MINERALOGY OF THE SAND AND CLAY FRACTIONS
OF TWO NEW BRUNSWICK PODZOLS.
THE QUEENS SERIES

A Thesis

by

Stewart Willis Reeder, B.Sc.

Submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Master of Science.

McGill University

April, 1956.

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ACKNOWLEDGEMENTS

The author extends his sincere appreciation to his directors of research, Dr. H. G. Dion, Professor of Soil Chemistry, Macdonald College and Dr. A. L. McAllister, Associate Professor of Geology, University of New Brunswick, for their advice and guidance during the course of this investigation and to Dr. W. F. Oliver and Mr. J. K. Kinnear, Department of Physics, Macdonald College, for their advice and assistance with the physical phases of this investigation.

The writer acknowledges with gratitude his indebtedness to the officers of the Field Husbandry Division, Canadian Department of Agriculture, whose support and assistance made this investigation possible.

The assistance of members of the staff of the New Brunswick Soil Survey Unit in the collection of the samples is sincerely acknowledged.

Grateful acknowledgement and sincere thanks are due to Dr. W. A. DeLong, Professor of Soil Chemistry, Macdonald College, for his interest and advice in this investigation.

Mineralogy of the Sand and Clay Fractions
of Two New Brunswick Podzols.
The Queens Series.

I INTRODUCTION

The mineralogy of the soil has in recent years received considerable attention, and much progress has been made in the separation and identification of minerals in this field.

The emphasis on mineralogical identification is due to the fact that a given mineral is not sufficiently characterized by its chemical composition alone. The bulk of the minerals in the soil may be considered to be of varying chemical composition, therefore, any given chemical analysis can be interpreted in many different ways as mixtures of two or more of these minerals. In view of this difficulty, it is necessary to use methods for the direct determination of these minerals, in addition to estimating their composition from a chemical analysis.

The identification of the minerals in the soil, especially the more resistant minerals, provides a powerful tool in the identification of soil parent materials, in the study of the relationships or differences of parent materials, and in estimating soil maturity or stage of weathering. An arrangement of these minerals in their order of importance regarding resistance to weathering emphasizes the more important similarities or differences of samples and greatly facilitates interpretation with respect to the processes of soil formation and degree of maturity.

In the southeastern part of the province of New Brunswick and the northern part of the province of Nova Scotia a number of reddish brown clayey soils have developed on glacial till derived from predominantly non-calcareous rock material of Carboniferous age. These soils have been divided into various soil series, the Queens series predominating.

This study was initiated to identify the minerals of the sand and clay fractions of the two soil types of the Queens series, the Queens loam and Queens clay loam, for the purpose of establishing their relationships or differences. There has been considerable speculation on the part of pedologists as to whether the two soil types, Queens loam and Queens clay loam, are different textural variations of one soil series developed on one type of parent material, or whether the textural difference is an indication of a different type of parent material (or perhaps significantly different weathering processes and degree of soil development) with the consequence that the soils should be delineated as separate series rather than two types of one series. In addition to this comparative study, it was anticipated that the investigation would cast some light on the processes of soil formation and development through information obtained by a chemical and mineralogical examination of the profiles of these two soils, developed above a glacial till of Pleistocene age, in the Havelock Region in New Brunswick.

II REVIEW OF LITERATURE

a. Mineralogy of the Sand Fraction

1. Resistance of Minerals to Weathering

Minerals differ widely in their resistance to chemical and physical weathering. Their resistance depends upon numerous factors including hardness, cleavage, coefficient of expansion, original cracks in the crystal, solubility under a given environment, etc. Minerals which are stable under one set of conditions may be quite unstable under another.

Numerous attempts have been made to arrange minerals in order of their resistance to weathering. Pettijohn (70), Smithson (83), Goldrich (19) have calculated orders of persistency by comparing minerals in sedimentary rocks of increasing geological age with those of recent sediments, but these independent estimates contain significant differences in order of resistance.

While it has been generally considered that zircon and tourmaline are stable under any weathering conditions, they are very hard and are not noticeably attacked by any acids or bases, work on tropical soils, however, has indicated otherwise (26). It was found that all minerals dissolve under the chemical conditions in the soil in the tropics. If this does occur, then the importance of the mineral reserve in the soil is even greater than has been generally thought probable.

Observations also indicate the possibility that zircon is attacked chemically. Butterfield (9) and Smithson (81) have recorded cases of secondary zircon. Goldrich (19) from a study of the weathering of granite gneiss concluded that zircon is sometimes chemically attacked. In such cases it displays a dusky, granular appearance.

The possibility that tourmaline may sometimes be authigenic is indicated by some oil well core samples in West Virginia, U. S. A. Authigenic tourmaline has also been described in the Oriskany Sandstone by Stow (86). Such cases show that under certain conditions the constituents of tourmaline exist in solution.

Russel (76, 77) has contributed some valuable information concerning the resistance of minerals to weathering and abrasion. He examined hundreds of sand samples from the length of the Mississippi river and was forced to conclude that there was no apparent destruction or sorting of any minerals by the river. He stated that it must, therefore, be concluded that the disappearance from sediments of minerals such as hornblende and augite, which are being deposited in the oceans, but which are uncommon in consolidated sedimentary deposits of older geologic age, has resulted from a chemical attack on these minerals after deposition. Possibly this change is brought about by sea water. Smithson's (83) work of the Estuarine Series of Yorkshire gives further support to the idea of mineral destruction by intrastratal solutions.

2. Minerals Occurring in Soils.

Lamar and Grim (49) have compared sands and gravels of the glacial period with those of the Cretaceous age. They found distinct differences in the heavy minerals present.

In making such studies, Cogen (13) recommends the separation of the sample into several grade sizes and make determinations of each fraction. He points out, however, that data so obtained cannot be compared with those of unseparated samples. Between size groups of the same sediment he mentions that minerals often vary considerably. Carroll (12) suggests that studies be made of the fractions 0.2 - 0.02 mm after treatment with dilute HCl to remove particle coatings of iron and aluminum oxides. She suggests counting only enough grains to give an accuracy of 5 percent, since greater accuracy is in general not practical. Smithson (82) believes it is better in making counts to use microscopic fields rather than lines, because lines tend to exaggerate the number of large-grained constituents. His method consisted of measuring the diameter of the minerals in two directions at right angles, and counting the grains at the same time. Using the geometric mean of the length and width measurements, the counts, and assumed specific gravities, the percentage of the species was calculated.

Ruby (75) points out the possibility of erroneous conclusions when one compares either (1) different size fractions of samples, or (2) the same size fractions of samples of the same origin; he found that epidote, kyanite, andalusite, rutile, and hypersthene are increasingly abundant in increasingly coarse grained samples, whereas magnetite, ilmenite, zircon, muscovite, and biotite increase in the successively finer grained samples. He stated that the study of unfractionated samples is objectionable since corrections cannot be made for effects of sorting and he concluded that the best way to compare samples would be to use heavy fractions from all possible size fractions of the sediments but, since this is too time consuming, he suggests the examination of two fractions only: "the same actual grain-size fraction for one comparison, as grain-size relative to the size distribution curve for the other fraction".

Dutch workers (26) have approached the problem somewhat differently. They believe that errors due to sorting are small, and that therefore it is necessary to examine only one comparable fraction of heavy minerals from each sample. This avoids errors in mineral percentages. They favor a less detailed examination of a large number of samples as the best procedure in tracing out petrographic provinces. They suggest that variations of percentages of a mineral species in different samples within an area or statigraphic section are generally due to the presence or mixing of detritus of different origin, and are not due to sorting differences.

Carroll (12), from a mineralogical study of the soils of Western Australia, concluded that: (1) the character of the heavy residue of a soil often gives a clear indication of the nature of the parent rock, (2) the diagnostic value is enhanced by determining the total amount of heavy minerals, any distinctive features of a mineral species, and the amount of magnetic material, (3) a study of the heavy minerals of soils can be useful in geological mapping.

3. Mineralogy as an Aid to Soil Classification

Hendricks and Newlands (27, 28) and later Hart (25) made studies of many glacial soils of England and Scotland. They separated by means of heavy liquids the minerals of the fine sand fraction into the orthoclase groups, the quartz group, and the heavy mineral groups. Microscopic studies were useful to indicate the nature of the parent rock and the reserve plant nutrients existing in the form of silicates. Local differences in silicate content of the soils reflected local differences in the parent rock from which the preponderance of the till was derived.

McCaughey and Fry (64) outlined in detail the methods used by geologists in mineral studies on consolidated sediments, and showed how these methods can be applied to soil studies. The sand and silt fractions of many soil types from all parts of the United States were studied by qualitative mineralogical methods. The authors found that epidote and hornblende are common in practically all soils. The alkali feldspars were found to be among the most abundant soil-forming minerals. Microcline and the micas were shown to be very persistent minerals displaying little alterations. The authors concluded, from their rather exhaustive study, that any mineral commonly occurring in rocks may be expected in soils, regardless of the origin of the particular soil. Their data and conclusions suggest the possibility of the contamination of surface soils over most of the United States by windblown materials. Fry (17) in a more recent paper further discussed the application of petrographic methods to soil laboratories. The progress of such investigations towards quantitative methods is suggested by the outlining of a simple procedure of making such determinations from carefully sized fractions.

Jeffries and White (38, 39, 40, 41) studied in detail the profiles of soils derived from various limestones, dolomites, and shales of Eastern United States.

The authors found all of the soils examined quite similar in their qualitative content, differing only in proportion and total quantities of various minerals. They, therefore, believe that in comparing soils it is best to choose only the more outstanding heavy minerals and to correlate on their relative percentages.

Cady (10) compared the heavy minerals of the "A" and "C" horizons of true podzols with those of brown podzolic forest soils. Podzolization was found to cause reduction in the hornblende, whereas epidote, garnet and magnetite were little affected.

Marshall (57) has outlined a petrographic method for use in studies of soil formation processes, based on the assumption that certain resistant minerals remain constant during soil development.

Haseman and Marshall (26) studied the heavy minerals of a number of different soils of Missouri. They showed that the origin of a soil is reflected in the kinds and amounts of heavy minerals present, and suggested that in making the heavy mineral comparisons between sola and parent materials, one should use the same size fractions. They also showed that differences in the origin of the parent material at different depths are readily shown by a heavy mineral analysis.

4. Removal of Oxide Stains

Marshall and Jeffries (60) describe and summarize semi-quantitative methods of a somewhat more precise nature than those normally employed by geologists in correlation studies, including methods of removing contaminating iron oxides. They state that the justification for this additional refinement lies in the effect of weathering processes, which may reduce the amounts of certain species, and may completely remove others. Thus, the soil scientist must concentrate first on the relative quantities of the most resistant minerals, and secondly, must accumulate evidence of the losses of others by weathering. They arranged the minerals in order of resistance to weathering and suggested that the comparisons are greatly facilitated by the presentation of results in histograms.

Further methods for the removal of iron oxide coatings from soil particles have been described by Dion (15) using reduction by nascent hydrogen from ammonium tartrate solution in contact with metallic aluminum, Matelski (63) by detergents, Aguilera and Jackson (2) by the sodium dithionite-citrate-versene method, and MacKenzie (66) by the sodium hydrosulfite method.

5. Identification of Minerals by X-rays

Jeffries (42) showed by X-ray diffraction that one can expect wide differences in the essential mineral content of the fine fractions of different soils. Under certain conditions kaolin may appear as a decomposition product of the feldspars or muscovite, but is not present in appreciable amounts in the clay fraction. He suggested the formation of intermediate clay minerals in the course of weathering, the kaolin possibly being present as films or coatings on the outside of particles of primary minerals and as such may play a part in certain soil reactions.

Jeffries (43) in a study of the various horizons of some Pennsylvania soils by x-ray methods found that the differences noted in the mineral constituents of the sand, silt and clay fractions were essentially due to depositional processes and the presence of materials of preglacial origin. The principal differences were found in the clay fractions.

Jeffries and Jackson (44) describe techniques for mineralogical analysis. They state that it is often useful to identify a very large number of individual mineral species, particularly among the accessory minerals, which are a small percentage of the total. Nevertheless, knowledge of the distribution of the gross mineral components permits a description of the principal mineralogical characteristics of soils. They suggest that mineralogical studies of soils can be considered from two general viewpoints: (1) determination of the principal constituent minerals, of their nature and characteristics, (2) determination and study of the accessory minerals and their relationships.

b. Mineralogy of the Clay Fraction

1. X-ray Diffraction Analysis

The first x-ray diffraction analysis of clay minerals was made in Sweden in 1923 and in Germany in 1924.

Ross and several colleagues (72, 73) studied the mineral composition of clays, at first the bentonites, but within a few years a variety of clays. From their work a classification of the clay minerals was suggested. The work of Ross also corrected the erroneous notion that microscope studies are of no value in clay research.

Hendricks and Fry (29) and Kelly, Dore and Brown (45) first demonstrated, chiefly on the basis of x-ray diffraction analyses, that soil materials, even in their finest size fractions are composed of crystalline particles and that the number of different crystalline materials likely to be found is limited.

The efforts of these and many other workers resulted in what has come to be known as the clay mineral concept becoming firmly established by the early 1930's. According to this concept, clays are composed essentially of extremely small crystalline particles of one or more members of a small group of minerals which have come to be known as clay minerals. The clay minerals are essentially hydrous aluminum silicates, with magnesium or iron substituting wholly or in part for aluminum in some minerals and with alkali or alkaline earths being present as essential constituents in others. In addition to the clay minerals, some clays contain varying amounts of so-called non-clay minerals, of which quartz, calcite, feldspars are examples. Also many clays contain organic matter and water-soluble salts. Some amorphous material has been found, but it is thought to be limited to a few unique clays. The recent work of Grim (23) indicates that very weakly crystalline material is not so rare as it was earlier believed to be.

Hendricks and a number of colleagues (30, 32, 33, 34, 31) have produced a series of papers on the structure of the clay minerals and on exchange capacity.

Kelly and his colleagues (46, 47) have contributed immensely to the knowledge of the distribution of the clay minerals in various soil types, and of the soil-forming conditions under which various clay minerals form and are stable. They state that by a combination of partial dehydration and x-ray analysis it is possible to determine what clay mineral is present, whether occurring alone or as mixtures of other types of clays.

Grim, Bradley and their colleagues (20, 21, 22) have studied the illite clay minerals and the composition of many clays and shales. They also worked on the development of the differential thermal procedure for the analysis of clay minerals.

In Germany several schools of investigators (23) began a study of the clay minerals and they suggested a structure for the mineral montmorillonite which is now widely accepted in its broader outlines. They showed that the indices of refraction of some of the clay minerals vary with the nature of the index liquid used to measure them. Noll (23) investigated a means of laboratory synthesis of the clay minerals and produced the best data yet available on the subject.

Nagelschmidt (68, 69) published clay mineral analysis of a variety of Scottish soils, and was the first to suggest that some of the clay minerals had an elongated fibrous form.

McEwan (52) and Brown (6, 7, 8) in studying the clay minerals in detail, presented the results of the analyses of many soil materials and contributed to x-ray techniques and to our knowledge of the structure of clay minerals.

Walker (88, 89) and MacKenzie (53) investigated the clay composition of Scottish soils and showed that "clay-biotite" (trioctahedral mica) was found in various stages of weathering, but was seldom found as unweathered material. More normally it occurred as a mixed-layer structure with vermiculite. This decomposition process was shown by x-ray analysis as a broadening of the first-order basal reflection at 10 A which has a tendency to "tail off" on the low-angle edge. The intermediate stages were characterized by the presence of diffraction bands stretching from 10 A to 14 A. The reflections were not displaced on treatment with glycerol.

Stephen (84, 85) showed that the clay fraction of a Scottish granitic soil had an integral series of x-ray reflections indicating spacings of approximately 10 A, being sharp on the outer edge but forming a "tail" towards the lower angles. He attributed this to hydration of the illite caused by the interpolation of layers of water molecules between the structural sheets, suggesting that the material was tending towards breakdown. He stated that the structure reveals the presence of three symetrical peaks with spacing at 13.8 A, 11.8 A and 10 A, which indicates that there are four crystalline phases present: (1) a chloritic phase, (2) a vermiculite phase, (3) a random mixture of (1) and (2), and (4) an illite phase.

Mitchell (67) states that the clay minerals in soils can be grouped into three categories according to their origin, (a) those which are inherited directly from the parent materials, these being most common and being derived from sedimentary rocks which are often composed almost entirely of clay minerals; these may suffer little alteration during pedogenesis beyond a purely mechanical breakdown to a small particle size; (b) clay minerals formed by an alteration of rock minerals of similar structure, much of the original structure being retained (as in the formation of illite from muscovite and of vermiculite from biotite); (c) minerals which are synthesized from the dissolved and from the amorphous products of weathering of the parent material: hence the final structures may have no relationship to those of the parent materials. He also states that illites and montmorillonites can occur either as dioctahedral or trioctahedral types. The dioctahedral type is by far the most common for illites, but the trioctahedral type is present in some soils. He suggested that in acid and iron-free surface layers trioctahedral illite is unstable and breaks down to the dioctahedral type. He could not find a podzol soil that contained trioctahedral clay minerals.

2. Electron Microscope Analysis

Shaw and his colleagues (79, 80) used the electron microscope in clay mineral identification and presented many pictures of what they believed to be characteristic of several clay minerals. Marshall (58), Martin (61), Kelly (48) and Jackson (37) also investigated clay mineral characteristics as revealed by the electron microscope.

MacKie (55) showed by the electron microscope that mica appears as irregular sharp-edged, thin tabular crystals, the extreme thinness being demonstrated by visible overlapping of several of the crystals, that illite consists of thin tabular crystals, many of which exhibit regular outlines tending towards 120 degree angles. He demonstrated that several samples earlier identified as illite are in reality a mixture of illite and thin tabular crystals which he called "Degraded Illite".

3. Soil Studies in Canada

Mineralogical studies were made of soil minerals from many parts of the world but very few have been made in Canada. Warder and Dion (90) studied the clay minerals in some Saskatchewan soils and found they were of the 2:1 layer lattice type. They found that the weathering conditions and types of vegetation caused no significant differences in the resulting clay minerals of contrasting profiles or of horizons within the profiles.

Webber and Shives (91) investigated the clay minerals of several Ontario soils by differential thermal and chemical analyses. They found that the clay minerals were of the 2:1 layer lattice type, illite predominating, with montmorillonite present in varying amounts.

Schalin (78) studied the clay fraction of one Nova Scotia and two Quebec soils and concluded, mostly from the chemical data, that the clay minerals were of the beideillite type, although other evidence pointed to the mica-like type of clay mineral, which Schalin rejected as a probable constituent.

III EXPERIMENTAL MATERIALS AND METHODS

a. Experimental Materials

1. Description of the Queens Soils

The Queens series covers approximately 500,000 acres in New Brunswick and approximately 600,000 acres in Nova Scotia (11). In New Brunswick it occurs on moderately well drained positions north of the Kingston Uplift, where it is commonly found with its ill-drained catenary associate, the Kings series. The latter covers approximately 300,000 acres. The Queens soils occupy the convex slopes of low knolls, ridges, and river basins. The topography varies from undulating to gently rolling with the average slopes between 2½ and 7½ percent (Plates 1 and 2).

Other soil series of the district which are closely related to the Queens series are: Harcourt, Dorchester, Salisbury, and Petitcodiac of approximately 1,000, 63,000, 27,000 and 74,000 acres, respectively. These are moderately well drained soils, apparently developed from the same parent material, but differentiated from the Queens soils on the basis of textural and structural differences.

The Queens series include two soil types: the loam and clay loam, of which the loam is most extensive. Their descriptions, in typical locations, are as follows:

PLATE 1.

Flat to undulating topography
Queens Series
Eagle's Settlement

PLATE 2.

Gently Rolling Topography
Queens Series
Wheaton Settlement

Queens loam

Location: 3.0 miles west of Havelock. Salem road.

Date: 14 October, 1954.

Geog. Position: Canaan river highlands.

Relief: gently undulating.

Elevation: 220 feet

Slope: one percent

Parent Material: Reddish-brown till mixed with coarse grey sandstone.

Profile:

Horizon	Depth	Description
A_0	0" - 3"	Black organic mat of decomposed roots and mixed forest litter, grading gradually into the mineral soil. The upper part of the horizon has ¼" to ½" of partially decomposed leaves and moss. Numerous fine roots of the undergrowth are closely interwoven in this layer. pH 4.3.
A_2	3" - 4"	Pinkish grey (5YR 6/2) loam, medium to fine crumb structure, moderately firm, breaks to fine powder with slight pressure. The horizon appears in pockets and is not too plentiful. Coarse skeleton; coarse grey angular and sub-angular sandstone, pH 4.5.

Horizon	Depth	Description
B_2	4" - 8"	Dark brown (7.5 YR 4/4) loam, fine crumb structure, soft and friable and with a loose open consistency. The A_2 grades gradually into this horizon. Coarse skeleton; coarse grey angular and sub-angular sandstone. pH 5.0.
B_3	8" - 13"	Dark reddish-brown (5 YR 3/4) loam to clay loam, medium crumb structure ranging from 2 to 5 mm in size, moderately firm but friable. Coarse skeleton; coarse grey angular and sub-angular sandstone. A few pieces of coarse red sandstone are also present. pH 5.2.
C	13" +	Dark reddish-brown (5 YR 3/3) clay loam, medium to coarse crumb structure ranging in size from 2 to 10 mm, firm, slightly sticky when moist. Numerous pebbles of coarse grey sandstone about ½" in size. Coarse skeleton; coarse grey angular and sub-angular sandstone, and some coarse red sandstone and gravel. pH 5.4.

Erosion: none.

Stoniness: moderately stony (i. e., with enough stones to interfere with proper cultivation unless they are removed).

Drainage: internal - fair in the solum, then impeded.

external - fair to good.

effective - fairly good.

Moisture: moderately moist.

Vegetation: fir, red maple, grey birch, poplar, scattered pine and spruce. Undergrowth: bracken, blueberry, hazel, chokecherry and herbaceous plants.

Remarks: the A_2 horizon at this site is found in widely scattered areas only. Roots of trees and undergrowth penetrate with ease to the parent material; few penetrate further. Underdrainage is a necessity for production of normal yields of agricultural crops. Land use: mixed farming and dairy farming.

Queens clay loam

Location: 5.0 miles west of Havelock. Salem road.

Date: 15 October, 1954.

Geog. Position: Canaan river highlands.

Relief: flat to gently undulating.

Elevation: 172 feet.

Slope: one percent.

Parent Material: Heavy reddish-brown glacial till mixed with grey sandstone.

Profile:

Horizon	Depth	Description
A_0	0" - 2"	Black, well decomposed organic mat consisting of decayed hardwood vegetation and roots. Covered with a ¼" to ½" layer of undecomposed leaves and herbaceous material. Closely interwoven with numerous fine roots. pH 4.3.
A_2	2" - 4"	Pinkish grey (5 YR 6/2) sandy loam, medium to fine crumb structure with aggregates 1 to 5 mm in diameter, firm but friable. Horizon is very irregular and has a tendency to be lumpy when damp. Grades gradually into the horizon below. Coarse skeleton; coarse grey angular to sub-angular sandstone. pH 4.4.
B_2	4" - 10"	Brown (7.5 YR 5/4) clay loam, medium to coarse crumb structure with aggregates 5 to 15 mm in diameter, firm, sticky when moist. Contains numerous pebbles of grey sandstone. Coarse skeleton; coarse grey angular to sub-angular sandstone and some coarse red sandstone. pH 5.2.
B_3	10" - 14"	Reddish brown (5 YR 4/3) clay to clay

Horizon	Depth	Description
		loam, medium to coarse crumb structure with aggregates 5 to 25 mm in diameter, firm, sticky consistency when moist. Coarse skeleton; coarse grey angular to sub-angular sandstone and some coarse red sandstone. pH 5.5.
C	14" +	Dark reddish brown (5 YR 3/3) clay to clay loam, blocky structure ¼" to ½" in diameter, coated with a yellowish green discoloration presumedly due to the presence of the sandstone, moderately plastic and compact. Coarse skeleton; coarse grey and red angular to sub-angular sandstone. pH 5.4.

Erosion: none.

Stoniness: moderately stony (i.e., with enough stones to interfere with proper cultivation unless removed).

Drainage: internal - fair to poor in the solum, then impeded.

Moisture: fairly moist.

Vegetation: second growth red maple, grey birch, white birch, poplar, scattered fir, pine, and spruce. Undergrowth: pin cherry, elder, willow, rhodora, bracken, wintergreen and other small herbaceous plants.

Remarks: well drained areas occur as small patches in an area which, as a whole, is poorly drained. Roots are fairly numerous to the parent material. Underdrainage is a necessity for production of normal yields of agricultural crops. Land use: mixed farming and dairy farming.

When the survey of the area, including these soils, was first started the Queens soil series was described as a loam soil with a clay loam parent material, but as the survey progressed a clay loam soil, with apparently the same parent material, was encountered and separated as a soil type of the Queens soil series, the separation based principally on the difference in texture of the solum. Recently there has been considerable speculation as to the reasons for this textural variation, such as, whether the two soil types are textural variations of the same series developed on the same parent material, or whether the textural difference is due to a different type of parent material, or whether the textural difference is an indication of different weathering processes and degree of soil development; consequently the origin of this comparative study.

2. Geology of the Area

Deposition of Carboniferous sediments in eastern Canada (24) took place in a large basin occupying an area of at least 300 by 500 miles and covering parts of Newfoundland, Quebec, Prince Edward Island, Nova Scotia and New Brunswick. The greater part of this basin lies under the Gulf of St. Lawrence, but an area of approximately 25,000 square miles is still above the sea in the provinces mentioned.

In this basin the Carboniferous formations, ranging from Mississippian to Pennsylvanian, lie with pronounced angular unconformity on a basement of earlier Palaeozoic and Precambrian rocks. The older rocks include gneiss, slate, quartzite, schist and greenstone, with granite and basic igneous intrusions. The earlier Palaeozoic sediments of Ordovician, Silurian and Devonian age, comprising crystalline limestone, slate, arkose and quartzite were considerably metamorphosed by earth movements and intrusions of granite during the Acadian revolution, in Devonian time.

The Carboniferous section includes great thicknesses of conglomerate, sandstone, siltstone, shale and limestone. It is characterized by "red beds" and in consequence the soil over the whole area is noticeably reddish in color. The thickness of the Carboniferous in this area exceeds 16,000 feet.

Conditions of deposition appear to have been uniform over the whole Carboniferous basin. The climate seems to have been arid, and while there are some marine sediments in the section, many of the rocks were laid down on deltas or on flood plains of rivers.

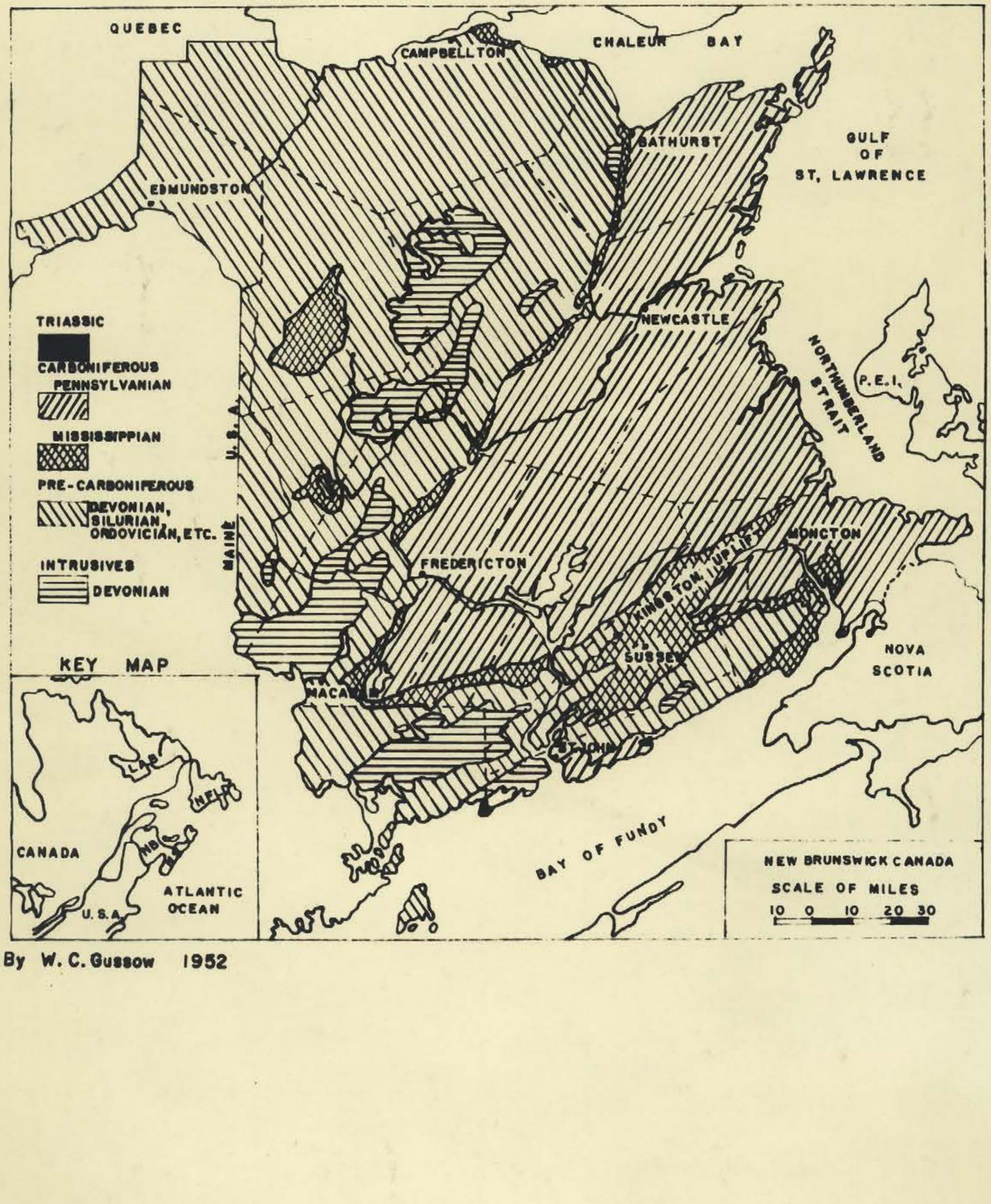
In New Brunswick, the Carboniferous sediments occupy an area which is roughly triangular. The base of the triangle extends generally north-northwest along Northumberland Strait and has a length of about 150 miles. Its apex lies inland approximately 130 miles at a point near Oromocto Lake. Altogether, about 12,300 square miles of the province is covered by Carboniferous rocks (Figure 1.).

The Carboniferous area in New Brunswick is marked by an erosion surface standing approximately 400 feet above sea level. This surface has been somewhat dissected, especially near the coast where there is evidence of recent rise in sea level. Standing above this lowland are the ridges of pre-Carboniferous rocks which were nearly buried by sediments. These ridges diverge, in a northeasterly direction, the most southerly being the Caledonia Mountain along the Fundy coast. The Carboniferous sedimentary basin is bounded by a mass of older rocks which runs from McAdam to Bathurst. Between these two diverging masses there are other ridges now partly covered by Carboniferous strata.

In general, the Carboniferous area of New Brunswick is separated into two basins by the Kingston uplift which brought Mississippian and older formations to the surface. The basin north of the Kingston uplift is occupied, except on its margins, by Pennsylvanian formations which lie flat or with very gentle dips. The basin south of the Kingston uplift, the Moncton basin, occupies an area of approximately

FIGURE I.

GEOLOGY OF NEW BRUNSWICK



By W. C. Gussow 1952

3,000 square miles.

The Carboniferous formations of New Brunswick may be taken as representative of the whole Carboniferous basin though here the section is perhaps more varied than in other portions of the region.

Pre-Carboniferous rocks from the Caledonia Mountains and other similar physiographic features have been the source rocks of the Carboniferous sediments. Therefore, an area of deposition close to the source material contains sudden facies changes, pinch-outs, local piedmount deltas and, where repeated uplifts have occurred, there is a repetition of this type of sedimentation over a long period of time.

The Memramcook formation which is the oldest of the Mississippian formations found in this region, consists mainly of coarse, red, poorly-sorted, clastic material grading into reddish sandstone and siltstone. This is sometimes referred to as the "Lower Red Beds".

The grey sediments of the Albert formation containing thin bedded and laminated shales, siltstone, limestone and sandstone lie above the red Memramcook sediments. These sedimentary types indicate deposition in shallow seas which at times were shut off from the ocean: this is indicated by the presence of local evaporite deposits of salt and anhydrite. The remains of numerous fossil fish are present in the Albert formation but it is questionable whether they are of fresh - or salt-water origin. The formation is generally rich in hydrocarbons.

The end of the Albert time is marked by a general uplift, followed by the deposition of coarse red clastic sediments of the basal part of the Moncton group or so-called "Upper Red Beds" which consist of red siltstone and shale of the Weldon formation and red sandstone and conglomerate of the Hillsborough formation that rest uncomformably on the former formation.

The deposition of the Windsor apparently took place in interconnected shallow evaporite basins following a marine invasion as shown by the widespread deposits of limestone, gypsum, and salt.

An upwarping of the land areas and retreat of the shallow seas ended deposition of the Windsor group. Then commenced a period in which coarse red sandstone and conglomerate of the Hopewell group were laid down. The deposition of the Hopewell formation was interrupted by a period of intense folding and faulting. During this tectonic interval and subsequent to it similar strata were deposited. The upper part of the Hopewell is Pennsylvanian in age, while the lower part of the Hopewell group belongs to late Mississippian.

Pennsylvanian sediments cover a much wider area than any previous Carboniferous deposits. The uppermost Pennsylvanian beds appear relatively undisturbed, so that the gently dipping beds of the upper

Pennsylvanian overlap the more intensely folded older formations, obscuring all evidence of structures associated with them. For the most part, Pennsylvanian sediments are sandstone with local occurrences of conglomerate and shale. The major portion of the Mississippian and Pennsylvanian sedimentation is of the fluviatile and lacustrine type of continental deposits. During the Pennsylvanian period the strata laid down were entirely continental.

Figure 2 shows the location of the upper Pennsylvanian formations, of the Pictou group.

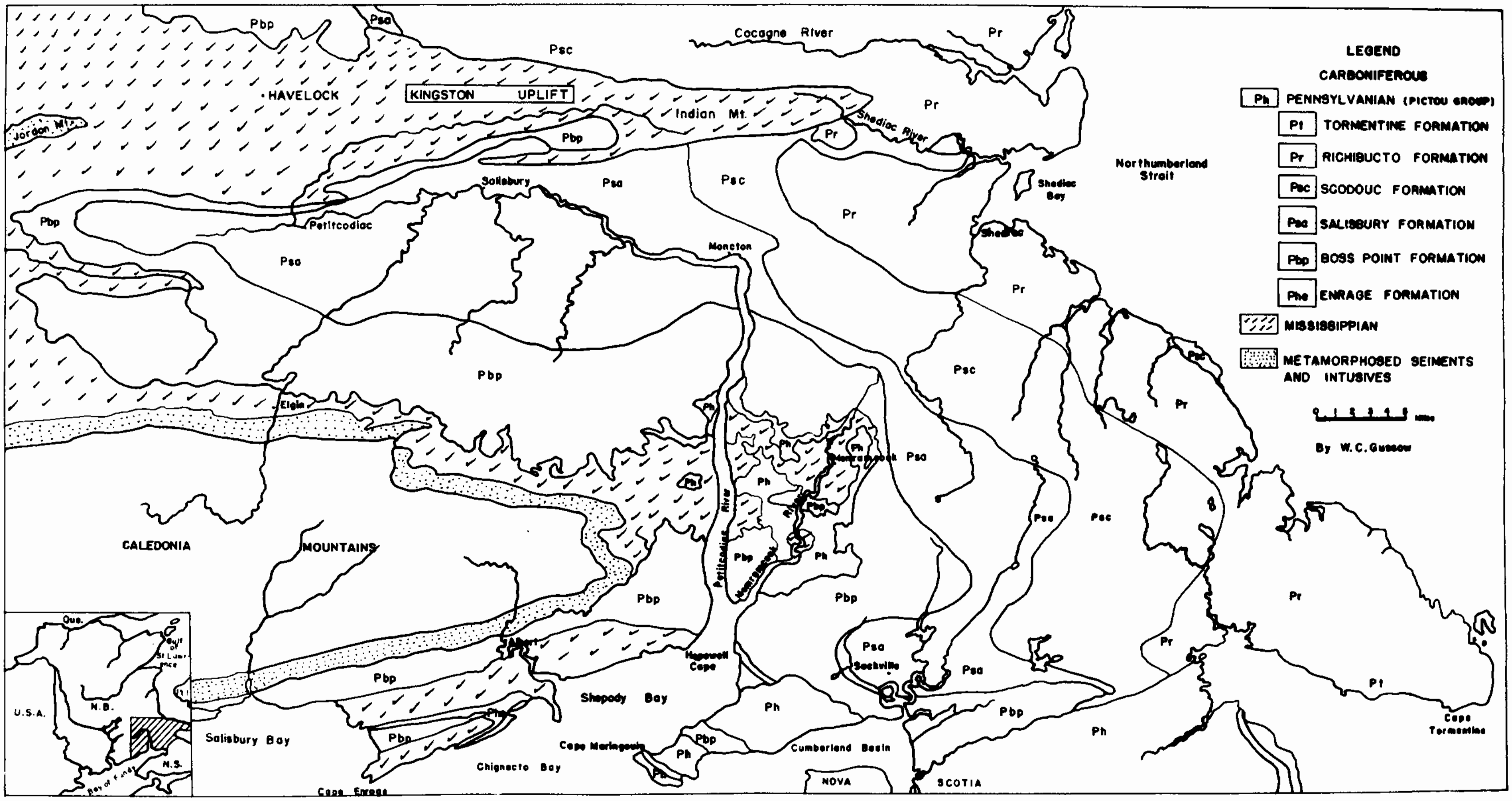
Gussow (24) classified the various formations of Carboniferous age, as follows, from the most recent to the oldest:

"CARBONIFEROUS
- PENNSYLVANIAN
  - 7. Pictou Group: continental.
    - a. Tormentine formation: red sandstone, with siltstone, shale, and conglomerate. Estimated thickness 500 feet.
    - b. Richibucto formation: predominantly buff feldspathic sandstone, green siltstone, some coal. Basal shale-pebble conglomerate. Estimated thickness 1,000 feet.
    - c. Scoudouc formation: feldspathic sandstone, shale, and conglomerate, buff to red. Estimated thickness 1,500 feet.
    - d. Salisbury formation: red shale, siltstone, some sandstone and conglomerate. Thin coal seams. Estimated thickness 2,500 feet.
    - e. Boss Point formation: grey quartzose sandstone and quartz-pebble conglomerate. Fossil plants. Estimated thick-

FIGURE 2.

UPPER PENNSYLVANIAN FORMATIONS

PICTOU GROUP



ness 6,200 feet.

MISSISSIPPIAN AND PENNSYLVANIAN

6. Hopewell Group: predominantly continental.
    - a. Enrage formation: red sandstone, grit, shale, and conglomerate. Estimated thickness 1,350 feet.
    - b. Shepody formation: grey-green and red sandstone and siltstone. Fossil plants. Estimated thickness 2,320 feet.
    - c. Maringouin formation: red shale and siltstone. Marine to continental. Estimated thickness 2,600 feet.

MISSISSIPPIAN

5. Windsor Group: predominantly marine.
    - a. Subzone C: fossiliferous grey limestones. Sandstone. Estimated thickness 24 feet.
    - b. Subzone B: fossiliferous limestone, gypsum, anhydrite, rock salt, shale and conglomerate. Estimated thickness 1,000 feet.
    - c. Subzone A: finely laminated calcareous anhydrite argillaceous limestone. Estimated thickness 175 feet.

MISSISSIPPIAN

4. Moncton Group: continental.
    - a. Hillsborough formation: red sandstone, conglomerate, and shale. Basal ash bed. Estimated thickness 2,900 feet.
    - b. Weldon formation: red siltstone, shale and conglomerate. Estimated thickness 5,000 feet.
3. Albert formation: grey-green to dark grey shale with interbedded siltstone, sandstone, limestone, conglomerate. Bituminous sandstone and oil shales. Locally, rock salt near top of section. Fossil fish and plants. Marine in part. Estimated thickness 5,500 feet.
2. Memramcook formation: red shale, sandstone, and conglomerate. Fossil plants. Estimated thickness 7,000 feet.

PRE-CARBONIFEROUS. (Basement complex)

1. Devonian granites, often porphyritic and with much quartz, and other related intrusives invading Devonian, Silurian, and Ordovician formations which comprise great thicknesses of black slates and volcanics with interbedded quartzites and crystalline limestone.

> Precambrian graphite schists, greenstone schists, and granite gneisses."

3. Discussion of the Queens Series

A comparative study of the geology and the physiography of the district covered by the soils of the Queens series reveals qualitative relationships between the bedrock and the parent material. Where the soils have formed in situ (more or less) the parallelism is unmistakable plain, but often it has been disturbed in varying degrees by the same geomorphological agencies (wind, water and ice) which have been active in the development of the landscape. Finally, the soils are not simply the by-products of rock decay, but the end result of the interaction of a number of factors peculiar to soil formation, to which those responsible for the landscape are contributory.

A comparison between geological maps and soil maps of this area show that the pattern of distribution of the soil series bears a strong resemblance to the geographic pattern formed by geological formations. Such a relationship can be expected in places where the soils have developed in situ from the weathering products of the underlying bedrock. During the Pleistocene period the district covered by the Queens soils was invaded by glaciers moving in a general southeasterly direction, and as they moved they transported huge amounts of weathered rock material and preglacial soil. The gradual transition from soil to bedrock is not found in these soils, instead there is a sharp change from the comminuted soil parent material to the bedrock on which it rests, and the stones and gravel contained in the soils are partly or fully rounded. These modifications are common, but the parent materials of these soils are comparatively "pure", the amounts of "foreign material" being of little consequence. This comparatively "pure parent material" may be explained by presuming that the glacial drift was carried only short distances and that the glaciers transferred the drift material from one formation to another only at formation boundaries. In the case of narrow formations, with which there appear to be no associated soils, it can be assumed that their weathering products were covered or mixed with till derived from a neighbouring formation, so that the soils now found where a narrow formation is indicated on geological maps are associated with more extensive adjoining formations.

These remarks apply specifically to upland soils developed on glacial till, and not to those soils that have formed from more or less distinctly sorted, stratified, water-deposited materials.

The soils of the Queens series are developed on till from predominantly non-calcareous rock material and are found on undulating to gently rolling lowland southwest of an irregular line from Fredericton on the St. John river to Shediac, to a smaller extent in the Newcastle area, and to a very small extent on rolling to hilly upland at other scattered points. The area, north and northwest of Moncton, mapped as Queens sandy loam as shown by Aalund and Wicklund (1) in reality is a sand deposit of varying thickness overlying the Queens till (Figure 3).

This deposit, according to Lougee (50), was probably the result of the DeGeer stability and DeGeer marine stage during the retreat of the last ice sheet (Figure 4).

At this time the St. John river was fed by the melting glacier. The continental shelf and the fishing banks formed a belt of elevated land enclosing the DeGeer sea and all of Nova Scotia was an island.

As the land rose (50), rivers were extended to the receding shore, and the Kennebec, Penobscot and St. John rivers were for a long time fed by the retiring ice border in northwest Maine and New Brunswick. The coast lay eastward of the present shore, somewhat below the 17 fathom line, making the Champlain stage of glacial sea level. Sea floors were exposed from Cape Cod to the Bay of Fundy, and rivers spread over the plains of marine clay before dissecting them. This was the period of greatest river terracing in New England history. River bluffs facing the blast of a strong prevailing westerly wind became a principle source of loess and dune sand, which

FIGURE 3.

LOCATION OF THE QUEENS AND RELATED SOILS
IN
NEW BRUNSWICK

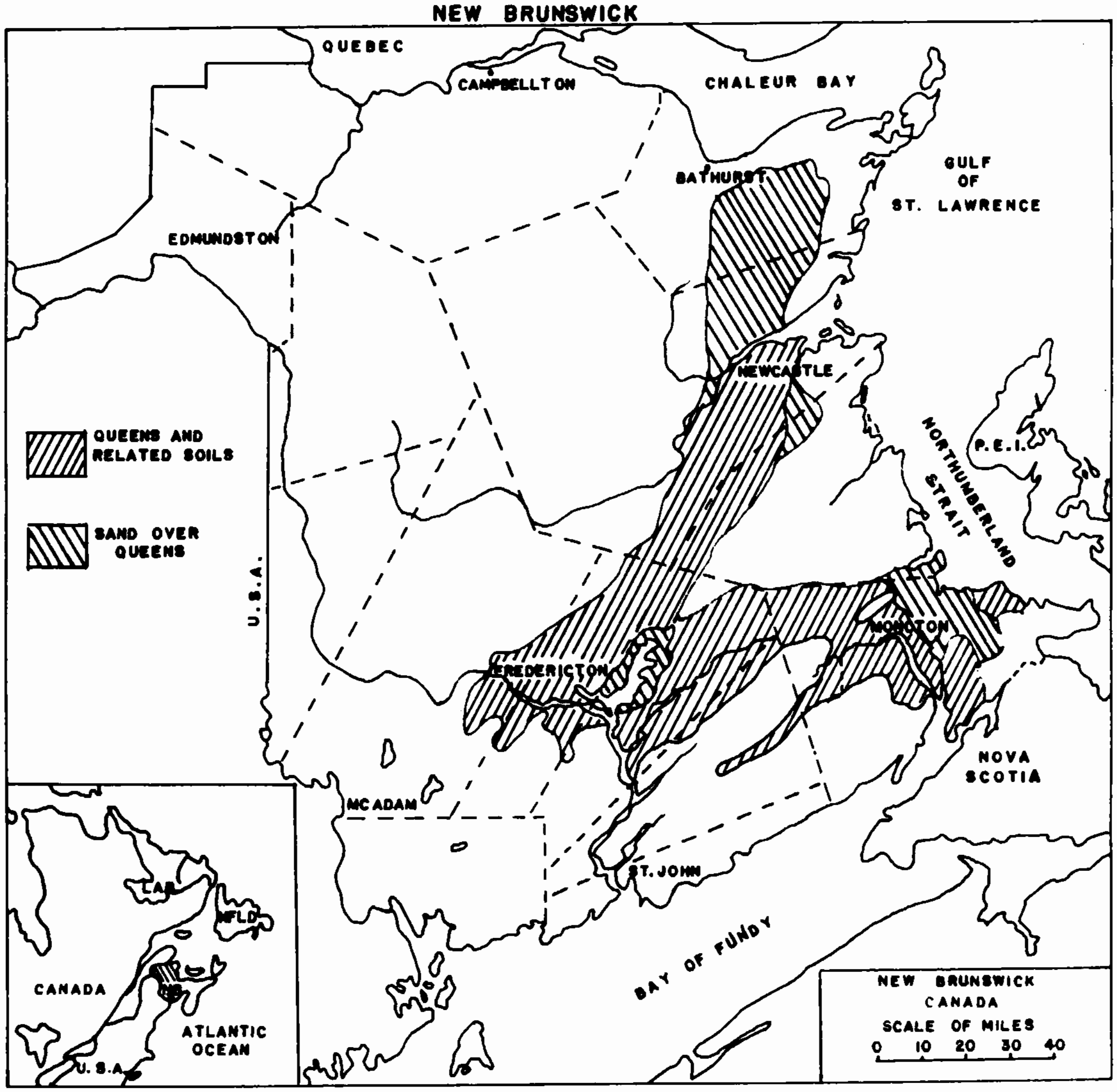
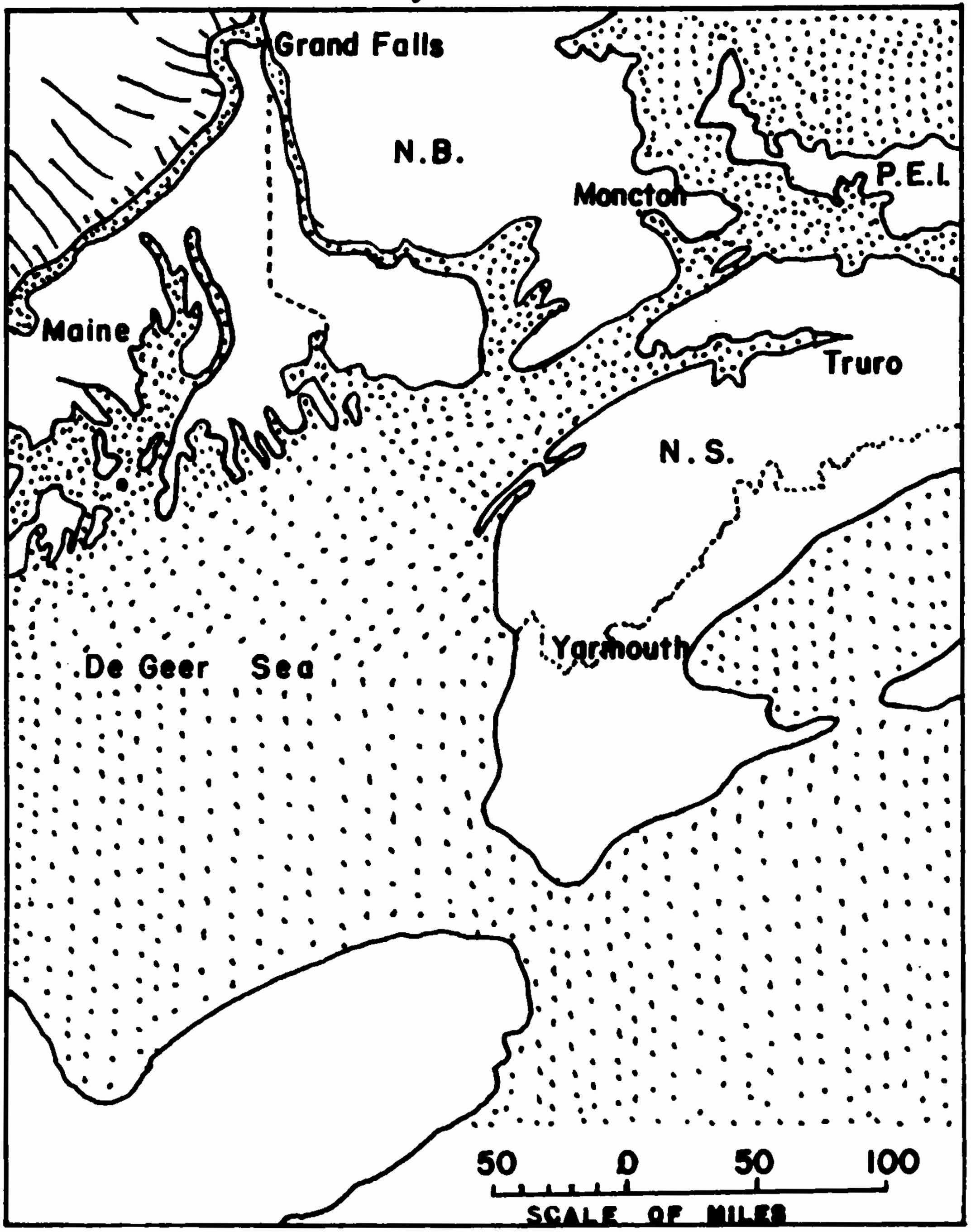


FIGURE 4.

DEGEER STABILITY AND MARINE STAGE

De Geer Stability Climax



were deposited on the east side of valleys before vegetation took hold.

The parent material of the Queens series is derived chiefly from shale, siltstone, sandstone and conglomerate, of a predominantly red color, of the Salisbury formation (1). Evidence of the influence of the Scoudouc and Richibucto formations are shown by the presence of feldspathic sandstone.

The parent material is a reddish brown, heavy boulder clay with gravel, small stones, and boulders, all usually rounded or subangular, firmly embedded. The coarse skeleton consists of grey feldspathic and red sandstone with the occasional metamorphic. The reaction of the parent material is quite acid, the pH varying between 5.0 and 5.5.

Mineralogical analysis of the Salisbury geological formation showed the presence of the same minerals as found in the parent material of the two soil types.

b. Experimental Methods

1. Sampling Procedure

The soils of New Brunswick mapped as Queens loam and Queens clay loam were thoroughly examined and two locations that conformed to the descriptions laid down by

Aalund and Wicklund (1) were carefully chosen as being representative of these soils. Bulk and core samples were carefully taken, special care being exercised to avoid contamination, of the A_2, B_2, B_3 and C horizons, plus an additional sample of the C horizon at 30 inches, at the two locations selected.

2. Preparation of Samples

The bulk samples were air dried, crushed, and screened through a 2 mm sieve, thoroughly mixed and the required samples taken by the quartering method.

The core samples were dried to constant weight in an electric oven at 105°C, cooled, weighed and the bulk density determined (Table II).

3. Hygroscopic Moisture

Duplicate 2 gm samples of the prepared soil were dried to constant weight in an electric oven at 105°C, cooled, weighed, and the hygroscopic moisture determined (Table VI).

4. Mechanical Analysis

(i) Removal of Organic Matter

50 gm samples of the prepared soil in 800 ml beakers were treated with 100 ml of 15 percent H_2O_2, covered with a watch glass, and allowed to stand overnight

at room temperature. The samples were then placed on a boiling water bath and heated until effervescence ceased, the watch glass was removed and evaporation continued to dryness. Two such treatments generally removed the organic matter adequately.

(ii) Dispersion and Separation of Fractions

Each sample of the organic matter free soil was transferred to a Bouyoucos dispersion apparatus and dispersed, with 10 ml of 10 percent Calgon solution, for 10 minutes. The percentage of the various fractions were determined by the Bouyoucos hydrometer method (3, 4).

Part of the clay fraction was separated from the sand and silt fractions by one decantation. The sand, silt and remaining clay were washed onto a 300 mesh sieve supported on a glass funnel; the silt and clay washed through the sieve, by means of a jet of water, and collected in a beaker.

The sand was washed twice with ethanol and twice with acetone, dried for a few minutes, and the sieve tapped over the same funnel to pass the remaining silt and clay. The sand was then dried at 105°C, and weighed.

Table I shows the mechanical analysis expressed as percent weight on an oven dry basis. Table II shows the mechanical analysis expressed on a volume weight basis (gms/cc of oven dry soil).

TABLE I

Results of Mechanical Analysis of 2 mm Soil Expressed as Percent Weight on an Oven Dry Basis

Series	Horizon	% Sand	% Silt	% Clay	Texture
	A_2	48.9	35.9	15.2	GL
Queens	B_2	41.9	33.4	24.7	GCL
	B_3	42.0	32.5	25.5	GCL
Loam	C_1	38.5	30.9	30.6	GC
	C_2	34.5	31.2	34.3	GC
Queens	A_2	37.3	47.0	15.7	L
	B_2	30.9	38.8	30.3	GCL
Clay	B_3	26.8	36.9	36.3	GC
	C_1	19.4	36.4	44.2	C
Loam	C_2	23.2	34.6	42.2	C

TABLE II

Results of Mechanical Analysis Expressed on a Volume Weight Basis (gms/cc of Oven Dry Soil)

Series	Horizon	Volume Weight of Soil	Gravel	Sand	Silt	Clay	Texture
	A_2	1.270	0.296	0.475	0.350	0.149	GL
Queens	B_2	1.210	0.312	0.376	0.300	0.222	GCL
	B_3	1.660	0.526	0.476	0.369	0.289	GCL
Loam	C_1	1.770	0.409	0.534	0.421	0.416	GC
	C_2	1.760	0.373	0.480	0.433	0.474	GC
Queens	A_2	1.080	0.128	0.356	0.447	0.149	L
	B_2	1.100	0.239	0.266	0.334	0.261	GCL
Clay	B_3	1.480	0.312	0.313	0.431	0.424	GC
	C_1	1.710	0.336	0.267	0.500	0.607	C
Loam	C_2	1.700	0.325	0.319	0.476	0.580	C

GL = gravelly loam, GCL = gravelly clay loam,

GC = gravelly clay, L = loam, and C = clay.

(iii) Fractionation of the Sand Fraction

The dried sand was placed on a nest of sieves (Nos 60, 140, and 300), separated by shaking on a mechanical shaker for 10 minutes and each fraction weighed. This gave a separation of $>$0.25 mm, 0.25 mm - 0.10 mm, and 0.10 mm - 0.05 mm in size. The portion that passed the 300 mesh sieve was added to the silt and clay fractions. The percentages of the separates are shown in Table III, and on a volume weight basis (gms/cc oven dry soil) in Table IV.

TABLE III

Separates of the Sand Fraction Expressed as Percent Weight of Total Sand

Series	Horizon	Total Sand	2.0-0.25 mm	0.25-0.10 mm	0.10-0.05 mm
Queens Loam	A_2	48.9	43.0	31.2	25.8
	B_2	41.9	45.7	31.9	22.4
	B_3	42.0	47.7	30.3	22.0
	C_1	38.5	47.2	29.4	23.4
	C_2	34.5	49.1	31.6	19.3
Queens Clay Loam	A_2	37.3	44.1	30.4	25.5
	B_2	30.9	46.5	28.6	24.9
	B_3	26.8	43.7	29.2	27.1
	C_1	19.4	39.5	30.2	30.3
	C_2	23.2	43.7	23.0	33.3

TABLE IV

Separates of the Sand Fraction Expressed on Volume Weight Basis (gms/cc of oven dry soil)

Series	Horizon	Total Sand	2.0-0.25 mm	0.25-0.10 mm	0.10-0.05 mm
Queens Loam	A_2	0.475	0.204	0.148	0.123
	B_2	0.376	0.172	0.120	0.084
	B_3	0.476	0.227	0.144	0.105
	C_1	0.534	0.248	0.154	0.122
	C_2	0.480	0.236	0.152	0.092
Queens Clay Loam	A_2	0.356	0.157	0.108	0.091
	B_2	0.266	0.124	0.076	0.066
	B_3	0.313	0.137	0.091	0.085
	C_1	0.267	0.105	0.081	0.081
	C_2	0.319	0.139	0.074	0.106

(iv) Separation of the Silt and Clay Fractions

The thoroughly agitated suspension of silt and clay was transferred to 800 ml beakers which were filled exactly to a depth of 10 cm, and allowed to stand overnight or at least 8 hours. The clay was carefully siphoned off without disturbing the sediment. The sediment was then washed into 250 ml centrifuge tubes filled to a height of exactly 10 cm and centrifuged so as to sediment all particles larger than 0.002 mm equivalent diameter. The clay was carefully siphoned off and wash solution (water containing Na_2CO_3 to give a pH of 9.0) added to exactly the 10 cm mark. The tube was stoppered and the material well dispersed by shaking. The procedure of centrifuging, siphoning, adding wash solution and shaking was repeated until the clay was washed free from the silt, ten washings being sufficient. This clay suspension was added to the clay suspension obtained from the Bouyoucos hydrometer estimation.

(v) Fractionation of the Clay Fraction

The clay suspension was diluted so that it contained one percent solids and run through the Sharples supercentrifuge at 12,000 r.p.m. at the rate of 465 ml per minute, which separated the clay into two fractions: $>$ one micron, and $<$ one micron. The coarse fraction was run through a second time to effect complete separation.

The clay from the finer fraction was flocculated by adding NaCl, centrifuged, washed free of chlorides with ethanol, transferred to an evaporation dish, the ethanol evaporated on the steam bath, then dried in the oven at 105°C.

After drying the clay was ground with a pestle and passed through a 300 mesh sieve. The clay was then ready for further investigation.

IV ANALYSIS OF THE SAND FRACTION

a. Methods

1. Cleaning Procedures

Several methods were examined in order to determine their efficiency in removing the oxide coatings and their effects on the destruction of the individual grains.

A method that is mild enough to have little or no effect on the minerals as a whole, and will still remove the oxide coatings would have the required experimentum crucis. Matelski's method (63) of detergents and "builders" is mild enough to fit this category but was found to be ineffective in removing the oxide coating on the minerals of these soils. A more drastic method was needed in this particular case. Microscopic measurements showed that the mineral grains were appreciably reduced in size by the more drastic methods (60), in some cases as much as 20 percent. The methods, however, were very effective in removing the oxide stains.

The minerals of the parent material of the Queens soil are derived from continental geological deposits which were deposited under fairly extreme conditions, therefore, most of the acid soluble minerals have probably been removed long since. With this consideration in mind it was decided to study the effects of various concentrations of HCl and the time of contact of these concentrations on the size reduction of the individual grains and their efficiency in cleaning. The results showed that a 10 minute contact with boiling (1+ 1) HCl gave effective cleaning and had little effect on size reduction. The method was tested on magnetite, hematite, and diopside with little effect.

The sand grains were treated with boiling (1+ 1) HCl for 10 minutes, diluted immediately with water and the supernatant liquid siphoned off. The procedure was repeated if microscopic examination still showed the presence of oxide stains. Usually one treatment was sufficient.

2. Heavy Liquid Separation

Mixtures of s-tetrabromoethane (specific gravity 2.95) and nitrobenzene (specific gravity 1.2) were used to prepare solutions with specific gravities of 2.95 and 2.70 as determined by a pycnometer, giving a sub-division into three fractions as follows: with specific gravities $>$ 2.95, the heavy mineral group; 2.95 to 2.70, mica group; $<$ 2.70, feldspar and quartz group.

The procedure of Volk (87) for specific gravity separations of soil minerals was followed, modified by transferring the suspension containing the light minerals from the first separation at specific gravity 2.95 onto hardened filter paper with acetone, washing free of the heavy liquid with additional portions of acetone, and drying. The procedure was repeated using the specific gravity solution 2.70 to give the final separations.

3. Identification of Separates

(i) Microscopic Methods

The petrographic methods described by Fry (17) and Milner (65) were used for the identification of the minerals.

The gelatin slide method described by Marshall and Jeffries (60) was used for mounting the mineral grains.

(ii) Chemical Methods

A modification of the method proposed by Gabriel and Cox (18) was used to identify the potash feldspars. The minerals of the specific gravity fraction < 2.70 were treated, by direct contact, with 48 percent HF for a period of 10 minutes, diluted immediately with distilled water and the supernatant liquid siphoned off. The sample was well dispersed over the bottom of the vessel, then a concentrated sodium cobaltinitrite solution was added and allowed to remain in contact with the mineral grains for one minute. The sodium cobaltinitrite solution was made by dissolving one gram of sodium cobaltinitrite in 5 ml of distilled water. The sample was then washed free of the reagent with distilled water by siphoning off the supernatant liquid, the final washing made with acetone, then dried. The potash feldspars were dyed a deep yellow.

The following procedure was used for the identification of the calcium feldspars.

Reagents; (1) Hematein - 0.05 gm of hematein was dissolved in 100 ml of 95 percent ethanol. (This must be freshly prepared at least once a month.) (2) Buffer solution - 20 gm of sodium acetate ($NaC_2H_3O_2.3H_2O$) was dissolved in 100 ml of distilled water, 6 ml of glacial acetic acid added and the whole made up to 200 ml. The solution was approximately 0.5N in acidity, and was buffered at pH 4.8.

Procedure; the mineral sample with a specific gravity <2.70 was placed, one layer deep, in a 25 ml crucible and treated, by direct contact, with 48 percent HF for a period of 10 minutes, diluted immediately with distilled water and washed free of the acid by siphoning off the supernatant liquid. Ten drops of the hematein reagent were then added to the mineral grains in the crucible, followed by 5 drops of the buffer solution and mixed well by swirling the crucible for 2 to 3 minutes. The solution was allowed to remain in contact with the minerals for 5 minutes. The sample was then washed free of the solution with ethanol, siphoning off the supernatant each time, then finally twice with acetone, and dried.

The calcium feldspars were dyed purple, the depth of color being greatest for anorthite, successively lighter with less calcic feldspars, and lightest with orthoclase or microcline.

b. Results

1. Heavy Liquid Separations

At room temperature (21°C) a mixture of 100 ml of s-tetrabromoethane (specific gravity 2.95) plus 16 ml of nitrobenzene (specific gravity 1.2) gave a specific gravity of 2.70 that did not vary more than ± 0.02.

Table V shows the amounts present in each separate expressed as percent by weight of the 0.10 - 0.05 mm sand fraction.

TABLE V

Specific Gravity Separates Expressed as Percent by Weight of 0.10 to 0.05 mm Sand Fraction

Series	Horizon	Heavy Minerals > 2.95	Mica Group 2.70-2.95	Quartz Group < 2.70
Queens Loam	A_2	1.82	1.71	96.47
	B_2	0.93	1.61	97.46
	B_3	1.04	1.58	97.38
	C_1	1.08	1.72	97.20
	C_2	1.10	1.74	97.16
Queens Clay Loam	A_2	1.62	1.68	96.70
	B_2	1.04	1.25	97.71
	B_3	1.44	1.86	96.70
	C_1	1.57	2.21	96.22
	C_2	1.68	2.34	95.88

2. Identification of Separates

(i) Heavy Minerals

The heavy mineral fraction contains a much greater variety of mineral species than the light fractions. Many are very easily recognized by characteristic color, pleochroism, birefringence, refractive index or shape. Others are less easily identified, due to overlapping of properties or to mechanical difficulties such as presence of highly resistant coatings.

The gelatine slide method was a considerable aid in identification, since the individual grains can be studied while immersed in liquids of different refractive indices.

Mineralogical methods for soil studies must be somewhat more precise than those normally employed by geologists in correlation studies. The reason for this additional refinement lies in the effect of weathering processes in the soil which may reduce certain species in amount and remove others completely, consequently the soil scientist must concentrate first on the relative quantities of the most resistant minerals, and secondly, he must accumulate information on the losses of the others due to weathering processes.

Some consideration should be given to the arrangement of minerals in their order of importance with regard to resistance to weathering so that the more important similarities or differences between samples can readily be determined. These of course will be governed to a great extent by the type of soil in question, its geographical location, and its origin.

The following is a proposed arrangement of minerals in order of decreasing resistance to weathering processes, and consequently in order of importance in correlation studies for the Queens soils.

1. Zircon - an almost invariable accessory mineral in detrital deposits and may survive several erosional cycles; occurs in soils in small amounts, usually as inert, disseminated grains; a constituent of acid and intermediate igneous rocks, less commonly crystalline schists and limestone.
2. Tourmaline - an ubiquitous detrital on account of its resistance to weathering; occurs in soil in small amounts as an inert ingredient, and may survive more than one erosional cycle, although under certain conditions it is liable to micaceous and chloritic alteration; produced usually as a result of very mature weathering, especially if transportation is involved; in such cases usually concentrated in noticeable amounts by the weathering out of the original silicates, it being among those most resistant to weathering processes; a constituent of acid igneous rock, pegmatites, schists, gneisses and phyllites.
3. Epidote - both detrital and the product of a destabilizing environment, the authigenic variety being consistent with continental and lacustrine deposition, detrital epidote being more frequent in marine deposits; a common mineral in soils and fairly resistant to chemical weathering; a common constituent in crystalline metamorphic rocks, especially altered impure limestone, there being evidence of its formation during rock breakdown.
4. Hornblende - decomposes quite readily and, although hard, also disintegrates rapidly under mechanical wear because of its easy cleavage; the brown variety appearing to be much less stable, which may be a criterion of geologically recent formations; green hornblende having a much greater time-range and its persistence appearing to be favored by marine environment; the amphibole group, of which hornblende is a variety, being of great importance in the liberation of iron oxides, iron, magnesium and calcium carbonates to the soil; a constituent of igneous

and metamorphic rocks, especially granite, syenite, diorite and equivalent volcanic types and also hornblende schist, etc.

5. Garnet - because of its great hardness and the great resistance to decomposition of the varieties low in ferrous iron and calcium, undecomposed grains of garnet are often found as constituents of sands; varieties with higher ferrous iron, magnesium and calcium contents usually altering with the production of epidote, chlorite, talc or serpentine; usually found as constituents of metamorphosed limestone, schist and nephelene-syenites.

6. Apatite - slowly soluble without decomposition; survives in argillaceous (impervious) rather than arenaceous (porous) rocks; destroyed in lime-free environments by solution action of carbonic acid present in percolating water; present usually in silt, clay, shale or red marl, products of continental, lacustrine, fluvial environment; occurs in soil only in small amounts as grains resulting from the weathering of the rocks containing it; that found in sediments normally fluorapatite with only a small amount of chlorite; a constituent of igneous rocks, especially granites and syenites.

7. Opaque Minerals - the opaque minerals of the Queens soil are largely composed of hematite, magnetite, and limonite or goethite.

Hematite - tends to be common only where sediments are "sealed" or where infiltration of meteoric water is prevented by impervious cover; occurs in sediments both as a primary and secondary constituent, in the latter case its partial alteration to limonite frequently being seen; a common "cementing" medium in sandstones; one of the most wide spread of soil minerals, occurring in distinct grains, scales, included matter in the pebbles of gravel, coatings on sand grains, as incrustations, pulverulent matter disseminated through clay, or as the cementing material in "hardpan"; the chief coloring material in the red soils; a constituent in igneous and metamorphic rocks, metalliferous veins, and limestones.

Magnetite - usually detrital, but may also result from alteration of marcasite and pyrite or from the oxidation of siderite; most characteristic of fine-grained, semi-porous deposits; fairly resistant to weathering, but slowly changing to hematite or limonite; in a direct way of small importance because of its scarcity as a soil mineral, but of great interest in soil study because of its serving as a primary source of much of the iron of soils and soil water; a constituent of basic and ultrabasic igneous rocks.

Limonite and goethite - so ubiquitous in sediments and the genesis so varied, that in the absence of other evidence they are seldom of any special significance for correlation studies; two of the most common soil constituents; when in finely powdered form, or as staining material in other minerals, the chief coloring material of clays and soils; in large grains the most abundant and wide spread of brown coloring pigments; sometimes occurring as cementing materials forming "hardpan"; constituents of iron ores of varying composition and iron bearing minerals.

A comparison of the proposed arrangement of minerals in their order of importance is greatly facilitated by the presentation of results in histograms, the heights of the columns representating percent by weight of whole soil and the horizontal axis representing the minerals in their order of resistance to weathering processes.

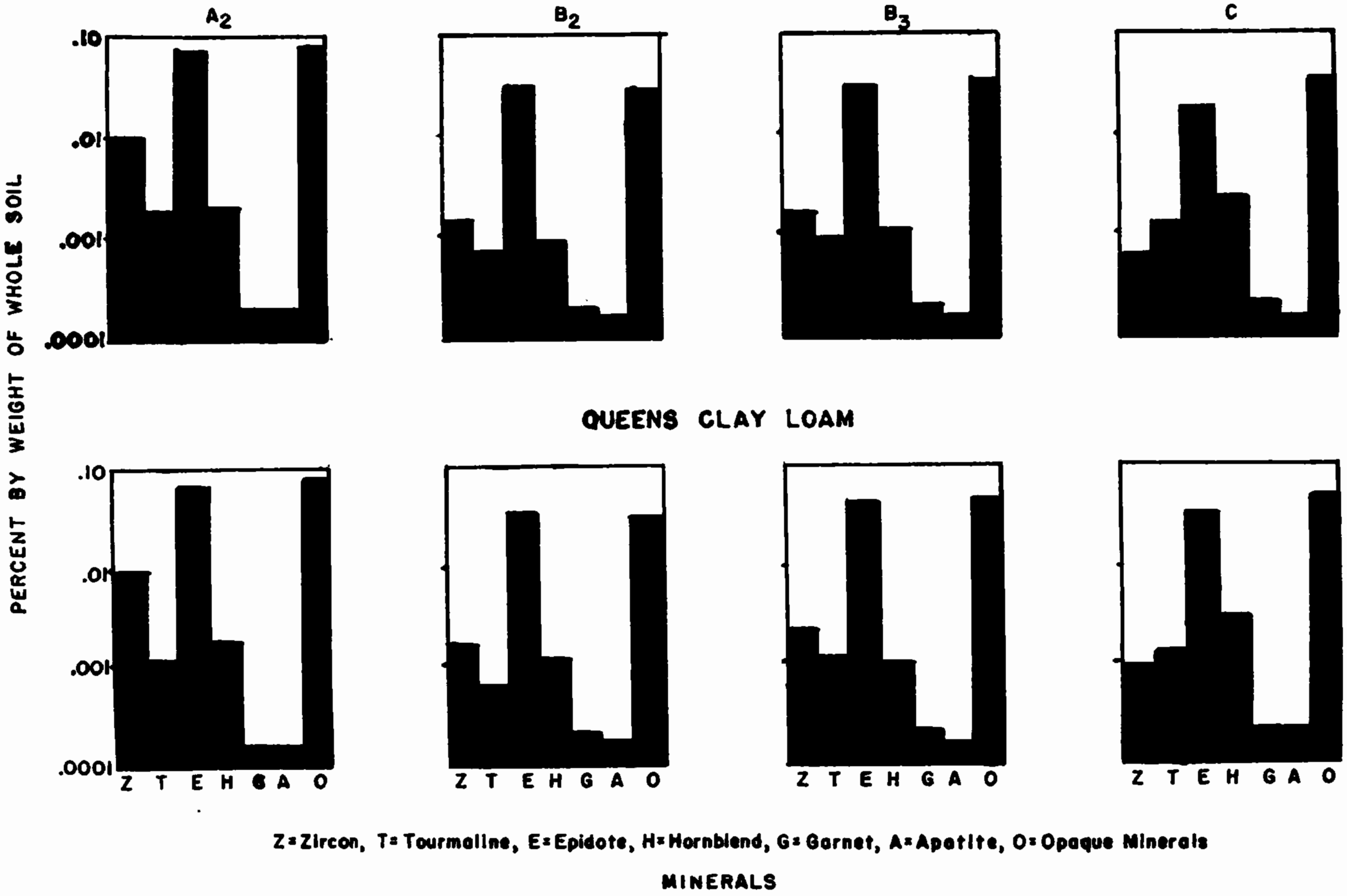
The percent by weight of whole soil was used to compare the minerals of these soils because, in the opinion of the author it gives a more exact concept of the actual proportion of each mineral present in the soils, and facilitates interpretation of the processes of weathering within the profiles.

Figure 5 illustrates the comparison of the heavy minerals of the 0.10 - 0.05 mm sand fraction, as prepared from the data in Appendix E, in the individual horizons of the loam and clay loam soils and also permits a comparison of the two soils.

The values given for the two soil types are very similar throughout the profiles, indicating a common parent material, and very similar conditions of development. The loam and clay loam soils are, on this basis, properly considered as variants rather than distinct types of the Queens series.

FIGURE 5
DISTRIBUTION OF HEAVY MINERALS SP. GR. >2.95
0.10 - 0.05 mm Fraction

QUEENS LOAM



Z = Zircon, T = Tourmaline, E = Epidote, H = Hornblend, G = Garnet, A = Apatite, O = Opaque Minerals

A comparison of the histograms of the heavy minerals, shows a trend toward a decrease in amounts with depth especially in the case of the more resistant minerals. This is more obvious in the loam than in the clay loam soil. In both soils a very noticeable increase, in the heavy minerals, is evident in the A_2 horizons, although the same kinds of minerals occur in the horizons of the solum as in the parent material. Mechanical analysis indicate similar results by showing a distinct textural break between the A_2 and B_2 horizons.

A possible explanation for this textural break in the top few inches of these soils is proposed. At the close of the Pleistocene ice epoch vast tracts of country adjoining the ice front were exposed and were undoubtedly subjected to fairly severe sheet erosion, resulting, it is suggested, in the removal of the fine material from the top few inches of the newly deposited till, leaving the coarse material as a thin layer, of varying thicknesses, governed by the severity of the erosion.

There is no evidence of accumulation of fines in any part of the profile, which seems to eliminate the possibility of significant downward movement of this material, the drainage being such that it could not be translocated completely out of the profile.

From a trend towards a decrease in amounts of the most resistant minerals with depth in the profile, and the comparatively large percentage of fairly readily weatherable minerals present in these soils, it is concluded that a noticeable degree of weathering has taken place, especially in the loam soil.

(ii) Light Minerals

Approximately 98 percent of the minerals of the Queens soil have a density <2.95. Although the minerals of the lighter fractions present much less variety than the heavy fraction, the remaining 2 percent of the minerals of these soils, they consist of at least three very important groups: the mica, feldspar, and quartz groups. Of the three groups the feldspars are by far the most difficult to identify by optical methods. For this reason chemical staining methods were employed to distinguish between the potash feldspars and the calcium feldspars.

The procedure as previously outlined permit the user to apply both staining procedures to the same sample from one treatment with HF. The staining procedure of Gabriel and Cox (18) was applied first, followed by the hematein method of staining with the result as shown in Plate 3.

The cobaltinitrite reagent produces on the potash feldspars a precipitate of yellow potassium cobaltinitrite which clings tenaciously to them. No precipitate is formed on the calcium feldspars. The hematein reagent, on the other hand, produces a purple stain on the calcium feldspars, the purple color resulting

PLATE 3

Results of Chemical Staining Methods
Yellow Stain - Potash Feldspars
Purple Stain - Calcic Feldspars
Colorless - Quartz

from the reaction of the hematein with aluminum. Both the purple and yellow colors change with time if exposed to the air, and are easily removed by abrasion.

After this simple treatment the potash feldspars are intensely yellow; the calcium feldspars are purple, the depth of color depending on the position in the isomorphic series, quartz is transparent; the micas remain white or black, depending on the variety, but can be differentiated by their flat surfaces. If the biotite is decomposed by weathering it yields a yellow precipitate but the original black shows through the yellow precipitate and gives the grains a decided green color. Muscovite is not usually decomposed by the treatment. The percentage of these minerals are then easily determined by a grain count under the petrographic microscope.

The results of the specific gravity separations of the mica group (2.95 - 2.70) and feldspar quartz group (<2.70) are grouped together in histograms for ease in presentation. Although knowledge concerning the occurrence of changes in composition of these minerals, brought about by weathering agencies, is lacking, for purposes of correlation the amounts of these minerals may give some idea as to the origin and transportation processes in soil formation, when combined with other supporting evidence.

An arrangement of these minerals in their order of resistance to weathering processes is also proposed for this fraction.

1. Quartz - one of the most stable minerals. This essential mineral of detrital deposits is significant of environment chiefly by reference to its form (nature and degree of abrasion), while a study of its inclusions is of prime importance in tracing the source of the deposit concerned; by far the most important mineral of sand and sandy soils, and in cases of extreme weathering usually the only mineral found in the sand; constituent of acid and intermediate rock types (more rarely basic), sedimentary and crystalline metamorphic rocks, and metalliferous veins; the most prolific constituent of detrital sediments, especially of arenaceous and argillaceous types.

2. Muscovite - one of the most stable of the common minerals chemically, decomposition taking place only in the latter stages of weathering, but is easily broken up by the physical agencies of weathering into small flakes. In the only easily recognizable weathering alteration the mineral may release potassium, the change being accompanied by loss of elasticity and transparency; a very common ingredient of sandy soils in which it occurs as sparkling flakes, generally of minute size; a constituent of igneous and metamorphic rocks and is more common in fluviatile and estuarine arenaceous sediments than in similar deposits of marine origin.

3. Orthoclase - very easily alterable by chemical weathering. The decomposition is facilitated by the cleavage which renders the mineral liable to disintegration and to the action of solution along the cleavage planes; a valuable indicator of climatic conditions attending deposition of the sediment in which it occurs; does not long survive a hydrous environment, especially if percolating waters are acid or if any associated sulphide ores are undergoing oxidation whereby acid may be liberated in situ; alteration is usually indicated by the presence of kaolinite, mica or hydrous silicates of alumina; mica will not be formed if alkalis have been removed; the largest primary source of soluble potash in soil and for this reason is an important soil mineral; a constituent of acid igneous rocks, and pegmatite veins.

4. Micaceous Mineral - This mineral could not be identified under the microscope due to its flaky composition, but x-ray analysis showed it to be a mixture of minerals composed mostly of weathered biotite, some talc and hematite. Its occurrence may be explained by the weathering of the grey sandstone found abundantly as the coarse skeleton of the Queens soil. A mineral of similar properties was identified as a constituent of the grey sandstone.

Figure 6 shows the comparison of the light minerals in the individual horizons of the loam and clay loam soils as well as permit a comparison of the two soils for the 0.10 - 0.05 mm sand fraction, as prepared from the data in Appendix E.

The light minerals of the two soils are strikingly similar, indicating a common origin, involving like parent materials, and similarity of weathering. There are no essential differences in kind, the differences being limited to differences of degree. No evidence is disclosed to suggest that these soils should be in different series, rather the indications are such as to substantiate the present classification as two textural variants of the same soil series.

The amount of quartz found in the different horizons, excluding the A_2, is very similar and substantiates the conclusion that the soils are relatively young in origin. The presence of orthoclase in the profile also adds weight to this conclusion.

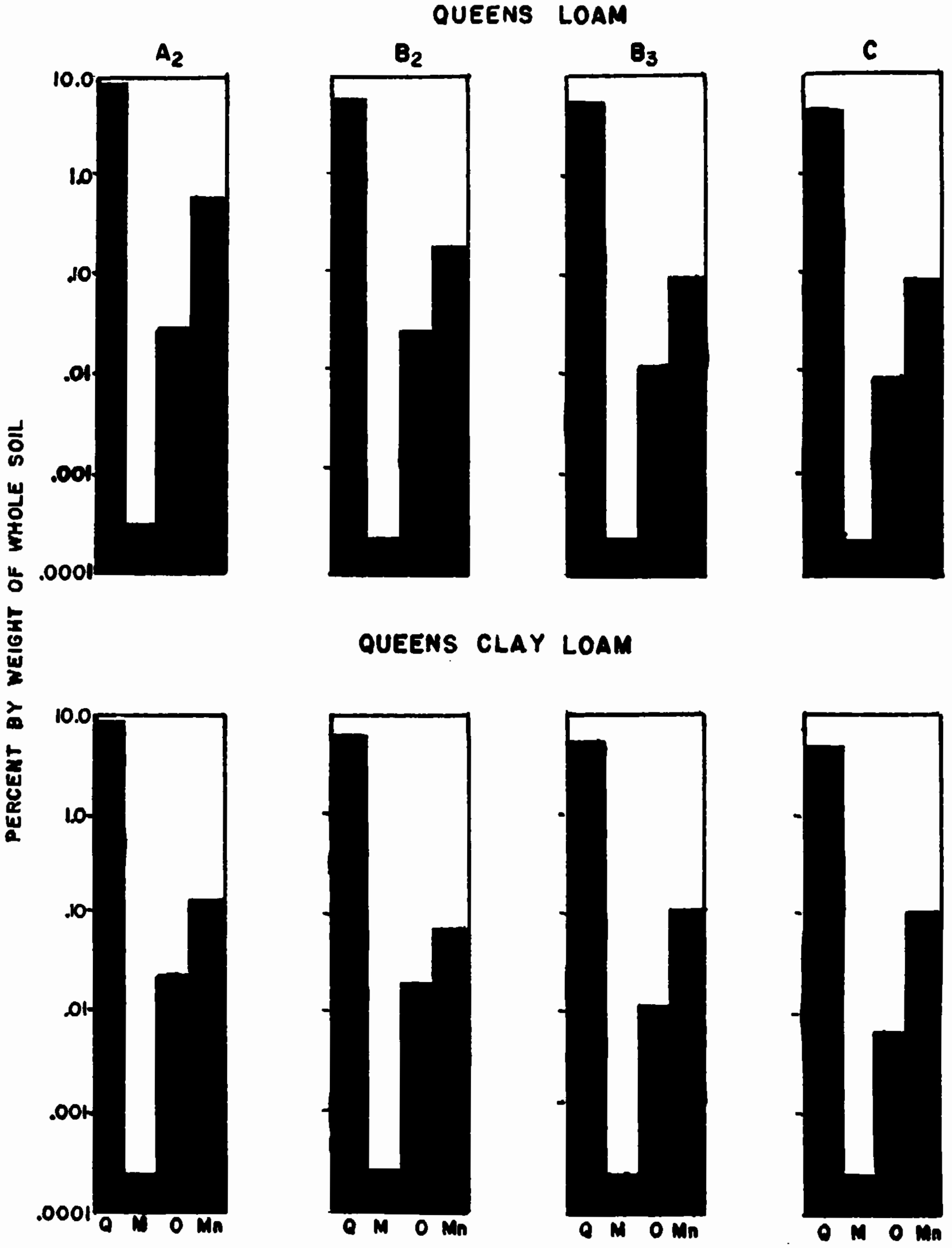
The mineral counts are presented for only the 0.10 - 0.05 mm sand fraction because they were found to be more representative, and contained the same minerals, as the other size fractions of the sand (2.0 - 0.25 mm and 0.25 - 0.10 mm), therefore, provide no additional information other than confirmation of the data given in Figures 5 and 6.

The mineralogical evidence based on petrographic studies indicates that the minerals of the sand fraction are similar within and between the two soils. The loam shows a slight increase in the amounts of these minerals

FIGURE 6

DISTRIBUTION OF LIGHT MINERALS SP. GR. < 2.95

0.10 - 0.05 mm Fraction



Q=Quartz, M=Muscovite, O=Orthoclase, Mn=Micaceous Mineral

MINERALS

over the clay loam, which indicates in all probability that the loam has been subjected to more severe weathering. A decrease in amounts, with depth, of the relatively stable minerals of these soils shows that the weathering has proceeded significantly.

The mineralogical nature of the sand fraction of the Queens solum is similar to that of the parent material, the characteristics of which are inherited from the Salisbury geological formations. A detailed study of the minerals of the sandstone of these formations showed the same minerals to be present as found in the soils.

A detailed study of the minerals of the red and grey sandstone found mixed with the Queens soil showed the red sandstone to consist of quartz cemented with hematite; the grey sandstone to consist of quartz, weathered biotite (almost a chlorite) with a silica-like cementing material.

V ANALYSIS OF THE CLAY FRACTION

a. Methods

(1) Cleaning Procedures

The iron oxide coating on the clay fraction was removed using the sodium hydrosulfite method of Mitchell and Mackenzie (66).

(2) Identification of the Clay

(i) Physical Analysis

(a) X-ray Analysis

A geiger-counter x-ray spectrometer with a 50 millivolt potentiometer and a copper target x-ray tube (Plate 4) was used to determine the minerals of the clay fraction $<$0.001 mm size.

The principle involved in the design, the units making up the apparatus, and its operation are discussed briefly by Jeffries (42).

Samples were prepared for x-ray diffraction using the glycerol solvation procedure described by MacEwan (51) and White and Jackson (92).

(b) Differential Thermal Analysis

The apparatus used for this study consisted of a furnace, nickelblock sample holder and two potentiometers, (Plate 5). One potentiometer records the temperature of the nickel block, the other records the temperature

PLATE 4

Geiger - Counter X-ray Spectrometer

PLATE 5

Differential Thermal Apparatus

difference between the sample and the reference material (calcined alumina). The heating rate was 10°C/min. and was controlled by an electronic program controller (shown above the potentiometer recording the temperature of the nickel block).

(c) Electron Microscope Analysis

The electron microscope used for this study is shown in Plate 6. The microscope has an accelerating voltage for the electron beam of 50 kilovolts which gives the electron beam a wave length of about 0.05A. The magnification was 6,000 x.

Specimen screens were prepared according to the procedure of Humbert and Shaw (36).

(ii) Chemical Analysis

(a) Ethylene Glycol Retention

The method originally proposed by Martin (62) was used for this study, as specified by Dyal and Hendricks (16) with the following modifications:

a. About 0.2 gm of organic matter-free calcium clay was weighed into a tared weighing dish and spread uniformly over the bottom.

b. The samples (6 per desiccator) were placed in a vacuum desicator containing phosphorus pentoxide and evacuated to ultimate vacuum of a good pump. Five hours were adequate to dry samples to constant weight.

PLATE 6

Electron Microscope

c. 300 mgm of redistilled glycol was added to the clay and carefully distributed over the entire surface. The glycol was allowed to soak in contact with the clay for at least 12 hours.

d. The glycol-treated samples and a dish containing pure glycol were placed in a desiccator containing carefully dried calcium chloride, and evacuated. The desiccator was placed in a water bath maintained at 25 ±°C to eliminate excessive temperature fluctuations.

e. The samples were weighed after 16 hours and every 4 hours thereafter until equilibrium was reached. Equilibrium criteria: when 3 weighings agree within ± 0.3 mgm.

f. Results are expressed as mgm/gm of clay by the use of the average weight of glycol retained, and the dry weight of clay. The weight of dry clay is the equilibrium weight obtained in an evacuated desiccator over phosphorus pentoxide.

(b) Cation Exchange Capacity

The method proposed by MacKenzie (54) was used to determine the cation-exchange capacity of the clay.

(c) Total Chemical Analysis

Silica was determined colorimetrically with ammonium molybdate from a sodium carbonate fusion as proposed by Corey and Jackson (14).

Iron was determined colorimetrically with KCNS using the method of Houlihan and Farina (35) from the carbonate fusion (14).

Aluminum was determined colorimetrically using the aluminon method of Robertson (71) on the same solution as for iron.

Potassium and magnesium were determined by flame photometry. The perchloric-hydrofluoric acid digestion (14) was used and the solution was made up so that the final volume was 2N in HCl. The following settings were used in making the estimations.

Element	Wave length mμ	Slit width	Photocell
K	766.0	0.045	Red
Mg	285.2	0.340	Blue

Soluble silica and alumina were determined by adding 100 ml of distilled water containing 5 gm of Na_2CO_3 to 1 gm of the clay sample and by boiling for 5 minutes. The silica and alumina were determined colorimetrically using the methods of Corey (14) and Robertson (71), respectively.

b. Results

1. Physical Analysis

(i) X-ray Analysis

X-ray diffraction patterns of the samples from each horizon of the Queens loam and Queens clay loam soils are shown in Figure 7.

The figure indicates that the clay minerals present in the various horizons of both soils are similar and show similar effects of hydration. This is particularly noticeable in the 9.8A and 13.8A range in the A_2 and B_2 horizons.

X-ray patterns of the Queens soils show reflections between 10A and 13.8A that are not displaced to 17A - 18A on treatment with glycerol, thus eliminating the possibility of expanding 2:1 lattice clay minerals.

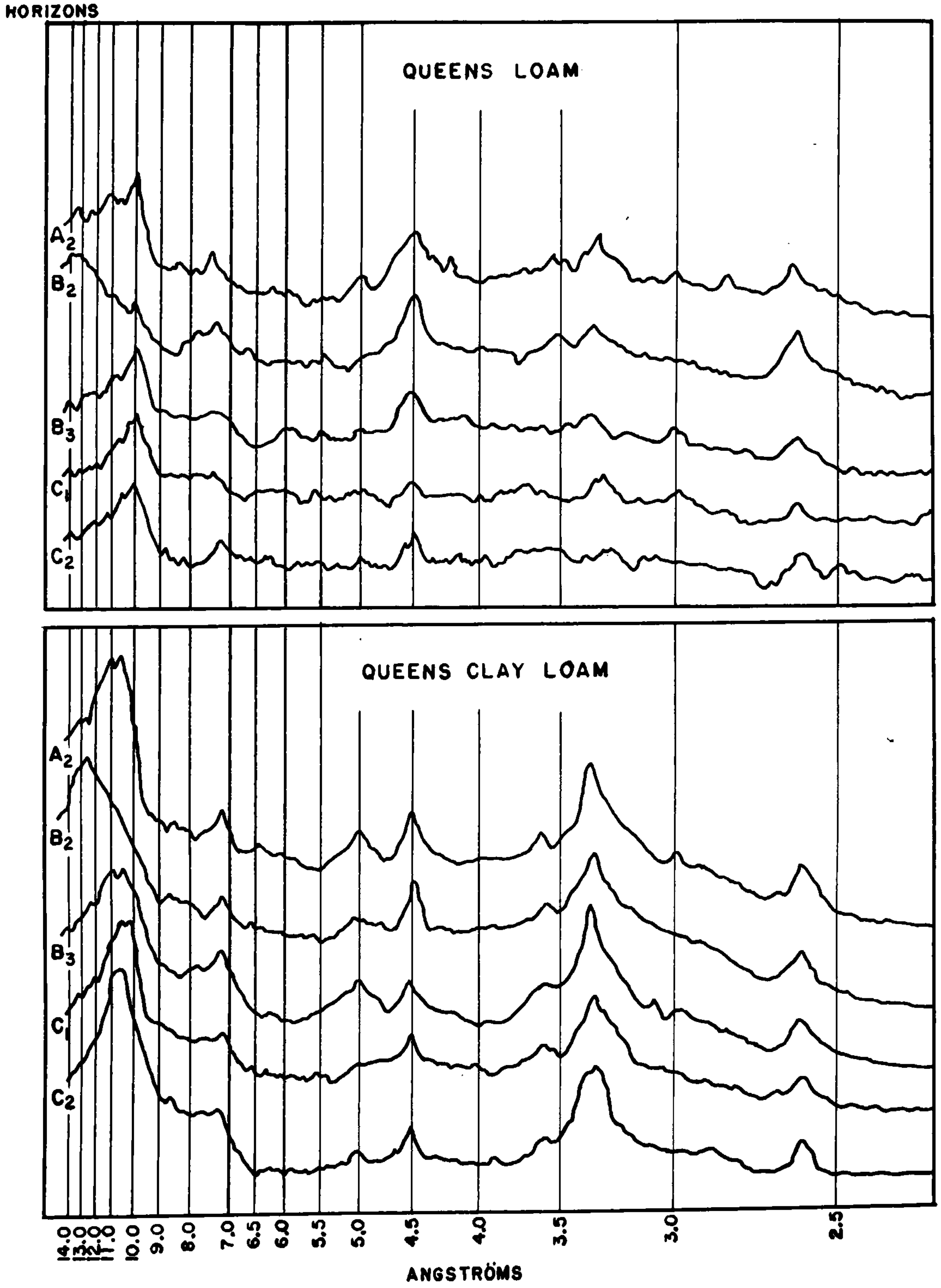
If it can be assumed that the spacings between 10A (non-hydrated) and 14A (fully hydrated) are the result of interstratification of water between modified illite units, the material in different stages of weathering would tend towards metastable phases in which the units are present in varying amounts. Such a clay would show a series of basal reflections between 10A and 13.8A governed by the degree of weathering and hence the degree of hydration (23, 88, 89, 67). This would account for the increase in the height of the peaks between 10A and 13.8A in the horizons, moving from the C horizon towards the surface, especially in the B_2.

From the x-ray patterns these soils are shown to be similar in all horizons, and to be composed of either (a) mainly illite with a small amount of mixed-layer mica, or (b) illite in different phases of weathering and hydration.

FIGURE 7

X-RAY DIFFRACTION PATTERNS

(<0.001 mm Clay Fraction)



(ii) Differential Thermal Analysis

Figure 8 shows the differential thermal patterns of the loam and clay loam soils, respectively. The curves indicate that the clay minerals are similar between and within the two soils which further substantiates the present classification, two textural variants of the same soil series, to be accurate.

The differential thermal curves are very similar for all the soil clay samples, which indicates a similarity of mineralogical constitution. The exothermic and endothermic peaks could be due to all the clay minerals; however, if kaolinite were present to the extent of 5 percent an exothermic peak at 980 degrees centigrade, would be present. Since there is no peak at 980 degrees centigrade, kaolinite may be considered to be absent, or at the most, to be present in amounts less than 5 percent. Therefore, the indications are that these soil clays may be characterized as 2:1 layer lattice clay minerals.

Differential thermal curves will not give conclusive evidence as to the type of clay mineral present, but when combined with x-ray and chemical analyses add to the knowledge of the characteristics of the minerals under study.

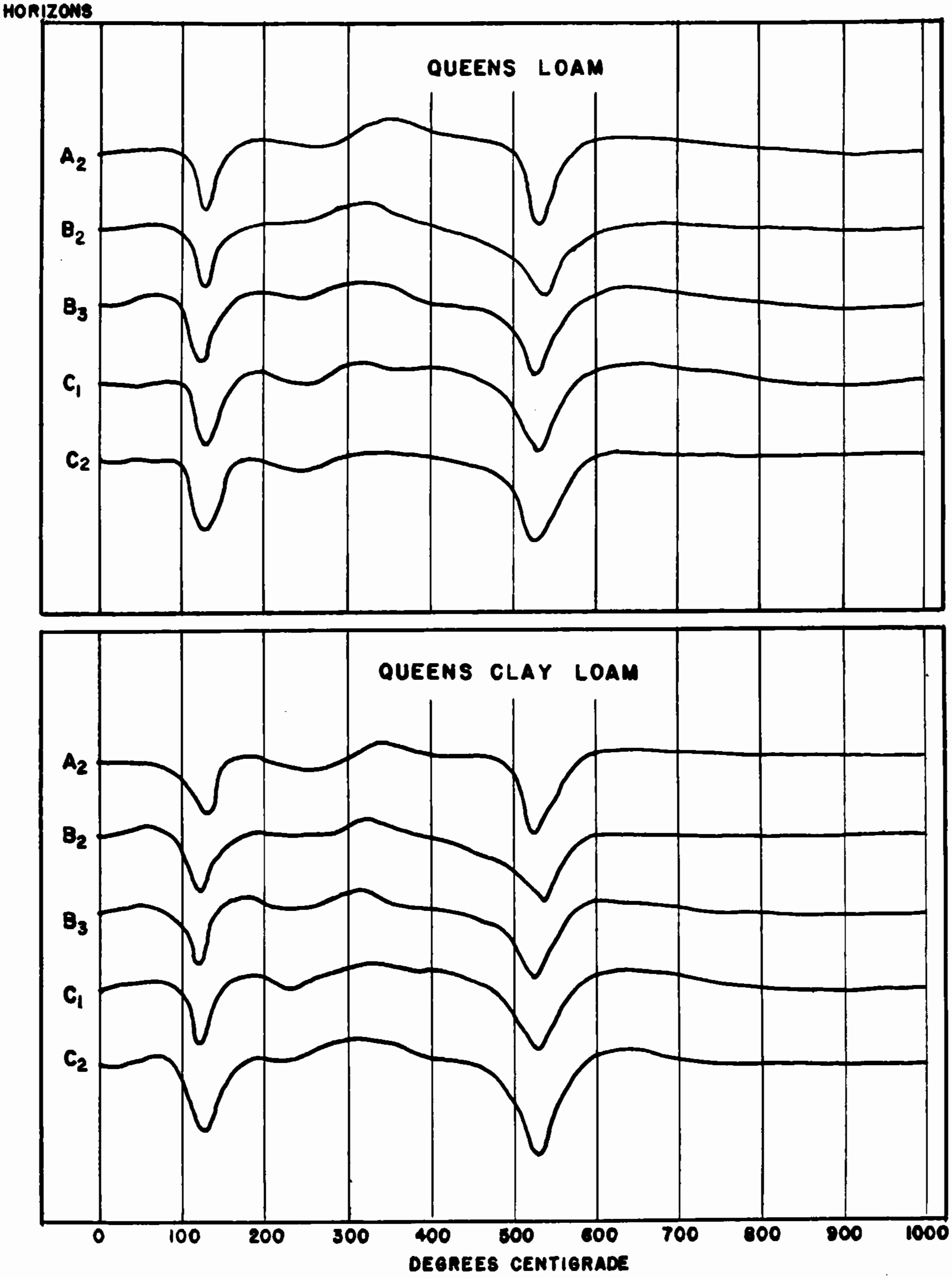
(iii) Electron Microscope Analysis

The electron microscope, because of its high resolving power, provides a means for investigating small

FIGURE 8

DIFFERENTIAL THERMAL CURVES

(<0.001 mm Clay Fraction)



mineral particles. It supplies information concerning shape, size, characteristic crystal habit, and surface features of the clay minerals. The crystal form of any particular clay mineral species is greatly influenced by the particle size, the nature of base-saturation employed and the concentration of suspension placed on the specimen screen.

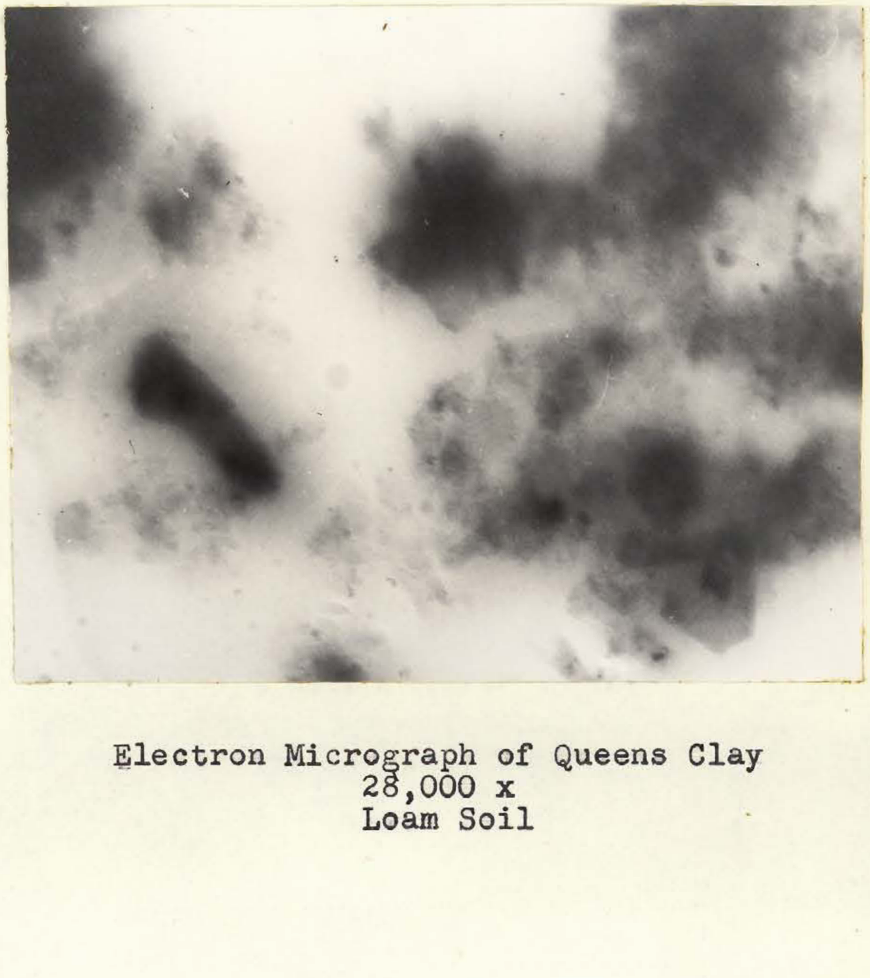
The clay fraction of the Queens soils consist of thin tabular crystals with regular outlines tending towards 120 degree angles, and irregular aggregates made up of very small crystals as described by MacKie (55) for illite, Plates 7 and 8. This corroborates the finding from x-ray analysis and further substantiates the presence of illite and mixed-layer mica. The ratio of illite to mixed-layer mica is considered to be approximately 10:1.

2. Chemical Analysis

Data for the chemical analysis of the $<$ 0.01 mm Clay Fraction is given in Table VI.

From this data it is seen that the analyses for the horizons within and between the soils are very similar, indicating a uniformity of at least the major constituents of the clay minerals present. The MgO content of these soils is low and the K_2O content is high, indicating appreciable amounts of mica-like minerals. The cation exchange capacity values are relatively high and are higher than would be expected if an appreciable amount of kaolinite

PLATE 7



Electron Micrograph of Queens Clay
28,000 x
Loam Soil

PLATE 8

Electron Micrograph of Queens Clay
28,000 x
Clay Loam Soil

TABLE VI

Chemical Analysis of the Clay Fraction (<0.001 mm) of the Queens Soils

Series	Horizon	Soil pH	% Hygro-Scopic Moisture	% SiO_2	% Al_2O_3	% Fe_2O_3	% MgO	% K_2O	E.C. m.e./100g	Glycol Retention mg/g
Queens Loam	A_2	4.5	0.51	59.97	37.17	1.67	0.48	3.89	50.76	145.8
	B_2	5.0	2.19	62.68	39.18	2.31	1.13	5.20	57.06	110.1
	B_3	5.2	1.15	63.33	37.42	2.31	0.33	5.15	52.20	134.2
	C_1	5.4	1.33	62.36	36.08	2.17	0.45	5.10	44.10	140.0
	C_2	5.4	1.36	61.80	37.11	2.09	0.33	5.05	38.70	149.1
Queens Clay Loam	A_2	4.4	0.74	64.20	31.11	0.24	0.56	4.12	48.60	153.5
	B_2	5.2	2.27	61.22	48.53	1.72	1.13	4.36	54.00	109.8
	B_3	5.5	1.77	58.96	46.78	1.36	0.56	4.30	51.30	113.8
	C_1	5.4	2.15	57.76	46.78	0.72	0.73	4.87	41.76	133.4
	C_2	5.4	2.33	58.19	47.03	0.31	0.56	5.00	37.80	157.0

were present. Ethylene glycol values, although variable, indicate the presence of a mica-like mineral, the mica-like material usually being considered to have a range of 80 to 200 mgm/gm.

Table VII shows the mineral formulae as calculated by the method of Ross and Hendricks (74) from the data in Table VI.

The data in this table show that the mineralogical formulae of the horizons are similar within each soil. The silicon in the tetrahedral coordination of the loam soil varies between 3.43 and 3.50 with an average of 3.45. The silicon in the tetrahedral coordination of the clay loam soil varies between 3.11 and 3.75 with an average of 3.24. The high value for Si in the A_2 horizon of the clay loam soil indicates the presence of Si in a form other than in tetrahedral coordination probably due to a breakdown of the clay mineral from the effects of severe weathering. The number of ions in octahedral coordination averages 2.03 for the loam soil and 2.13 for the clay loam soil, indicating that weathering has been more effective in the loam than in the clay loam soil.

The mineralogical formulae indicates that the clay fractions of the horizons of each soil are very similar, that the clay material is of the mica-like series, and that the loam soil shows a greater effect from weathering than the clay loam soil. Both soils show a decrease in cation

TABLE VII

Calculated Mineralogical Formulae of the Clay Fraction (<0.001 mm) of the Queens Soils

		Tetrahedral Coordination		Octahedral Coordination						
Series	Horizon	Si^4	Al^3	Al^3	Fe^3	Mg^2	Total	Fixed K	B.E.C. Calculated	B.E.C. Observed
Queens Loam	A_2	3.43	0.57	1.94	0.07	0.04	2.05	0.29	0.18	0.18
	B_2	3.39	0.61	1.89	0.09	0.09	2.07	0.27	0.19	0.21
	B_3	3.47	0.53	1.89	0.09	0.03	2.01	0.36	0.17	0.19
	C_1	3.50	0.50	1.88	0.09	0.04	2.01	0.36	0.15	0.16
	C_2	3.46	0.54	1.91	0.09	0.03	2.03	0.36	0.13	0.14
Queens Clay Loam	A_2	3.75	0.25	1.89	0.01	0.05	1.95	0.30	0.17	0.18
	B_2	3.11	0.89	2.02	0.07	0.09	2.18	0.28	0.16	0.19
	B_3	3.13	0.87	2.06	0.05	0.04	2.15	0.29	0.16	0.18
	C_1	3.11	0.89	2.08	0.03	0.06	2.17	0.31	0.14	0.15
	C_2	3.12	0.88	2.09	0.01	0.05	2.15	0.34	0.13	0.14

Note - The formula for the Queens loam A_2 clay fraction can be expressed from the above figures as

$$\underbrace{\underbrace{\left[Al_{1.94}\,Fe_{.07}\,Mg_{.04}\right]}_{+.11}\underbrace{\left[Al_{.57}Si_{3.43}\right]}_{-.57}}_{-.46}O_{10}(OH)_2\cdot\underbrace{K_{.29}\ x\ .18}_{+.47}$$

exchange capacity which is accompanied by an increase in potassium content with depth, indicating the effects of weathering in the upper horizons.

VI SUMMARY

(a) Minerals of the Sand Fraction

The minerals of the sand fractions of the various horizons of both soils were separated by mechanical analysis into three size fractions: 2.0 - 0.25 mm, 0.25 - 0.10 mm, and 0.10 - 0.05 mm. Each size fraction was further separated into three specific gravity fractions: > 2.95, heavy mineral group, 2.70 - 2.95, mica group, and < 2.70, quartz-feldspar group.

A number of methods were investigated for their efficiency in removing iron and aluminum oxide stains, and their effects on the individual mineral grains. The methods that were effective in removing the stains gave evidence on microscope examination of reducing appreciably the size of the mineral grains, in some cases as much as 20 percent. The method adopted, a 10 minute treatment with boiling (1+ 1) HCl, was found to have little effect on size reduction of the minerals of these soils and resulted in efficient cleaning of the mineral grains.

Standard petrographic methods were used to identify the minerals present in these soils. The feldspars were differentiated by chemical staining methods, whereby the potash feldspars were stained yellow, the calcic feldspars exhibited varying shades of purple, with quartz and micas giving no indication of staining.

The following minerals were found to be present in the sand fractions of these soils; (1) heavy mineral group - zircon, hornblende, epidote, tourmaline, garnet, apatite, magnetite, hematite, limonite and goethite; (2) mica group - muscovite, and a micaceous mineral identified as an aggregate of weathered biotite, talc and hematite; (3) quartz-feldspar group - quartz and orthoclase.

An arrangement of the minerals in their order of resistance to weathering processes and their order of importance for correlation studies is proposed. The amounts of each mineral found are presented in histograms, the height of the columns representing percent by weight of whole soil and the horizontal axis representing the minerals in order of resistance to weathering processes as follows: (1) heavy minerals - zircon, tourmaline, epidote, hornblende, garnet, apatite, and opaque minerals; (2) light minerals - quartz, muscovite, orthoclase, and micaceous mineral.

Mineral counts are presented for only the 0.10 - 0.05 mm sand fraction because they were found to be more representative, and contained the same minerals as the other size fractions of the sand (2.0 - 0.25 mm and 0.25 - 0.10 mm), therefore, provided no additional information other than confirmation of the data presented.

The minerals of the sand fraction are shown to be similar within and between the two soil types, indicating a common parent material, and similar soil development. The loam soil shows a slight increase in the amounts of the resistant minerals over the clay loam indicating that the loam soil has been subjected to more severe weathering. A decrease in amounts, with depth, of the relatively stable minerals of these soils indicates that weathering has proceeded to some extent, but with decreasing intensity with greater depth.

The mineralogical nature of the sand fraction of the sola of these soils is similar to that of the parent material which inturn is inherited from the Salisbury geological formations. A detailed study of the minerals of the sandstone of these geological formations showed the same minerals to be present as identified in the soil. The minerals of the coarse skeleton of these soils (red and grey sandstones) were identified as quartz cemented with hematite for the red sandstone, and quartz and weathered biotite (almost a chlorite) cemented with silica for the grey sandstone.

The noticeable increase in amounts of the minerals of the sand fraction in the A_2 horizons over the lower horizons is considered to be the result of sheet erosion while the soil was without benefit of a protective plant cover immediately following the Pleistocene ice epoch. The lack of evidence of accumulation of fines in any part of the profiles seems to eliminate the possibility of the downward movement of this material, the drainage being such that it would not be translocated completely out of the profiles.

A study of the mineral constituents of a soil provides an exceedingly useful tool in the establishment of soil parent materials and their relationship to the geological formations from which the soils were derived. It provides valuable information concerning profile development or stage of weathering. Certain minerals decompose differently under different weathering conditions and, by the variations in their amounts throughout the profile, provide a qualitative clue to intensity of profile development. Common hornblende and apatite are examples - the presence of micas and feldspars is good evidence of relative immaturity.

The mineral constituents of a soil and the rate of weathering provide valuable information on certain essential plant element reserves, which control the reaction of the soil to applications of these essential plant elements. Information on the minerals that release the essential plant elements to the soil, especially phosphorus and potash, is of particular value in agronomic research and should be included in the inventory prepared in Soil Survey Reports.

This study provides information that corroborates the original presumptions of the surveyors that classified these soils as textural variants of the same soil series. It shows that the soils have undergone similar development on like parent materials which were derived almost exclusively from the Salisbury geological formations.

Furthermore, the presence of common (green) hornblende and apatite in relatively large amounts in the heavy mineral fraction, and orthoclase in the light mineral fraction provides evidence that the soils are relatively young geologically.

(b) Minerals of the Clay Fraction

The clay fractions were separated from the various horizons of both soils by mechanical methods. They were further separated into two size fractions, 0.002 - 0.001 mm and <0.001 mm by running the samples through the Sharples supercentrifuge. The clay fraction of <0.001 mm effective diameter was used in the identification of the clay minerals of these soils.

The oxides of iron and aluminum were removed by the sodium hydrosulfite method (66).

X-ray diffraction analysis, differential thermal analysis, electron microscope analysis, and detailed chemical analysis were used in identifying the clay minerals present in these soils.

X-ray analysis showed the clay minerals to be similar in all horizons of both soils, and to be composed of either (a) mainly illite with a small amount of mixed-layer mica, or (b) illite in different phases of weathering and hydration. The x-ray diagrams of the clay from the horizons of these soils showed an integral series of reflections between 9.8A and 13.8A, indicating hydration of the illite which probably accounts for the reflections at the angles greater than 9.8A. The spacings were not effected by the treatment with glycerol, which excludes the possibility of expanding 2:1 layer lattice clays.

Differential thermal analysis showed the presence of 2:1, and the absence of appreciable amounts of 1:1, layer lattice clay minerals. The differential thermal curves were similar for all horizons of both soils.

Electron micrographs showed the clay particles as thin tabular crystals with regular outlines tending towards 120° angles and irregular aggregates of very small crystals, indicating the presence of illite and mixed-layer mica. The ratio of illite to mixed-layer mica is considered to be approximately 10:1.

Chemical analysis show a marked similarity within and between both soils, indicating a uniformity of at least the major constituents of the clay minerals present.

The high K_2O content, and ethylene glycol retention values point to the presence of appreciable amounts of a mica-like clay mineral.

The results of all methods of analyses support the concept that the clay of both soils may be characterized as an illite type of clay mineral with a small amount of mixed-layer mica, and that kaolinite and montmorillonite-beidellite in appreciable amounts are absent. The results also indicate that the clay minerals in the horizons of each soil are similar, and that the loam soil shows greater effects from weathering than the clay loam soil. The A_2 horizons of both soils show greater effects from weathering than the horizons immediately below. Both soils show a decrease in the effects of weathering with depth.

The mineralogical nature of the clay fraction of the sola of both soils is very similar to that of the parent material and is inherited from the shales and mudstones of the Salisbury geological formation.

The data presented for the minerals of the sand and clay fractions of these soils show the two soils to be similar throughout the profile, to have like parent materials, and to have developed under very similar conditions. The Queens loam and Queens clay loam, therefore, may be considered properly classified as two textural variants of one soil series, and to have been derived almost exclusively from the underlying Salisbury geological formation.

VII CONCLUSIONS

1. The minerals of the sand and clay fractions of these two soils, the Queens series, were found to be similar throughout the profiles, in the parent materials and in the underlying Salisbury geological formations, indicating they were developed on similar parent material, derived from common geological formations and subjected to similar weathering and development processes since deposition. The soils, therefore, may be considered as two textural variants of the same soil series.
2. The arrangement of the minerals, occurring in the sand fractions of soils, in order of their importance with respect to resistance to weathering emphasizes the important similarities or differences within and between soils and facilitates comparisons for maturity studies.
3. The occurrence of appreciable amounts of unweathered, readily weatherable, minerals in the sand fractions (common hornblende, apatite and orthoclase) and the large amount of illite type of clay mineral in the clay fraction of these soils, in conjuction with the presence of similar minerals in the sandstone and illite in the shales and mudstone of the underlying Salisbury geological formations, indicates that these soils represent an early stage in the weathering sequence.
4. A 10 minute treatment with boiling (1+1) HCl effectively

removes the oxide stains from the minerals of the sand fraction of the Queens soils without noticeable effects as to size reduction of the individual grains.

5. Calcium feldspars are readily identified from potash feldspars by first etching the minerals by direct contact with HF then applying staining techniques employing the use of sodium cobaltinitrite which stains the potash feldspars yellow, and hematein, buffered at a pH of 4.8, which stains the calcic feldspars purple, the degree of purple color depending on the position in the isomorphic series.

6. The integral series of x-ray reflections between 9.8A and 13.8A is considered to be the result of weathering, accompanied by hydration, of the illite clay minerals of these soils.

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IX APPENDIX

APPENDIX A

Size Distribution Expressed as Percent by Weight of the Whole Soil

Series	Horizon	Gravel	Sand			Total	Silt	Clay	Texture
		2 mm	2-.25 mm	.25-.10 mm	.10-.05 mm	Sand	.05-.005 mm	<.005 mm	
Queens Loam	A_2	23.30	16.10	11.67	9.66	37.43	27.53	11.74	GL
	B_2	25.80	14.21	9.91	6.94	31.06	24.78	18.36	GCL
	B_3	31.70	13.68	8.68	6.33	28.69	22.20	17.41	GCL
	C_1	23.10	13.99	8.70	6.92	29.61	23.76	23.53	GCL-GC
	C_2	21.21	13.38	8.63	5.25	27.26	24.59	26.94	GC
Queens Clay Loam	A_2	11.88	14.51	9.98	8.38	32.87	41.42	13.83	L
	B_2	21.70	11.24	6.93	6.02	24.19	30.38	23.73	GCL
	B_3	21.09	9.24	6.18	5.73	21.15	29.12	28.64	GC
	C_1	19.67	6.15	4.71	4.72	15.58	29.24	35.51	C
	C_2	19.11	8.20	4.33	6.24	18.77	27.99	34.13	C

GL - Gravelly Loam GCL - Gravelly Clay Loam

GC - Gravelly Clay L - Loam C - Clay

APPENDIX B

Specific Gravity Separates Expressed as Percent by Weight of the Whole Soil 0.10 - 0.05 mm Sand Fraction

Soil Series	Horizon	>2.95	2.70-2.95	<2.70	Total
Queens	A_2	0.176	0.165	9.319	9.660
	B_2	0.064	0.112	6.764	6.940
	B_3	0.066	0.101	6.163	6.330
Loam	C_1	0.075	0.119	6.726	6.920
	C_2	0.058	0.091	5.101	5.250
Queens	A_2	0.136	0.141	8.103	8.380
	B_2	0.063	0.075	5.882	6.020
Clay	B_3	0.083	0.106	5.541	5.730
	C_1	0.074	0.104	4.542	4.720
Loam	C_2	0.105	0.146	5.989	6.240

APPENDIX C

Specific Gravity Separates Expressed as gms/cc of the Whole Soil 0.10-0.05 mm Sand Fraction

Soil Series	Horizon	> 2.95	2.70-2.95	< 2.70
Queens Loam	A_2	.0022	.0021	.1187
	B_2	.0008	.0014	.0818
	B_3	.0011	.0017	.1022
	C_1	.0013	.0021	.1186
	C_2	.0010	.0016	.0894
Queens Clay Loam	A_2	.0015	.0015	.0880
	B_2	.0007	.0008	.0645
	B_3	.0012	.0016	.0822
	C_1	.0013	.0018	.0779
	C_2	.0018	.0025	.1017

APPENDIX D

Mineral Proportions of Specific Gravity Separates in 0.10-0.05 Sand Fraction (Expressed as Numerical Percentage of Total Grains Present in Each Separate)

Soil		Specific Gravity > 2.95							Specific Gravity 2.70-2.95		Specific Gravity < 2.70	
Series	Horizon	Opaque Minerals	Horn-blende	Tour-maline	Epidote	Zircon	Garnet	Apatite	Micaceous Mineral	Muscovite	Orthoclase	Quartz
	A_2	48.01	1.26	1.02	43.86	5.58	0.14	0.13	99.84	0.16	0.33	99.67
Queens	B_2	45.84	1.41	1.10	49.01	2.24	0.20	0.20	99.80	0.20	0.40	99.60
	B_3	49.28	1.62	1.32	44.77	2.60	0.23	0.18	99.76	0.24	0.25	99.75
Loam	C_1	55.52	2.92	1.59	38.32	1.17	0.25	0.23	99.74	0.26	0.21	99.79
	C_2	60.83	3.98	1.98	31.59	1.12	0.28	0.22	99.74	0.26	0.18	99.82
Queens	A_2	48.61	1.16	0.82	43.80	5.42	0.10	0.09	99.89	0.11	0.29	99.71
	B_2	45.44	1.16	1.00	49.21	2.31	0.23	0.20	99.86	0.14	0.32	99.68
Clay	B_3	49.78	1.12	1.30	44.81	2.62	0.21	0.16	99.82	0.18	0.20	99.80
	C_1	55.73	3.72	1.69	37.20	1.17	0.27	0.22	99.79	0.21	0.14	99.86
Loam	C_2	59.64	5.21	2.08	31.45	1.16	0.26	0.20	99.77	0.23	0.09	99.91

APPENDIX E

Mineral Percentages of 0.10-0.05 mm Sand Fraction

(Expressed as Percentage by Weight of Whole Soil)

Series	Horizon	Opaque Minerals	Horn-blende	Tour-maline	Epidote	Zircon	Garnet	Apatite	Micaceous Mineral	Muscovite	Orthoclase	Quartz
Queens Loam	A_2	.0830	.0021	.0018	.0768	.0096	.0002	.0002	.1647	.0003	.0298	9.2915
	B_2	.0303	.0009	.0007	.0324	.0015	.0001	.0001	.1155	.0002	.0270	6.7313
	B_3	.0315	.0011	.0009	.0286	.0016	.0002	.0001	.1032	.0002	.0144	6.1491
	C_1	.0408	.0022	.0012	.0281	.0009	.0002	.0002	.1187	.0003	.0141	6.7133
	C_2	.0349	.0024	.0012	.0182	.0006	.0002	.0001	.0911	.0002	.0093	5.0918
Queens Clay Loam	A_2	.0671	.0016	.0011	.0604	.0085	.0001	.0001	.1388	.0002	.0235	8.0786
	B_2	.0291	.0010	.0006	.0315	.0015	.0002	.0001	.0729	.0001	.0188	5.8642
	B_3	.0403	.0009	.0011	.0363	.0021	.0002	.0001	.1098	.0002	.0111	5.5279
	C_1	.0434	.0028	.0013	.0283	.0009	.0002	.0002	.0998	.0002	.0064	4.5365
	C_2	.0633	.0055	.0022	.0333	.0012	.0003	.0002	.1467	.0003	.0054	5.9816