	6	27	<5	18.27	30.57	12.30	8.8	11.0	II	B	36	30	34
445	36	124	9	6	7.8	10.5	2.6	80	24	300	1	6	27	12				7.3	11.2	II	C	34	34	32
446	3	123	12	6	8.0	10.6	2.6	80	24	300	1	6	27	<5	17.33	30.38	13.05	9.5	14.7	-	B	33	39	28
447	31	124	11	6	7.8	16.5	2.2	60	27	300	2	7	23	<5	19.17	29.26	10.09	9.1	11.7	II	B	32	45	23
448	28	126	10	6	8.1	12.7	2.6	120	32	300	5	7	22	<5	19.83	25.40	5.57	7.6	16.9	II	B	24	55	21

National Topographic Series Sheet 84N

449	3	117	16	5	7.9	4.0	3.2	100	29	300	4	6	47	12	20.17	37.89	17.72	7.6	10.7	I	C	21	36	43
450	25	115	18	5	8.0									<5				6.9	12.6	I	C	23	43	34
451	27	118	17	5	7.9	7.4	2.7	90	37	250	3	6	41	<5	21.35	34.70	13.35	6.9	9.9	II	C	30	36	34
452	32	120	22	5	8.4	24.5	1.5	80	9	200	1	5	15	7	16.17	24.45	8.28	12.3	15.9	I	D	29	48	23
453	5	124	18	5	7.9	13.0	2.3	70	18	300	<1	7	33	<5	19.43	31.42	11.99	12.5	17.7	I	D	29	46	25
454	36	123	22	5	8.1	3.9	3.0	110	25	350	1	6	30	<5	17.13	30.08	12.95	7.9	10.3	II	B-C	36	36	28
455	4	122	23	5	7.6	3.2	3.0	70	27	300	1	6	33	<5	16.87	31.79	14.92	7.9	11.2	II	B	34	37	29
456	35	126	21	5	7.4	4.0	3.1	90	26	400	2	6	35	<5	15.90	30.56	14.66	8.3	10.2	II	C	37	31	32

					CHEMICAL ANALYSIS										MINERALOGICAL AND PHYSICAL ANALYSES									
	Location																	Feldspar		Clay* Minerals				
Sample No.	Sec	Tp	R	West of Mer	pH	CaO %	Fe %	Zn ppm	Cu ppm	Mn ppm	Mo ppm	Co ppm	B ppm	Soluble Salts meq/100g	Plastic Limit	Liquid Limit	Plasticity Number	K %	Na-Ca %	M	I	Sand %	Silt %	Clay %
National Topographic Series Sheet 84 O																								
457	6	118	4	5	7.6	4.5	3.2	80	24	350	1	6	37	<5	19.60	37.46	17.86	6.9	10.3	II	B	25	38	37
458	13	120	3	5	5.6	0.8	3.0	85	23	350	<1	7	36	<5	16.10	28.82	12.72	6.3	10.0	II	B	37	32	31
459	23	122	1	5	8.1	13.2	1.6	35	12	200	<1	6	22	<5	12.30	17.00	4.70	4.7	6.2	I	C	48	33	19
460	9	122	3	5	7.3	3.8	3.2	95	33	250	1	6	43	<5	21.40	37.50	16.10	7.3	9.4	II	C	17	49	34
461	22	121	5	5	7.6	3.1	3.3	90	32	350	<1	6	43	<5	24.57	39.57	15.00	7.5	9.1	II	B	4	56	40
462	3	120	6	5	8.1	4.3	2.8	90	23	350	<1	7	34	<5	14.70	23.41	8.71	6.6	10.6	II	C	46	39	15
463	34	119	7	5	5.7	0.9	3.4	80	27	350	<1	6	32	<5	18.67	36.22	17.55	7.3	11.1	II	C	33	38	29
464	11	118	8	5	7.5	2.2	3.2	95	28	300	<1	7	39	<5	18.80	32.45	13.65	7.4	10.4	II	B	29	42	29
465	12	121	10	5	7.3	4.0	3.0	100	27	350	1	7	38	<5	18.93	32.46	13.53	15.3	11.4	I	C	30	39	31
466	30	123	9	5	8.2	7.8	2.5	65	21	250	1	5	29	<5	16.27	26.65	10.38	8.3	12.5	I	C	31	50	19
467	26	124	8	5	5.6	0.9	3.4	70	32	350	1	6	37	<5	20.30	36.40	16.10	6.3	9.6	III	B	33	35	32
468	21	126	2	5	8.1	13.7	2.6	50	13	350	<1	6	16	<5	21.23	30.25	9.02	9.7	12.7	I	C	13	50	37
National Topographic Series Sheet 84 P																								
469	31	120	15	4	8.1	3.6	2.3	30	16	250	<1	8	27	<5	12.47	17.45	4.98	5.0	7.6	I	C-D	60	19	21
470	27	123	13	4	8.4	31.7	1.3	35	9	100	<1	6	16	<5	14.63	23.02	8.39	7.9	14.2	II	C	24	50	26
471	6	121	20	4	8.2	9.8	2.0	50	11	250	4	6	29	<5	-	-	-	4.9	8.8	I	B-C	43	30	27
472	3	121	23	4	7.9	16.0	2.3	55	13	400	3	7	29	<5	17.53	30.38	12.85	5.0	7.0	II	B	22	50	28
473	32	117	23	4	7.6	5.4	2.1	55	11	250	<1	5	40	13	14.86	30.43	15.57	4.2	6.5	I	C	34	32	34
474	6	125	17	4	8.5	19.9	1.6	45	11	200	<1	6	13	<5	14.67	20.15	5.48	16.2	27.4	I	C	37	43	20

APPENDIX C.

CORRELATION BETWEEN SOME CHARACTERISTICS OF ALBERTA TILLS

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	22	23
		Iron	Manganese	Calcium Oxide	Boron	Cobalt	Copper	Zinc	Molybdenum	pH	Soluble Salts	Sand	Silt	Clay	Plastic Limit	Liquid Limit	Plasticity Index	K Feldspar	Na-Ca Feldspar	Montmorillonite as % of clay	Activity	Montmorillonite as % of total sample
1	Iron	▨	0.16	-0.50	0.65	0.45	0.75	0.53	0.44	-	-	-0.65	0.14	0.67	-	-	-	-	-	-	-	-
2	Manganese		▨	-0.10	-0.12	0.19	0.18	0.14	-0.04	0.28	-	-0.01	0.11	-0.08	-	-	-	-	-	-	-	-
3	Calcium Oxide			▨	-0.36	-0.15	-0.35	-0.21	-0.14	0.49	-	0.00	0.28	-0.24	-0.08	-0.19	-0.22	-	-	-	-0.02	-
4	Boron				▨	0.37	0.63	0.30	0.41	-	-	-0.54	-0.02	0.68	-	-	-	-	-	-	-	-
5	Cobalt					▨	0.59	0.26	0.19	-	-	-0.36	0.10	0.35	-	-	-	-	-	-	-	-
6	Copper						▨	0.42	0.44	-	-	-0.58	0.12	0.61	-	-	-	-	-	-	-	-
7	Zinc							▨	0.37	-	-	-0.52	0.36	0.34	-	-	-	-	-	-	-	-
8	Molybdenum								▨	-	-	-0.31	0.12	0.28	-	-	-	-	-	-	-	-
9	pH									▨	0.24	-	-	-	-0.24	-0.17	-0.07	-	-	-	-	-
10	Soluble Salts										▨	-	-	-	0.02	0.11	0.14	-	-	-	0.20	-
11	Sand											▨	-0.10	-0.72	-	-	-	-	-	-	-	-
12	Silt												▨	-0.12	-	-	-	-	-	-	-	-
13	Clay													▨	0.59	0.71	0.59	-	-	-0.32	-0.42	0.56
14	Plastic Limit														▨	-	-	-	-	-0.06	-	0.41
15	Liquid Limit															▨	-	-	-	0.06	-	0.61
16	Plasticity Index																▨	-	-	0.13	-	0.58
17	K Feldspar																	▨	0.74	-	-	-
18	Na-Ca Feldspar																		▨	-	-	-
19	Montmorillonite as % of clay																			▨	0.45	-
22	Activity																				▨	0.00

CORRELATION COEFFICIENTS

r = .12 at 1% level of significance for 472 D.F.

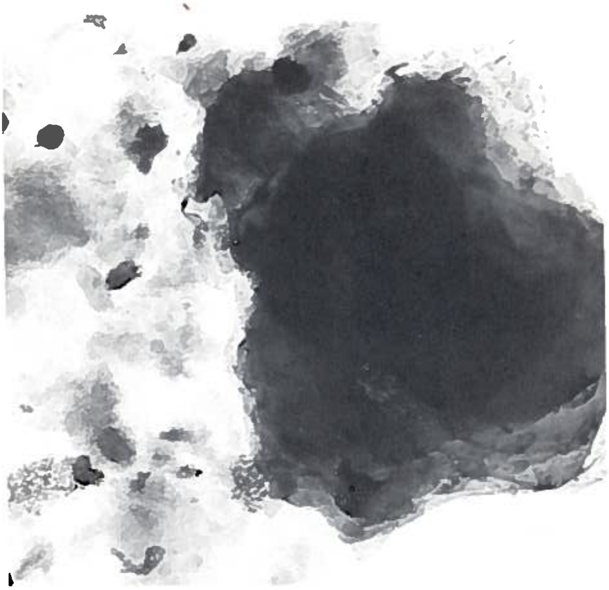
r = .08 at 5% level of signi.cance for 472 D.F.

COEFFICIENTS OF DETERMINATION

high correlation:	$r^2 > 50\%$
moderate correlation:	$r^2 = 25-50\%$
low correlation:	$r^2 < 25\%$

PLATES 1 – 4

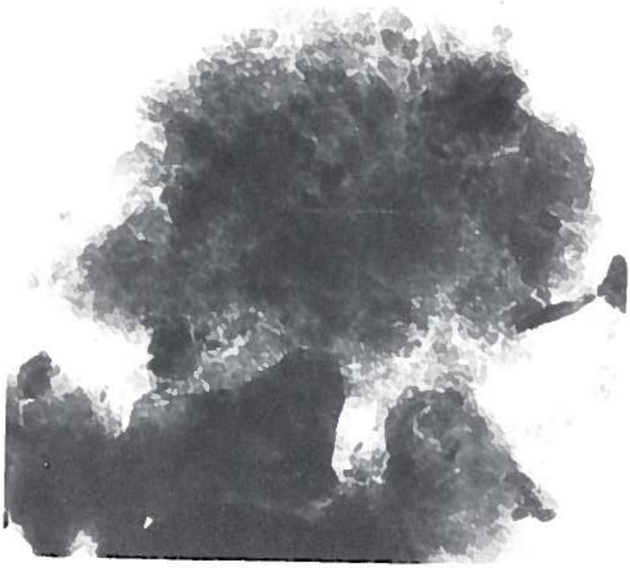
PLATE 1



(a) Sample 453 containing a high chlorite content with lesser amounts of hydrous mica and montmorillonite (from northern Alberta). Electronmicrograph largely illustrates chlorite. Magnification: X40,000.

(b) Sample 62 containing a high montmorillonite content with lesser amounts of hydrous mica (from south-central Alberta). Electronmicrograph largely illustrates hydrous mica in the coarse clay fraction. Magnification: X50,000.

PLATE 2



(a) Sample 208 containing a high montmorillonite content with lesser amounts of hydrous mica (from central Alberta). Electronmicrograph illustrates montmorillonite typical of the area. Magnification: X50,000.

(b) Sample 385 containing a major amount of montmorillonite with minor amounts of hydrous mica (from Grande Prairie). Electronmicrograph illustrates montmorillonite typical of the area. Magnification: X50,000.

PLATE 3

(a) Sample 449 containing a major amount of hydrous mica with minor amounts of montmorillonite (from northern Alberta). Electromicrograph illustrates largely montmorillonite typical of the area. Magnification: X80,000.

(b) Sample 62 containing a high montmorillonite content typical of south-central Alberta. Magnification: X24,000.

PLATE 4

(a) Sampling 1 containing a minor content of 7Å mineral. The electronmicrograph verifies the presence of kaolinite in the area. Magnification: X20,000.

LEGEND

narine sandstone and shale

JS

ИONTON AND BELLY RIVER FORMATIONS:
narine sandstone and shale

RPAW FORMATION: marine shale

EMOST FORMATION: marine and
narine sandstone and shale

LORADO GROUP:
ne shale

NVEGAN AND MILK RIVER FORMATIONS:
ıly marine sandstone, some shale

US

ne shale; locally extensive
narine sandstone

onates and evaporites; includes Mesozoic shales
sandstones in mountains and foothills

ite, gneiss, sandstone

Scale in Miles
20 0 40 80

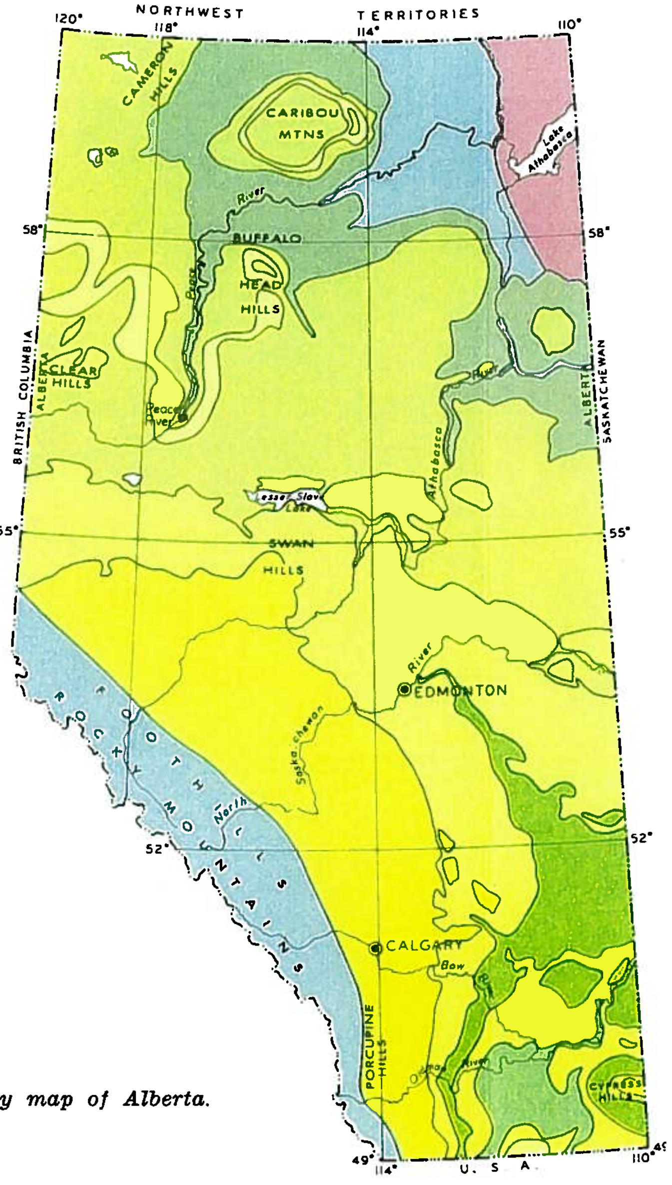


FIGURE 1. *Bedrock geology map of Alberta.*

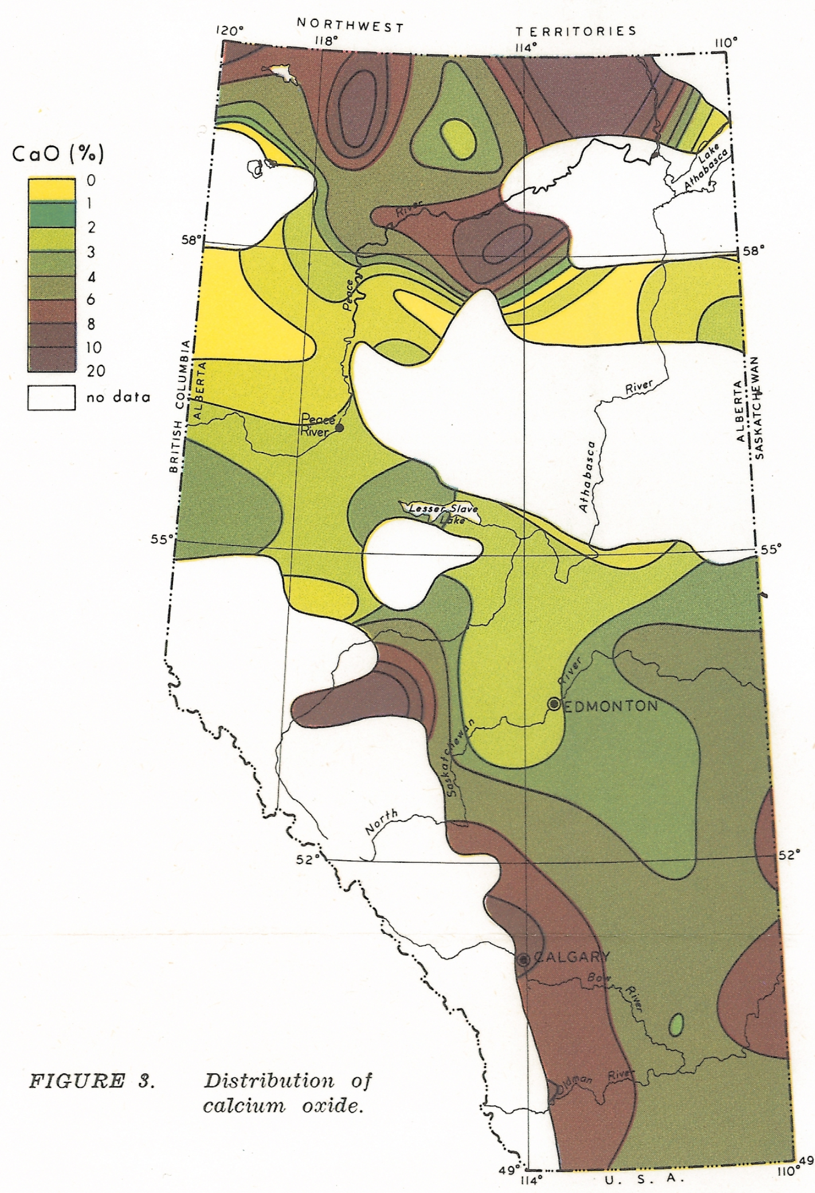


FIGURE 3. Distribution of calcium oxide.

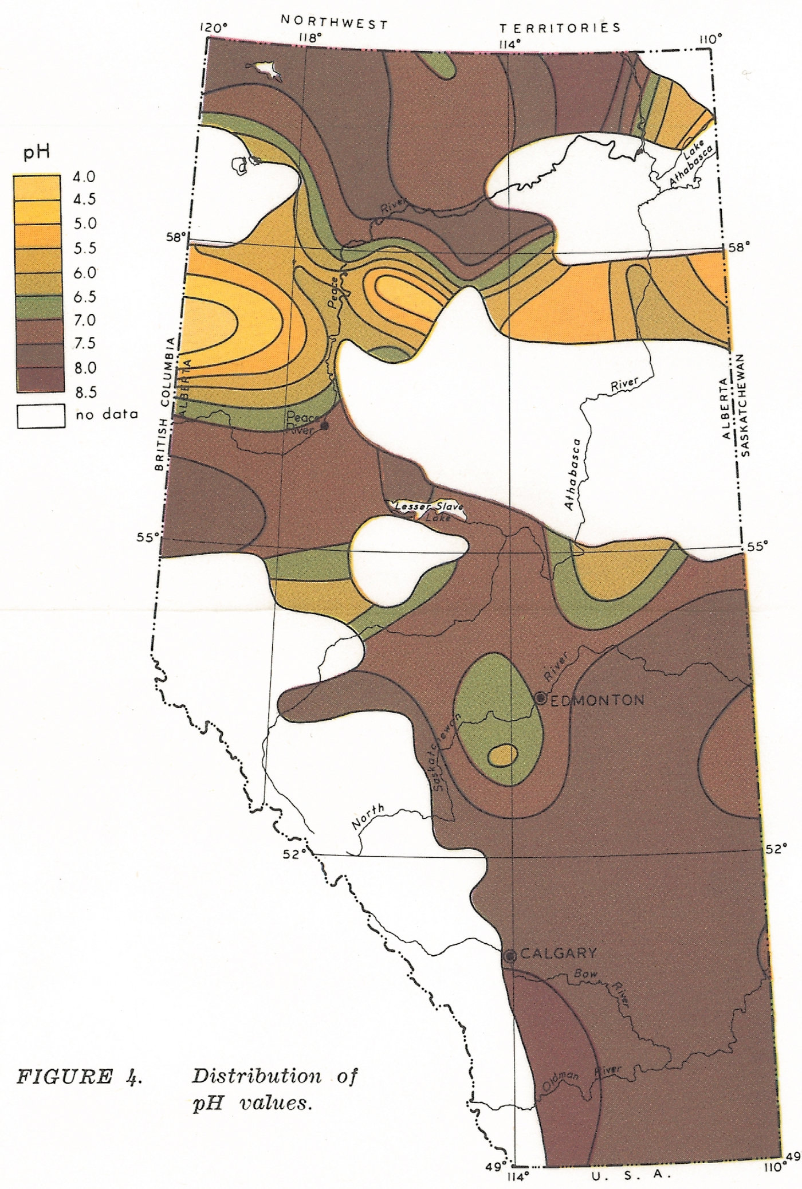


FIGURE 4. Distribution of pH values.

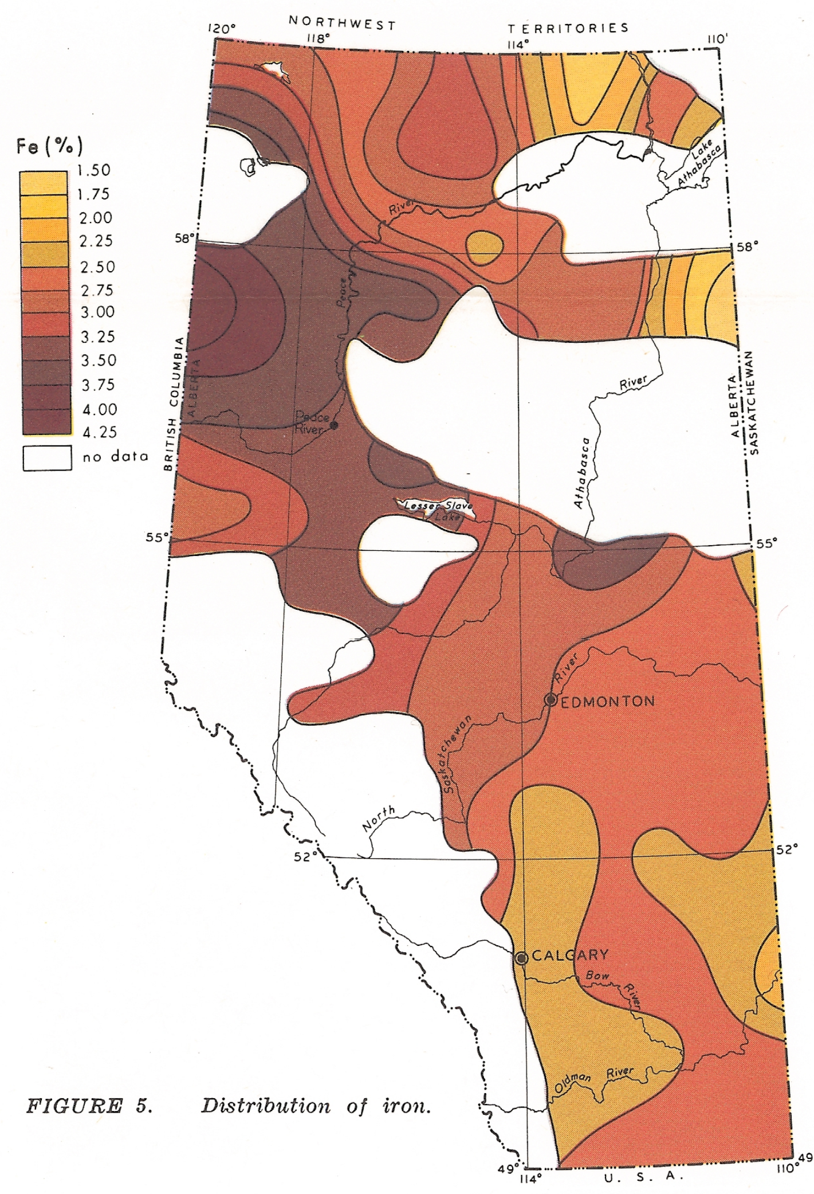


FIGURE 5. Distribution of iron.

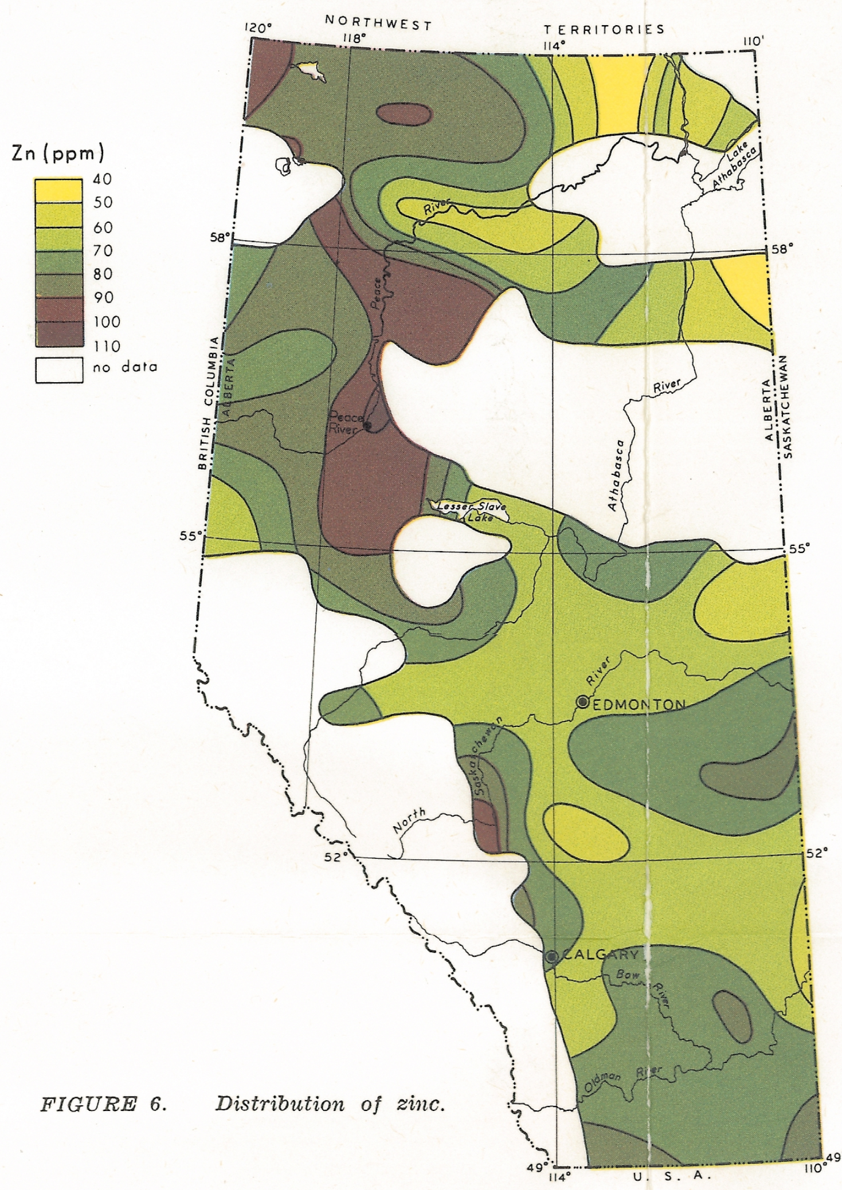


FIGURE 6. Distribution of zinc.

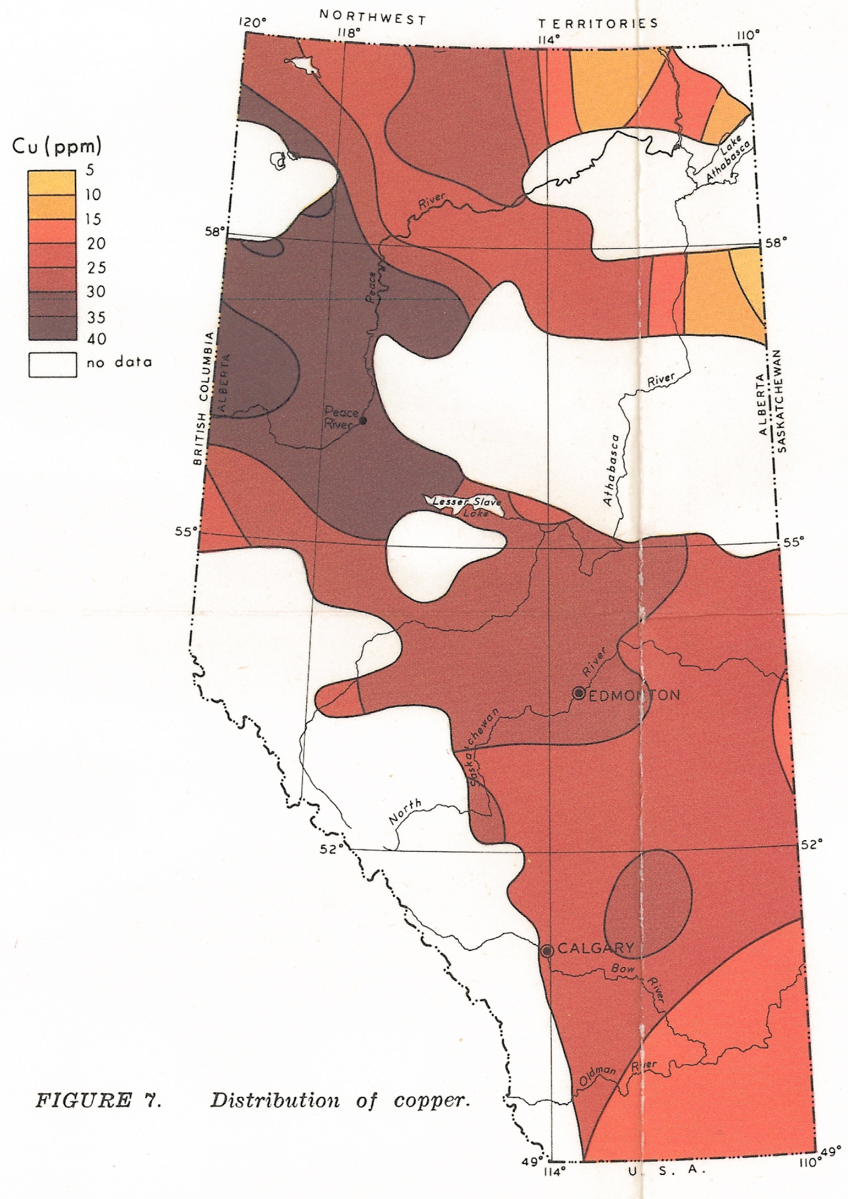


FIGURE 7. Distribution of copper.

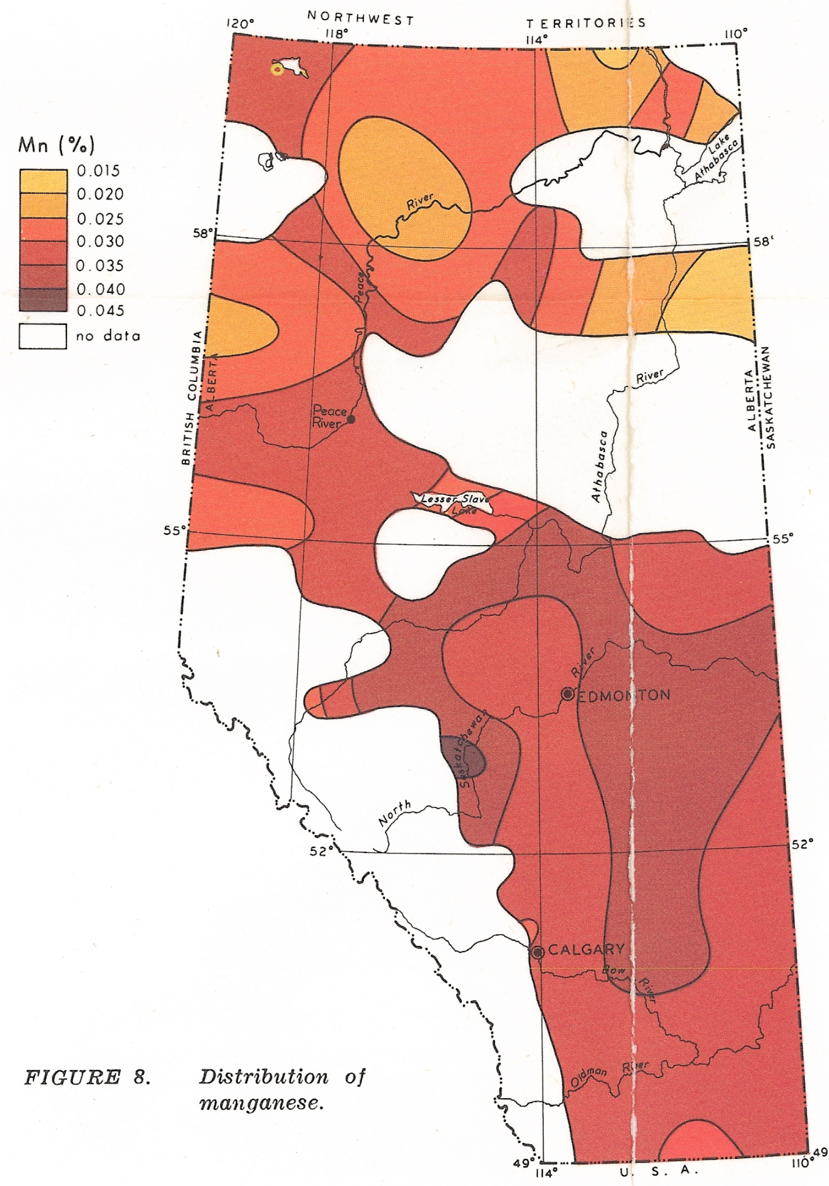


FIGURE 8. Distribution of manganese.

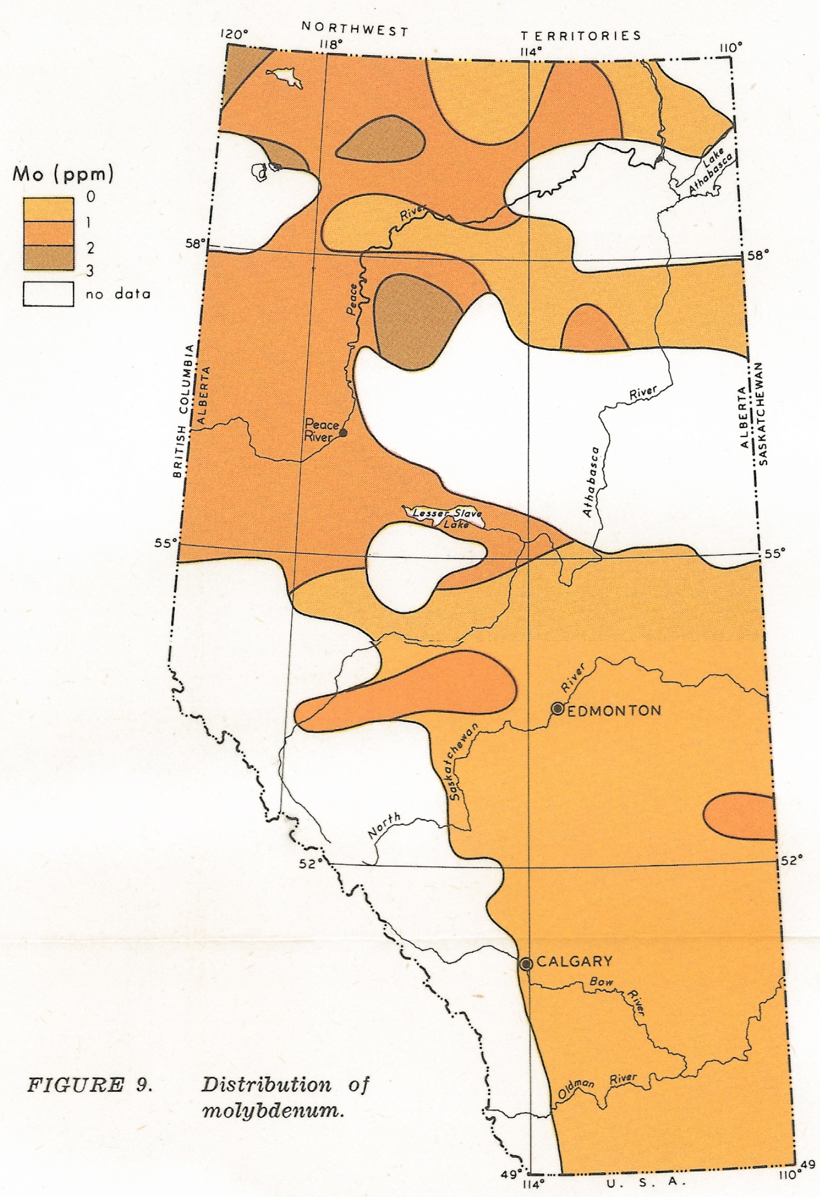


FIGURE 9. Distribution of molybdenum.

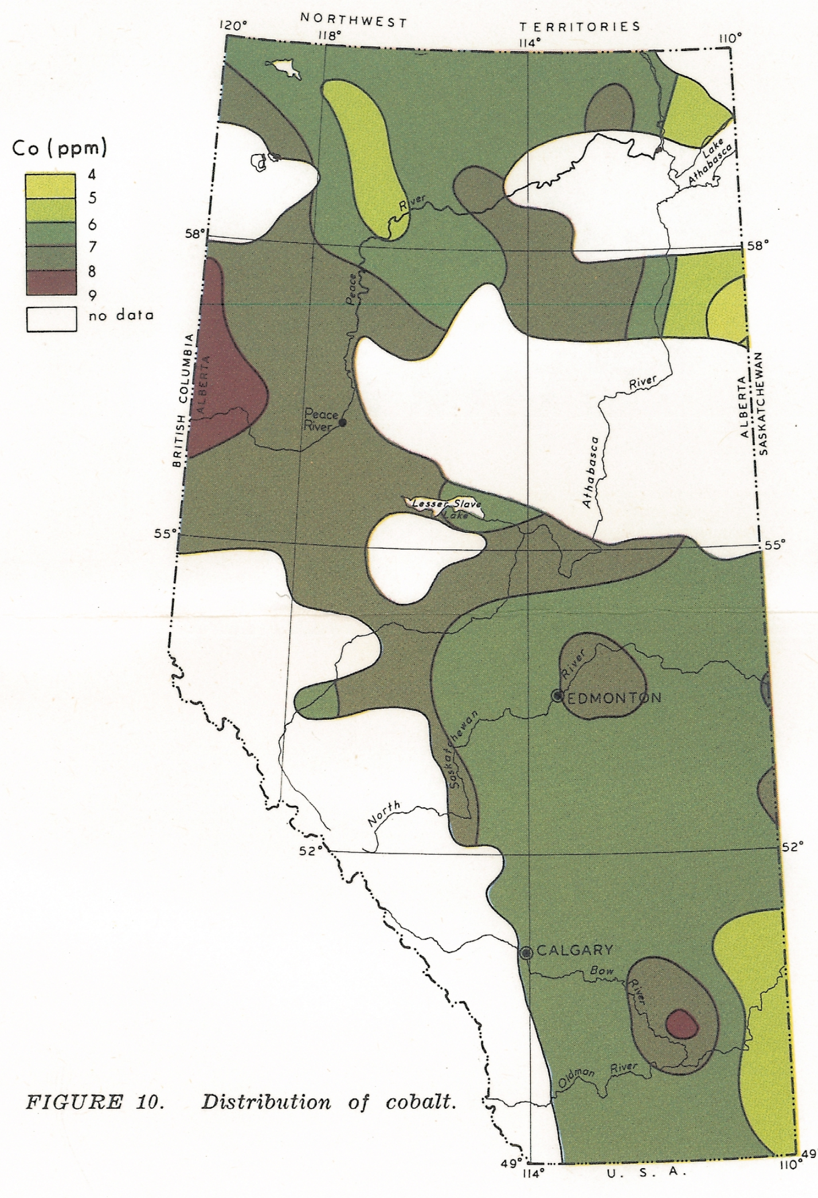


FIGURE 10. Distribution of cobalt.

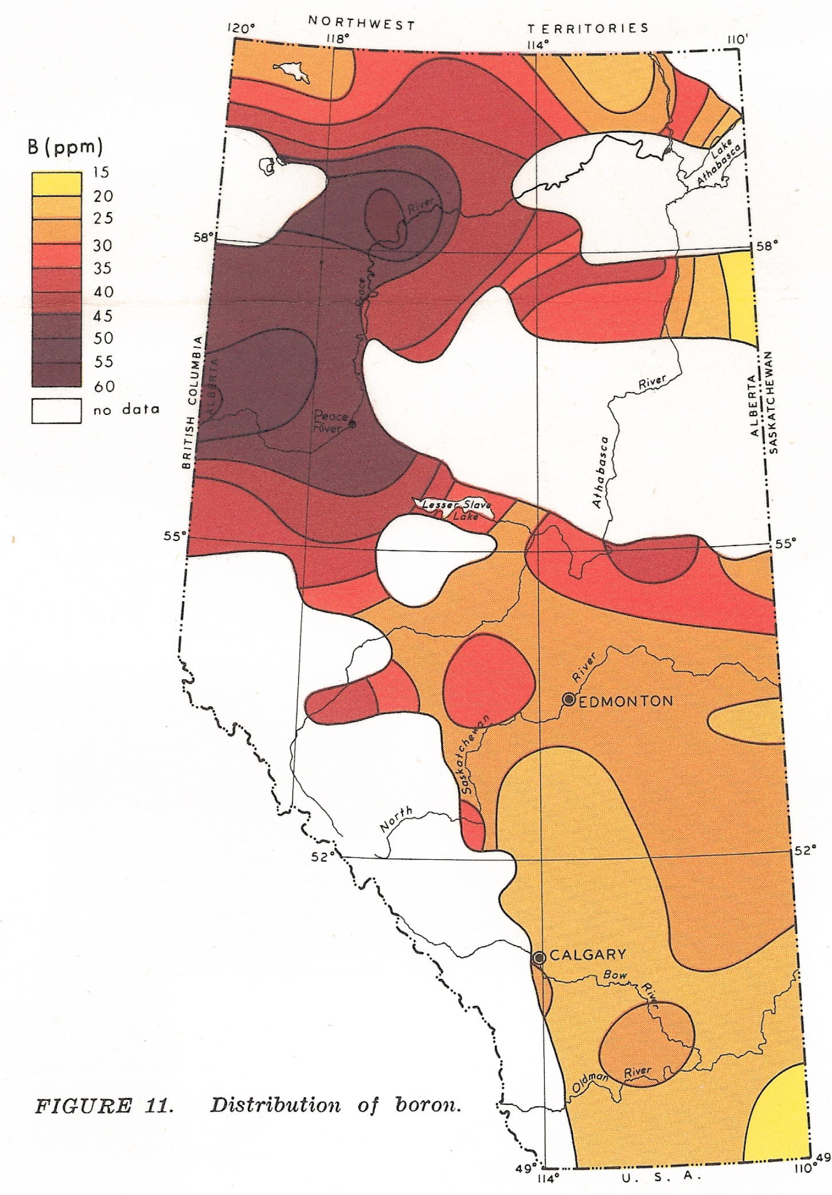


FIGURE 11. Distribution of boron.

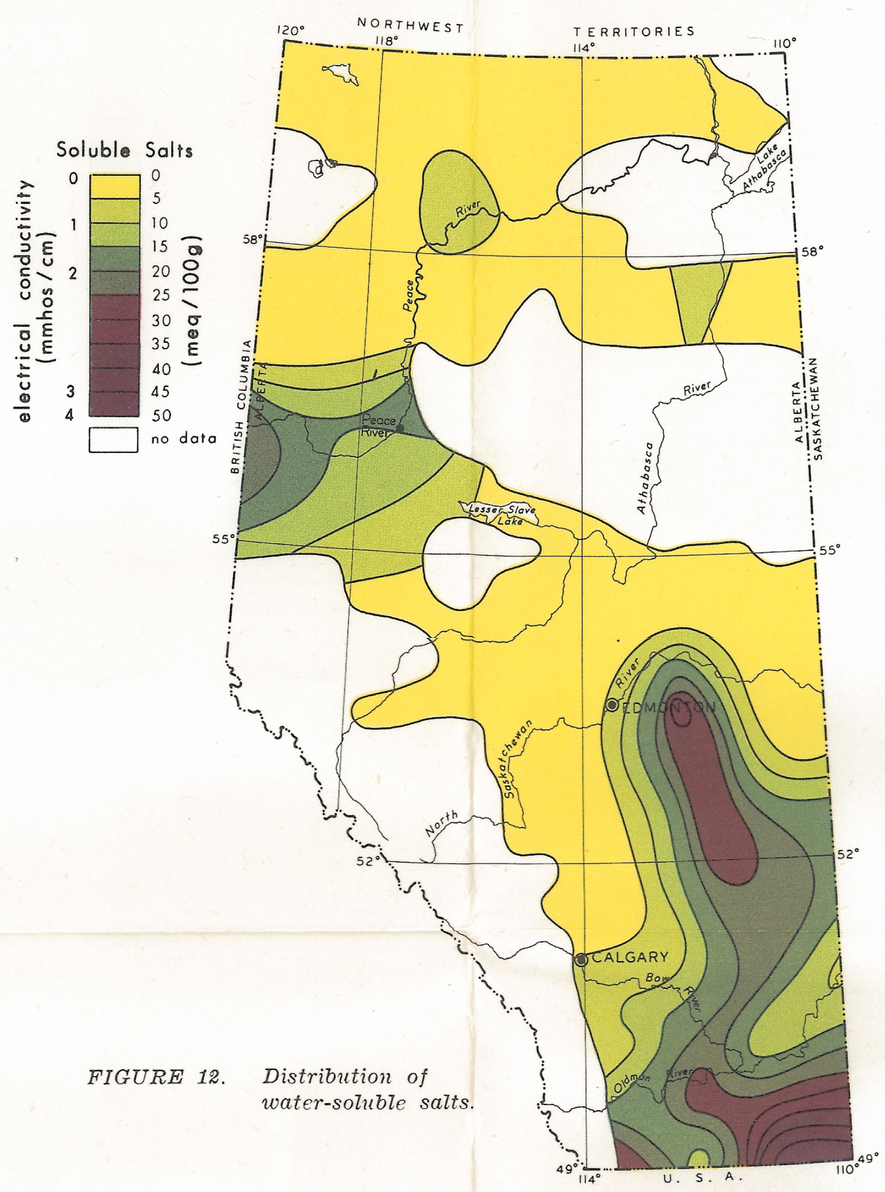


FIGURE 12. Distribution of water-soluble salts.

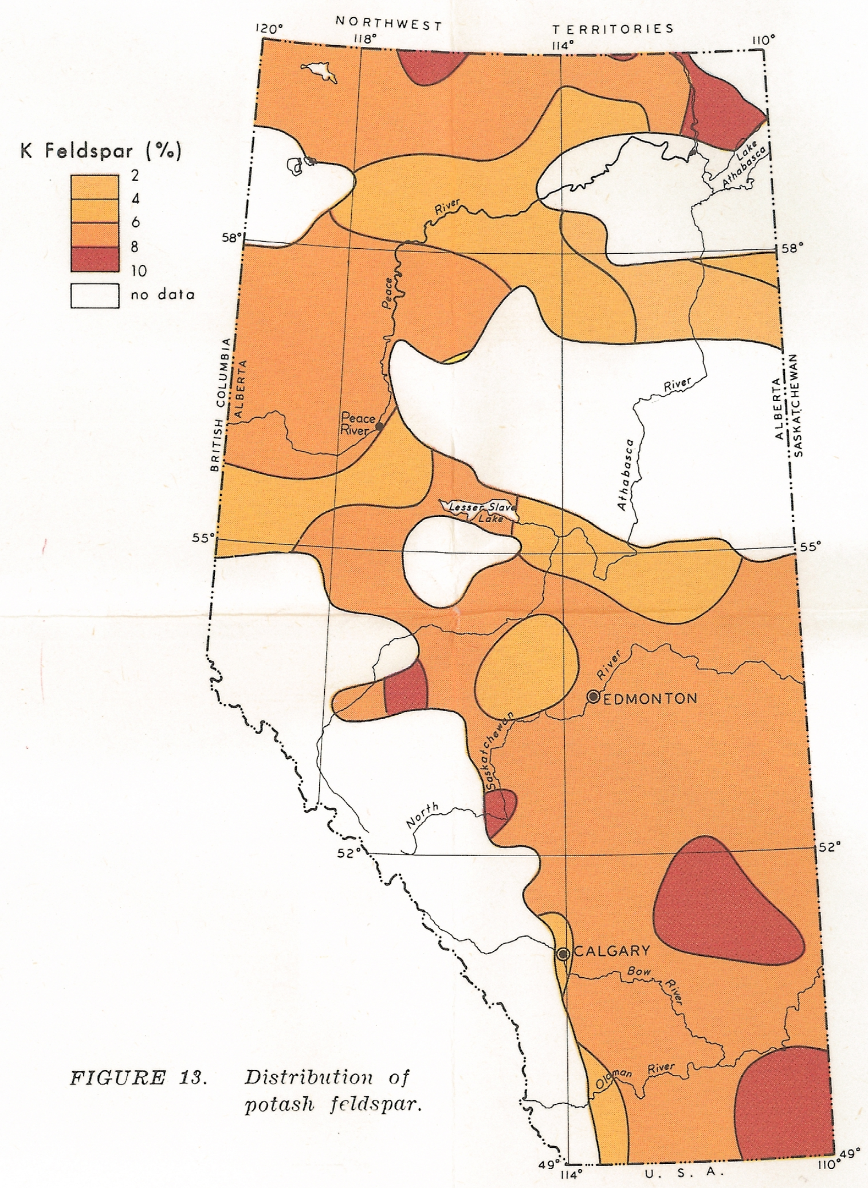


FIGURE 13. Distribution of potash feldspar.

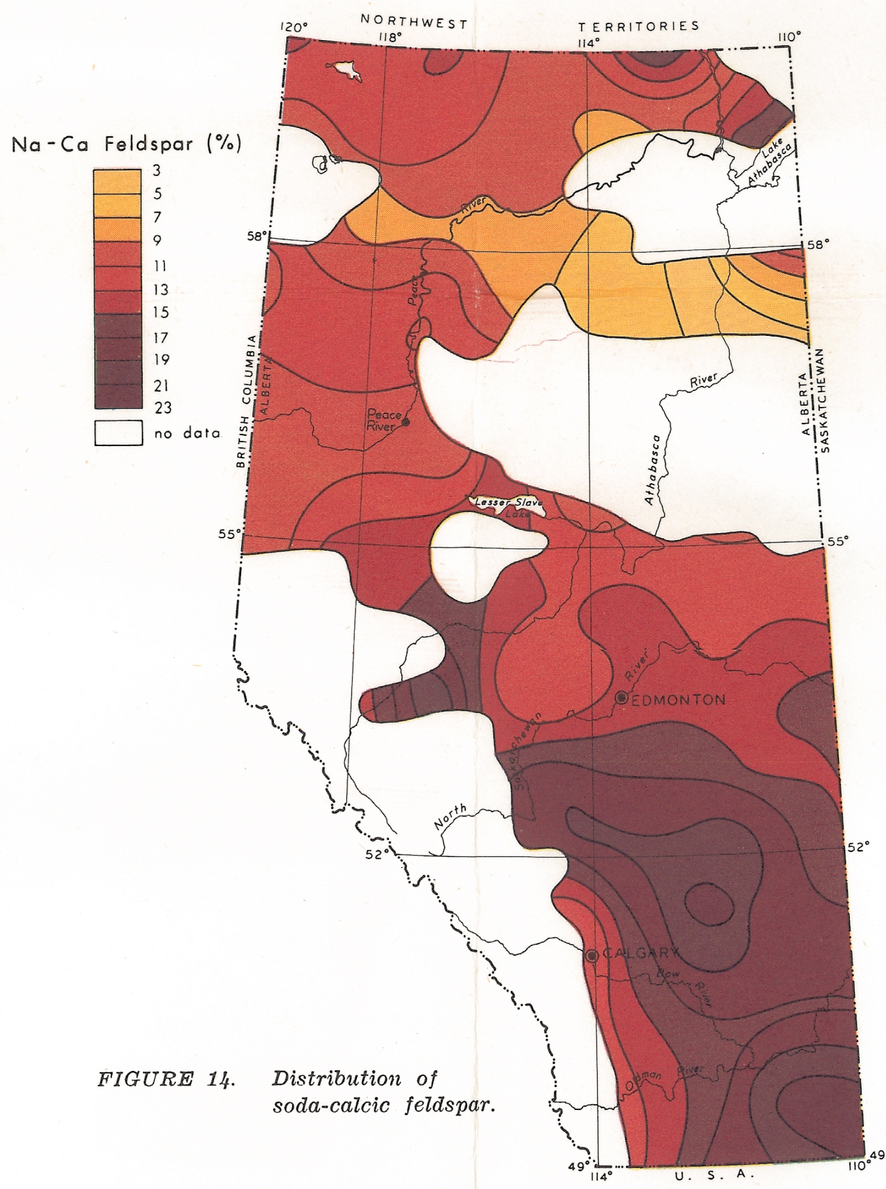


FIGURE 14. Distribution of soda-calcic feldspar.

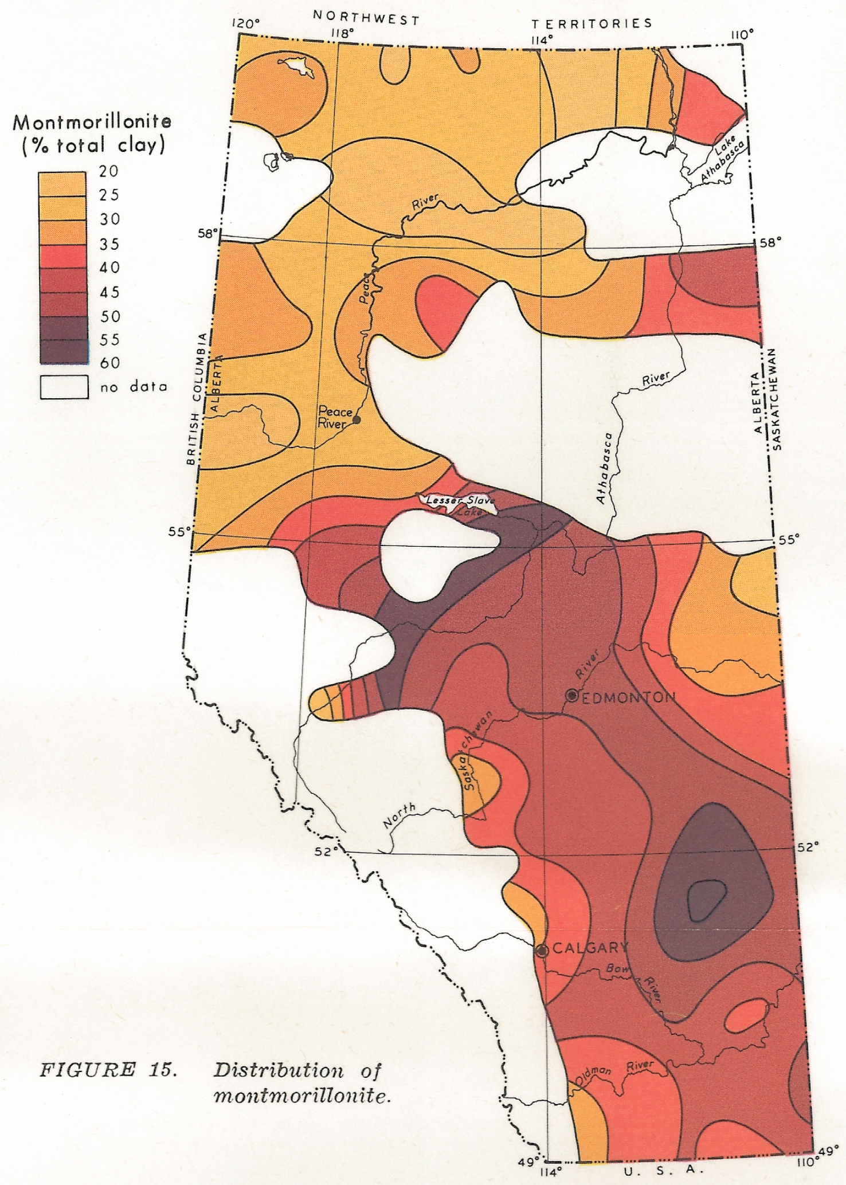


FIGURE 15. Distribution of montmorillonite.

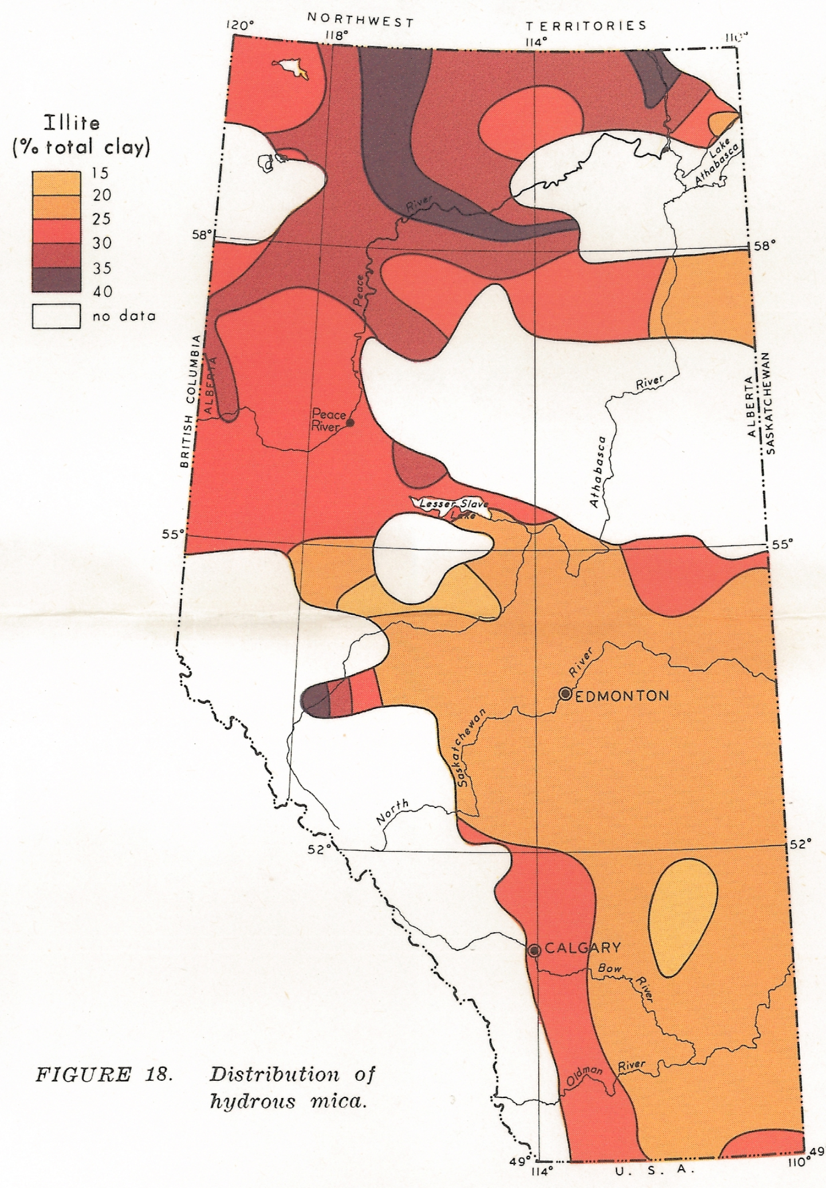


FIGURE 18. Distribution of hydrous mica.

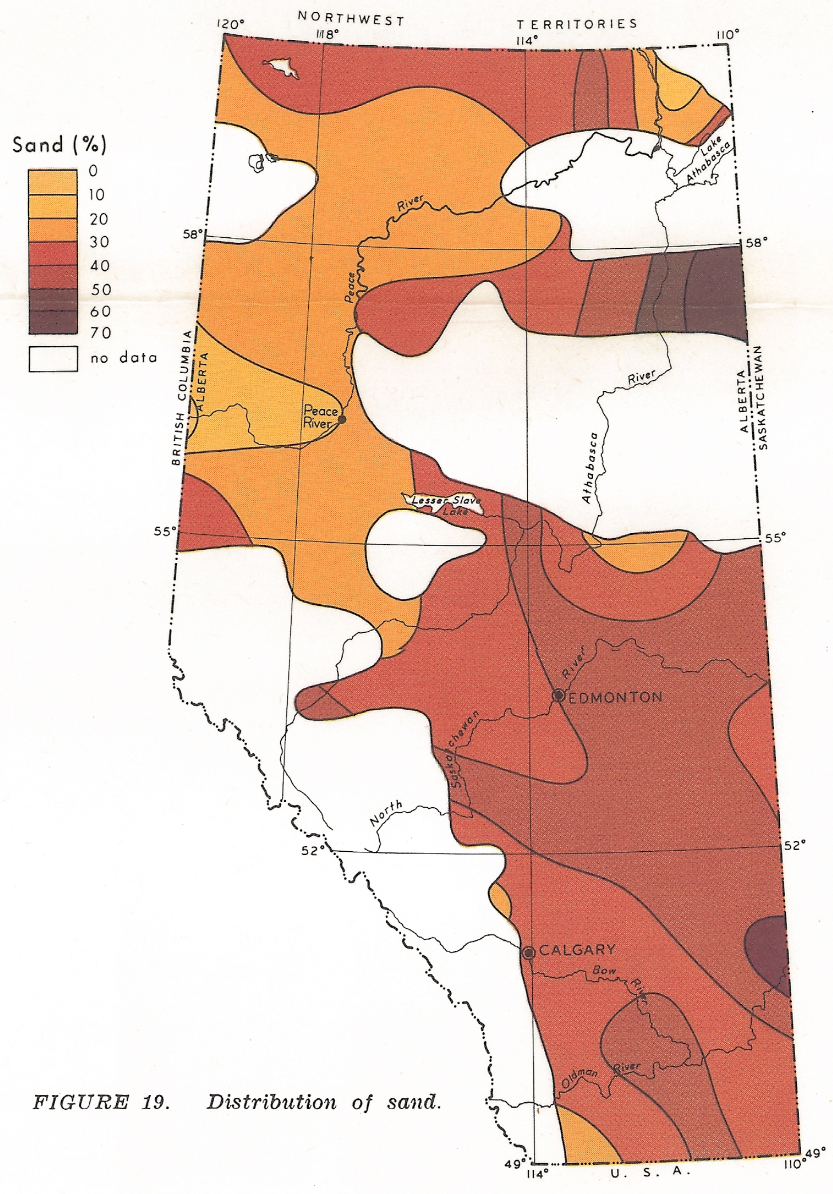


FIGURE 19. Distribution of sand.

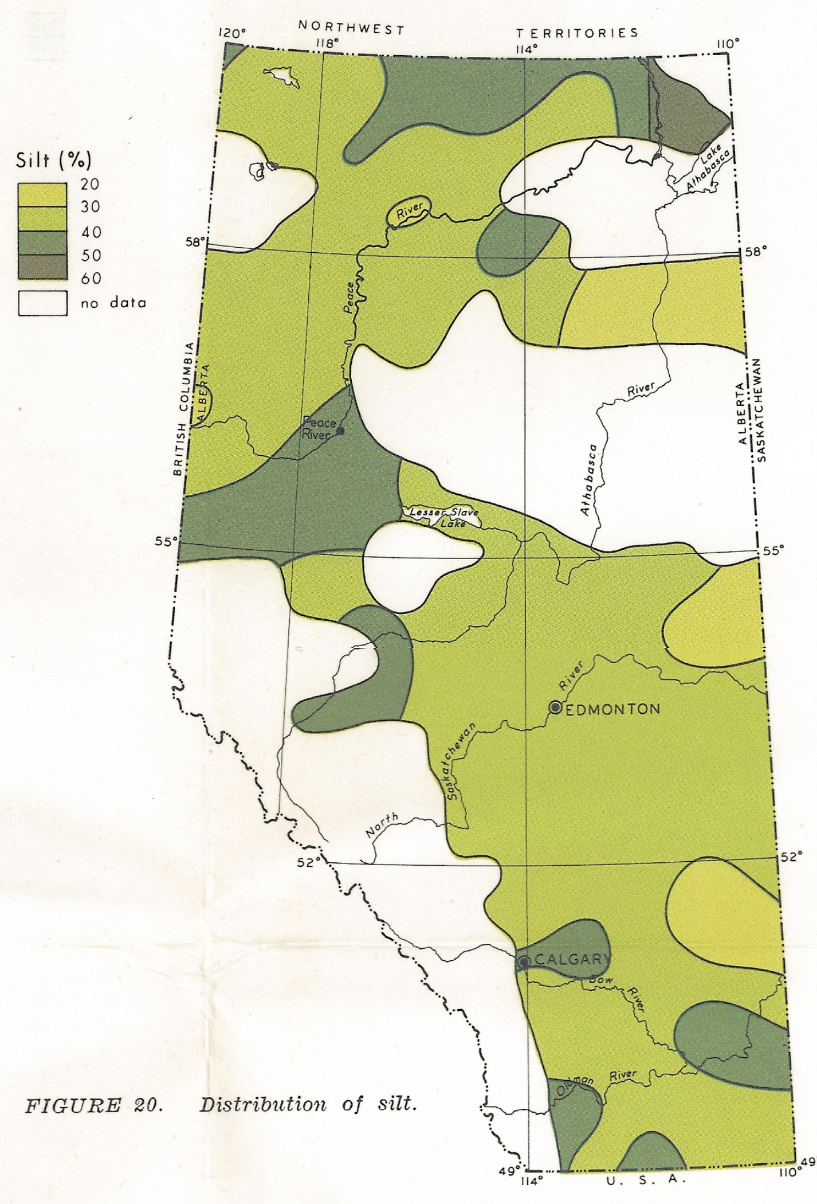


FIGURE 20. Distribution of silt.

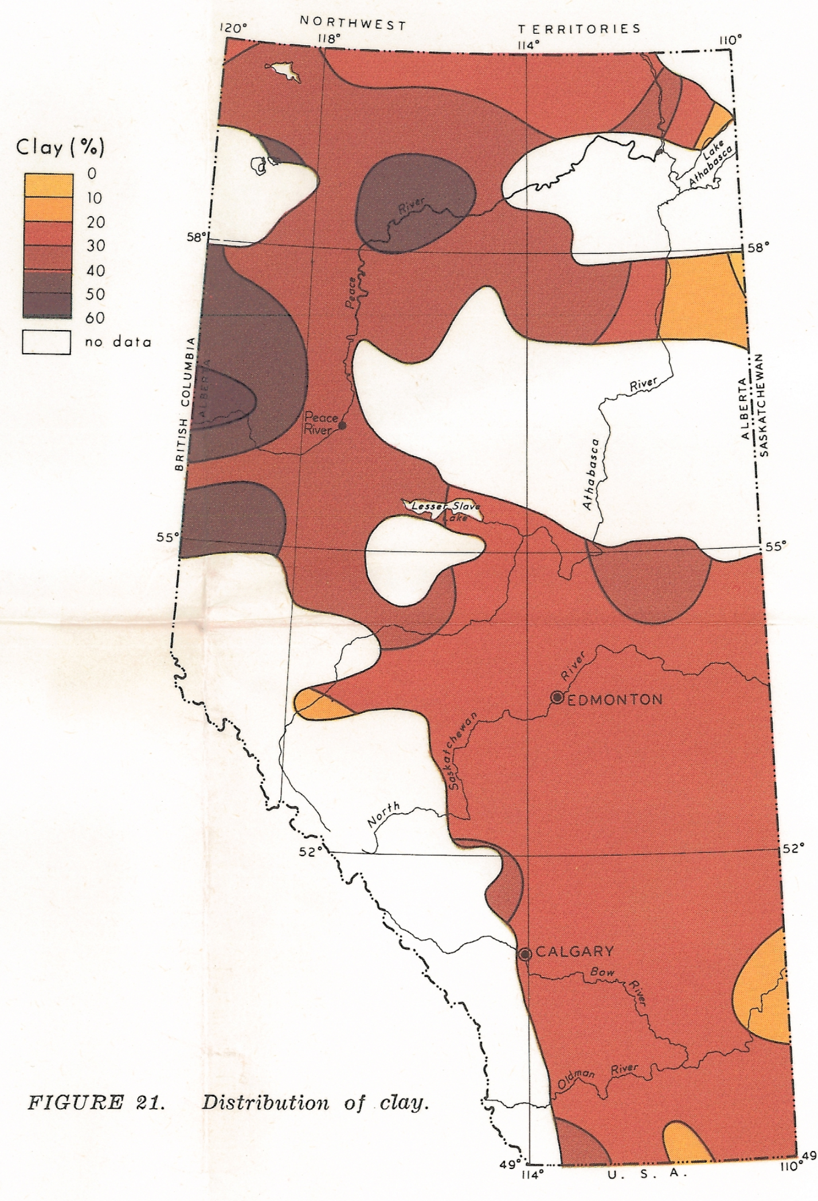


FIGURE 21. Distribution of clay.

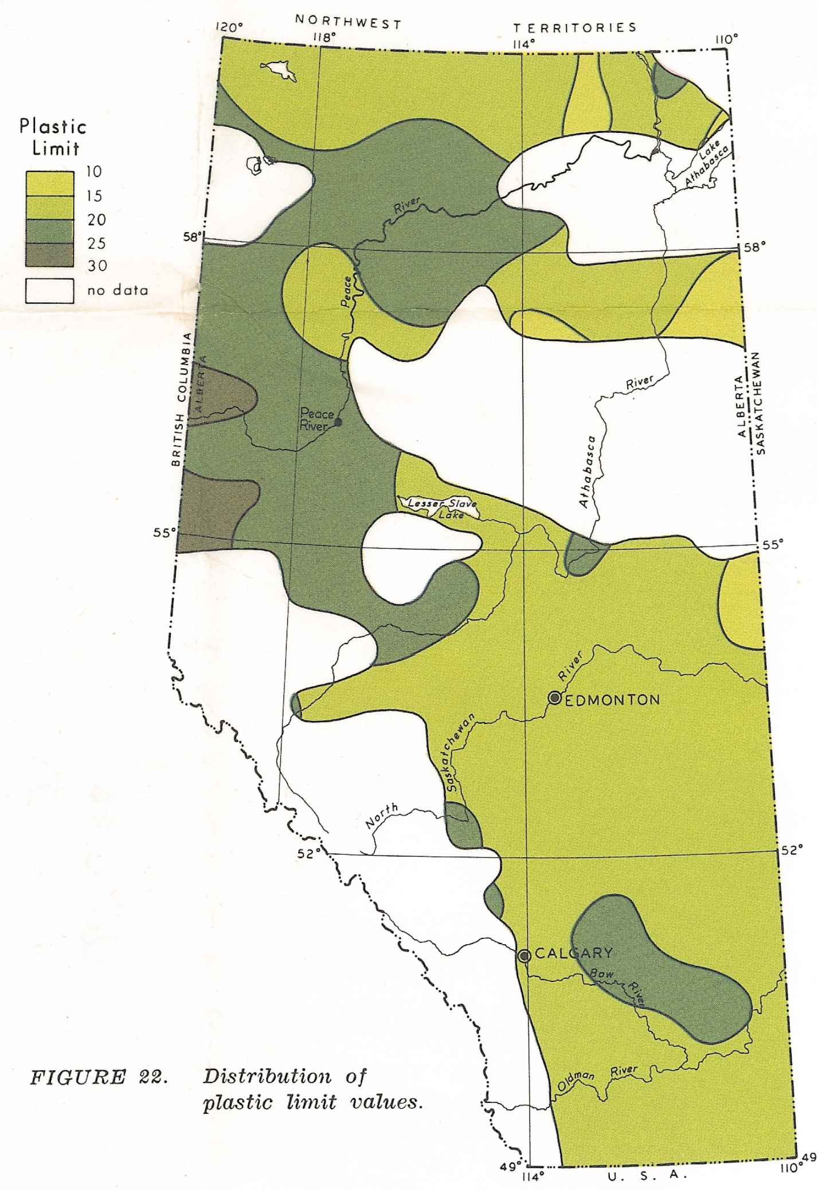


FIGURE 22. Distribution of plastic limit values.

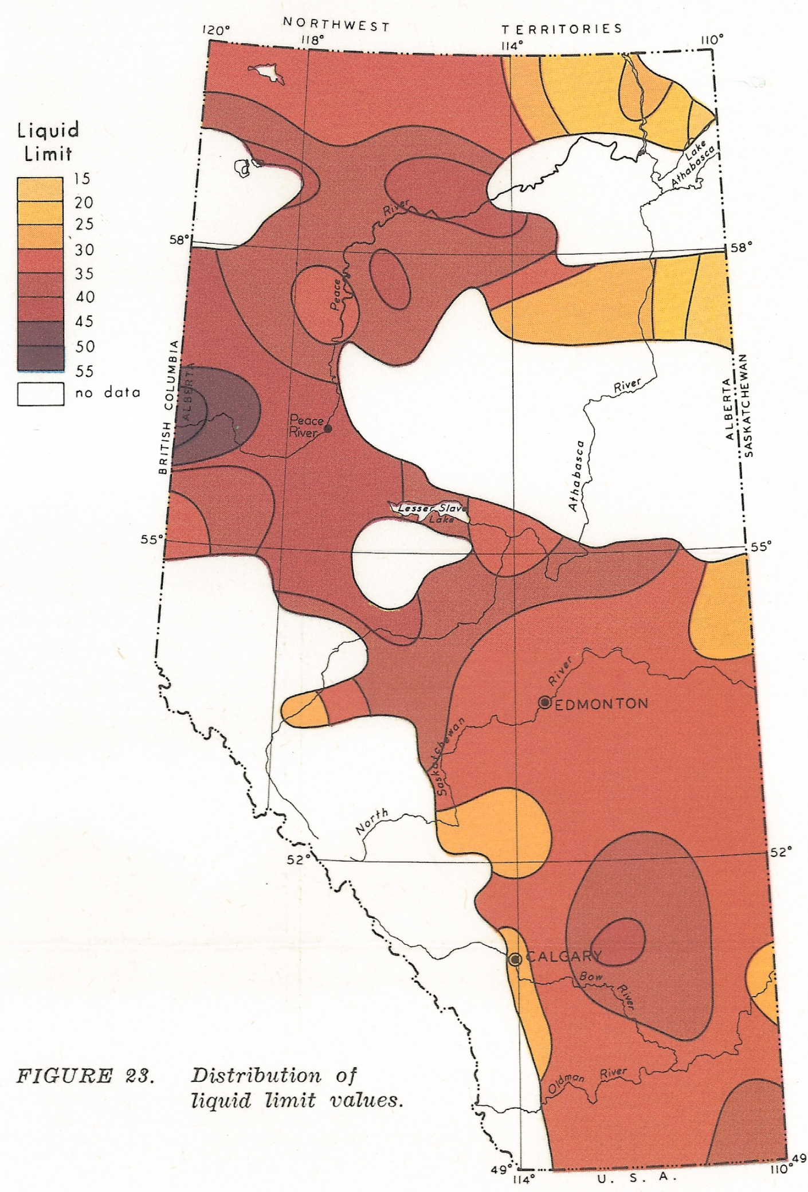


FIGURE 23. Distribution of liquid limit values.

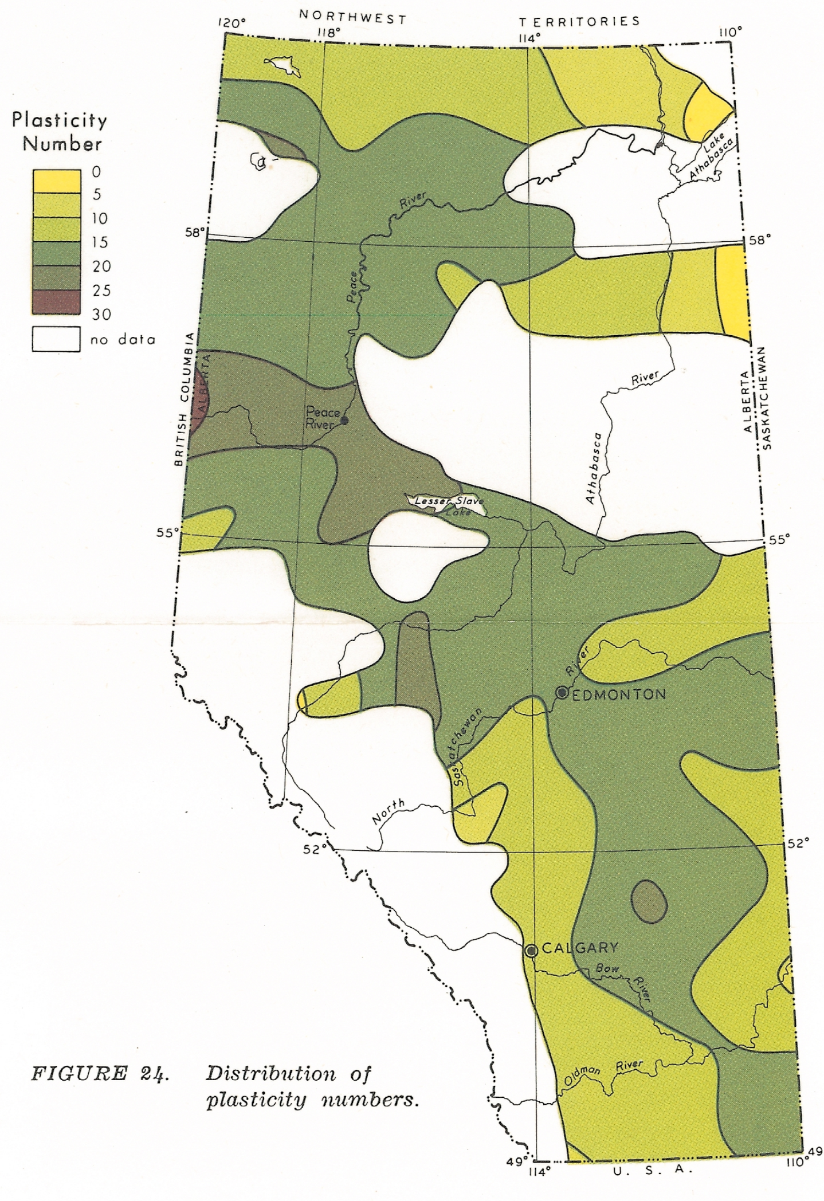


FIGURE 24. Distribution of plasticity numbers.

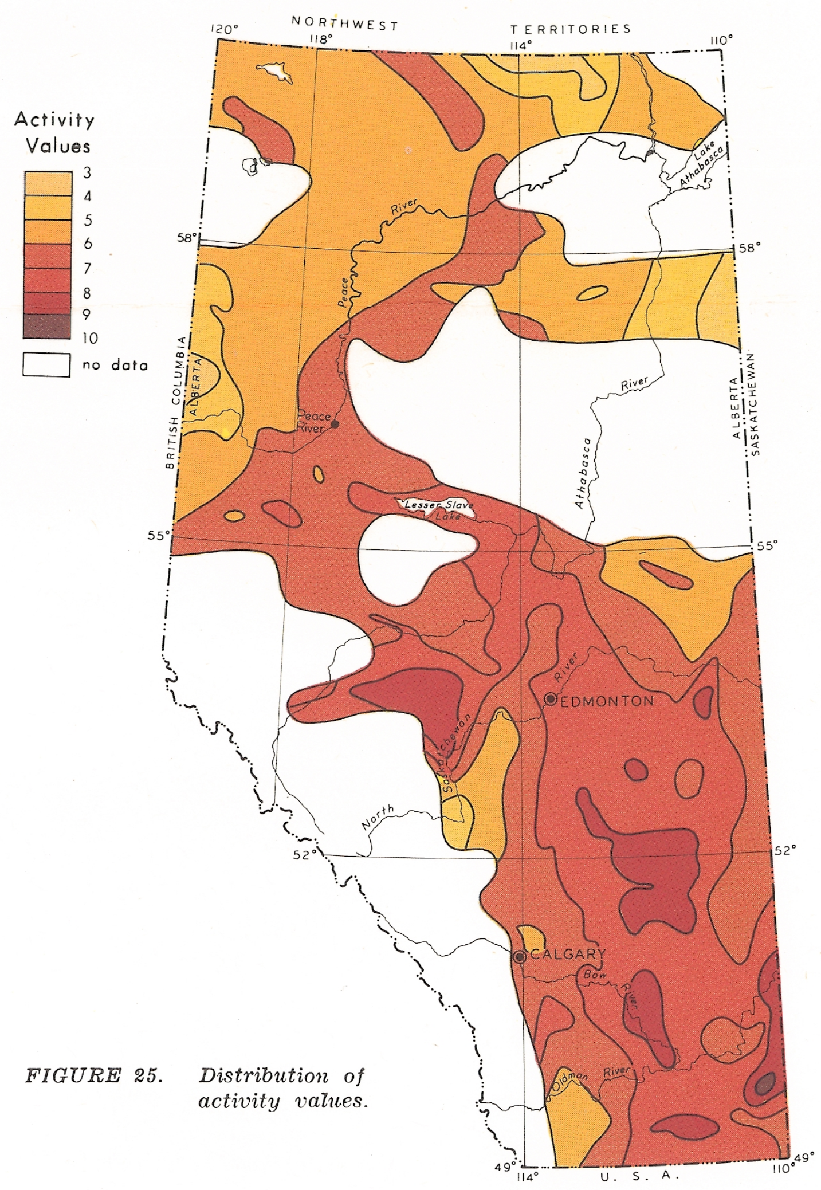


FIGURE 25. Distribution of activity values.

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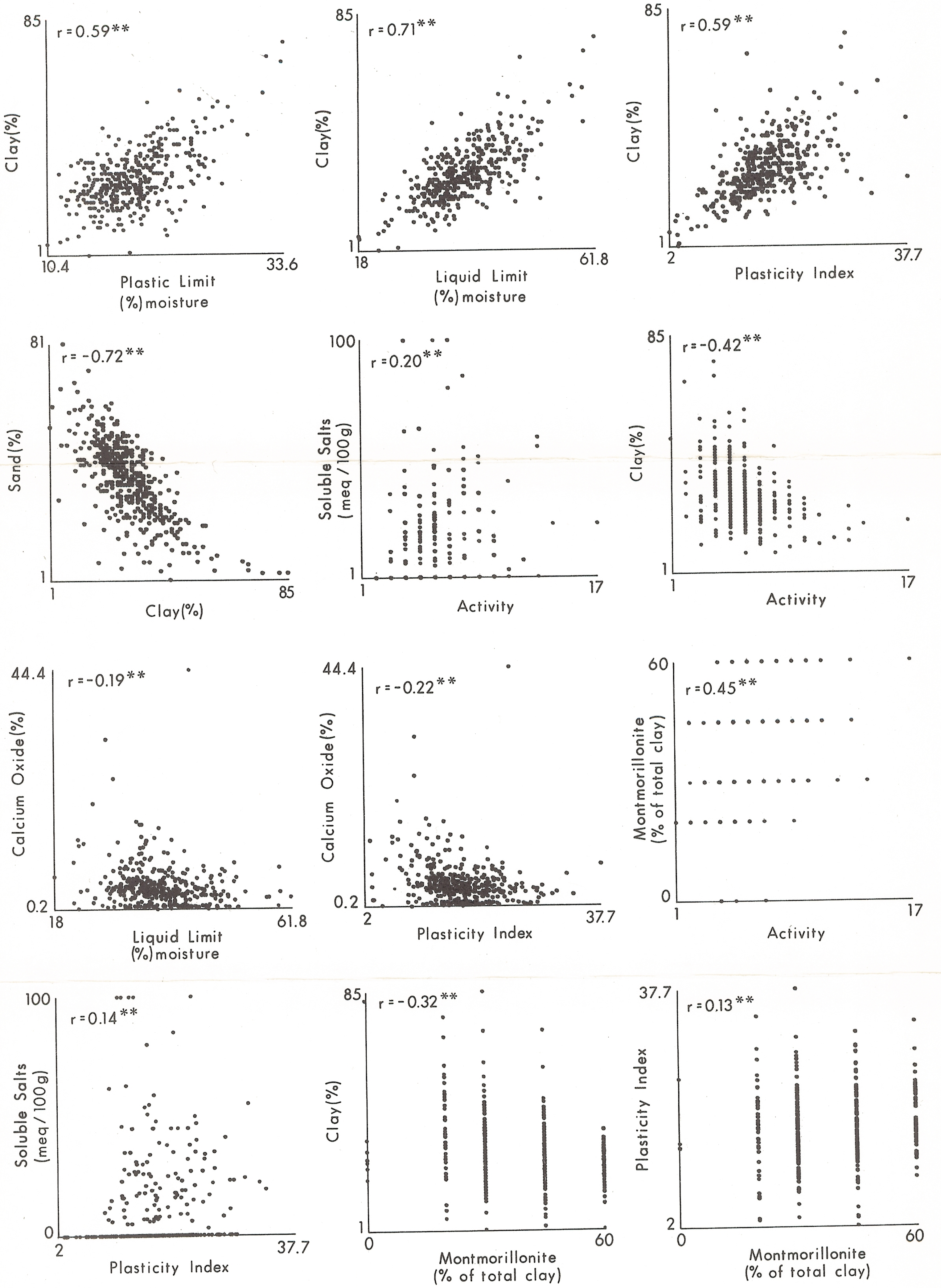

APPENDIX D.

SCATTER DIAGRAMS SHOWING RELATIONSHIPS BETWEEN SOME CHEMICAL AND MINERALOGICAL CONSTITUENTS OF TILL.

(** r = 0.12 at 1% level of significance for 475 D.F.)

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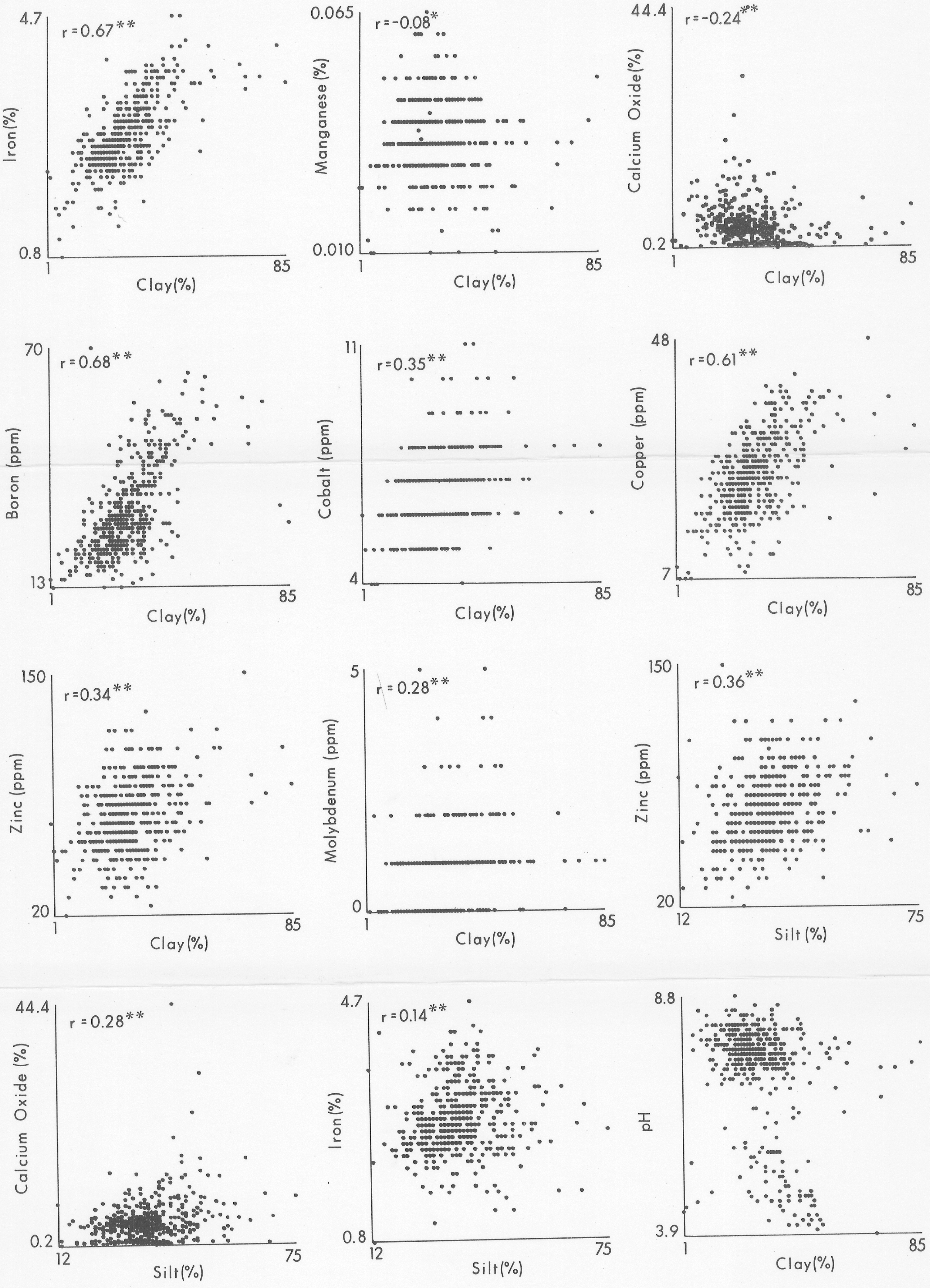

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(*r = 0.8 at 5% level of significance for 475 D.F.
**r = 0.12 at 1% level of significance for 475 D.F.)

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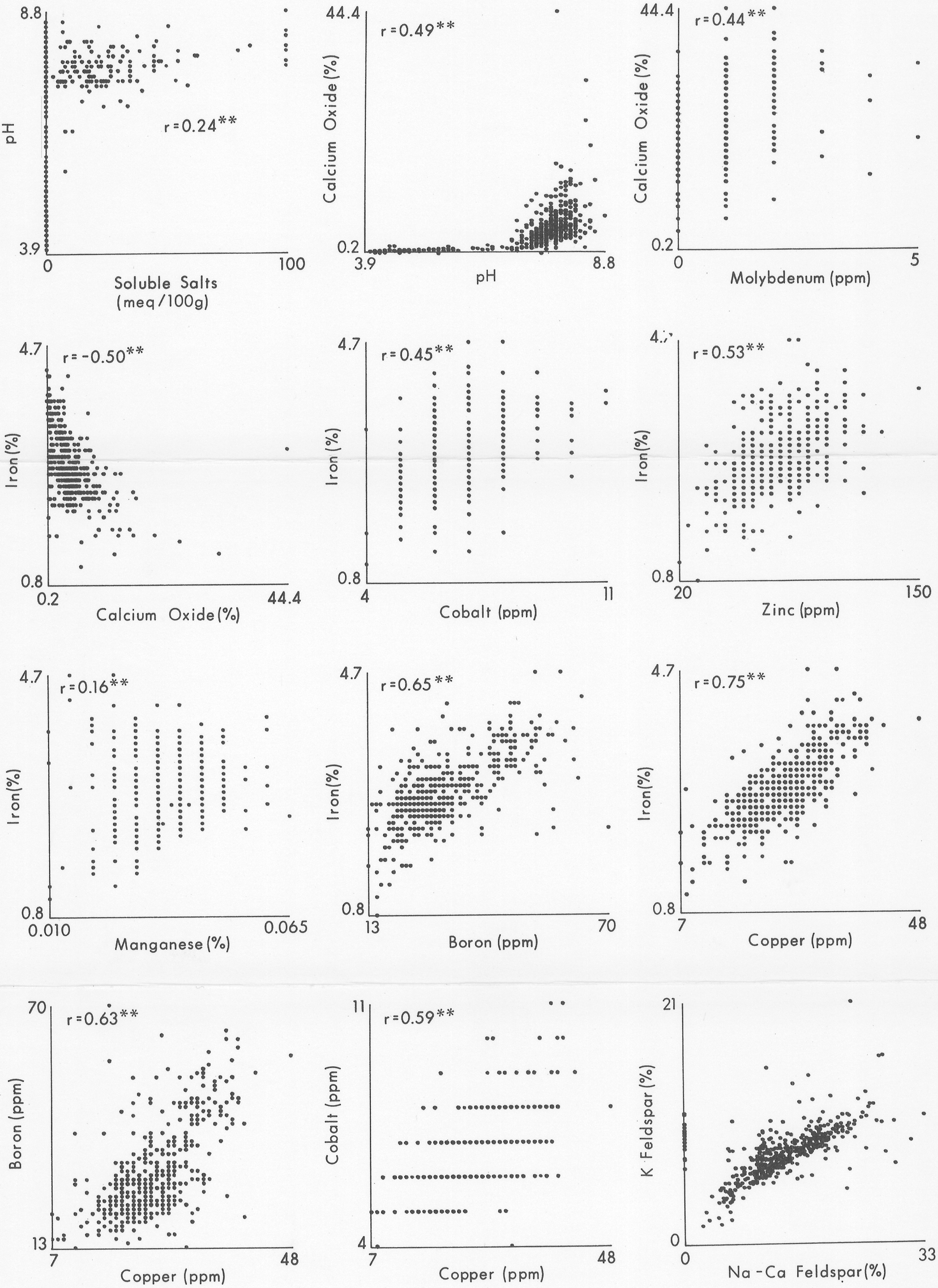

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