# CHARACTERISTICS OF A TOPOSEQUENCE OF SOILS, THE CARIBOU CATENA, IN THE PODZOL REGION OF EASTERN CANADA

Thesis for the Degree of Ph. D.

MICHIGAN STATE COLLEGE

Reuben Edward Wicklund

1955

This is to certify that the

thesis entitled

Characteristics of a Toposequence of Soils,
the Caribou Catena, in the Podzol Region
of Eastern Canada

presented by

Reuben Wicklund

has been accepted towards fulfillment
of the requirements for

Doctor's degree in Philosophy

R L Cook
Major professor

Date May 13, 1955

O-169

# CHARACTERISTICS OF A TOPOSEQUENCE OF SOILS, THE CARIBOU CATENA, IN THE PODZOL REGION OF EASTERN CANADA.

By

Reuben Edward Wicklund

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Soil Science

Year 1955

Approved ________________________________________

## ABSTRACT

Investigations of Podzol development in the regions of Eastern Canada reveal that those soils possess porfile characteristics that differ in many respects from Podzol soils reported elsewhere. This study presents the physical and chemical characteristics of soils occurring on a given slope and evaluates the factor of topography in their development.

Four soil profiles were selected to represent the variations in this toposequence. Core samples were taken of the various horizons in the several profiles from which was obtained data on percolation rates and bulk densities. Bulk samples of each horizon were used for other physical and chemical analyses.

The $A_0$ horizon was present in all profiles and increased markedly in thickness with decreasing slope. The $A_2$ horizon that occurred in the well drained positions was replaced at the base of the slope by an $A_1$ horizon. The overall depth of profiles decreased with decreasing percent of slope.

In order to estimate net gains and losses within the profiles a modification of the resistant mineral method used by Marshall and Haseman was applied. This study used total silica, instead of zircon as the resistant reference mineral.

Results showed that there had been a net gain in

weight in the sola of all profiles and that the $A_2$ was the only horizon having a net loss of materials in these soils. Large volume changes had occurred in the $A_0$, $A_1$, and $B_{21}$ horizons as a result of frost action, organic activity, and organic matter addition. Even the $A_2$, $B_{22}$, $B_3$, and G horizons had increased considerably in volume.

Marked increases in silt had occurred in all horizons of all profiles, whereas net losses in clay had taken place in all the horizons of the zonal soils. The soil in the poorly drained position showed a net gain in clay.

All the profiles were acid in reaction. The acidity decreased from the surface of the soil to the parent material and decreased with decreasing slope.

The profiles showed marked gains in organic matter content particularly in the $A_0$, $A_1$ and B horizons. Increases had occurred in all horizons of all profiles except the $A_2$ of the best drained soil. Aluminum had accumulated in all horizons except the $A_2$ and was distributed relatively evenly throughout the profile. All the zonal soils showed a small net gain in iron but without having any definite horizon of accumulation.

The exchangeable cations calcium, magnesium, and potassium, were largely concentrated in the surface horizons. The predominant cation was calcium. The exchangeable base status of the soil increased from the crest to the toe of the slope.

# CHARACTERISTICS OF A TOPOSEQUENCE OF SOILS, THE CARIBOU CATENA, IN THE PODZOL REGION OF EASTERN CANADA

By

Reuben Edward Wicklund

A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Soil Science

Year 1955

Approved ______________________________

# ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Dr. L. M. Turk, Dr. R. L. Cook and Dr. S. G. Bergquist for the inspiring professional instruction received from them in their respective fields.

Acknowledgement is especially due to Dr. E. P. Whiteside under whose direction this work was undertaken and who has at all times very kindly given inspiration and assistance.

The writer deeply appreciates the financial support of the Canadian Department of Agriculture which made it possible for him to carry on this study during the course of his regular duties.

The author also extends his appreciation to his wife who has given her good share of encouragement and support to him during his graduate study.

# BIOGRAPHY

Born: August 3, 1905. Mutrie, Saskatchewan.

Undergraduate studies: University of Manitoba, 1930-1935.

Graduate studies: University of Minnesota, 1939-1940.

Michigan State College, 1950-1955.

Experience: Graduate Assistant, University of Manitoba, 1936-1940. Soil Specialist and Instructor in Soils, Nova Scotia Agricultural College, 1941-1946. Officer in charge, Soil Surveys, University of New Brunswick, 1947-1952. Senior Pedologist, Ontario Agricultural College, 1952- .

Member of the Agricultural Institute of Canada.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

## LIST OF FIGURES

FIGURE

LIST OF TABLES

# 1. INTRODUCTION

Much study has been undertaken to determine the relationships between soil properties and differences in environment. In such studies it is necessary to control the conditions of an experiment in such a way that only one variable exists [75]. The groups of environmental factors which govern the conditions under which profile development takes place are topography, organisms and climate. In addition the factor of age and the variables of parent material must be similar in such an experiment.

The purpose of the present investigation was two-fold: first to determine the physical and chemical characteristics of some Eastern Canadian Podzols, and second to ascertain whether a quantitative relationship exists between the position on a slope of the land surface or topography as a group of soil development factors, and certain profile characters of the soils.

The characteristics of Podzol soils commonly described have emphasized certain features, as the removal and deposition of sesquioxides, as an essential process in the development of Podzols. In addition many analytical data have shown the accumulation of colloidal inorganic material in the B horizon. In the United States Department of Agriculture Yearbook (Soils and Men, 1938) it is stated that Podzols occur most frequently on coarse textured materials. Although the present study does not deal with very fine textured materials, the soils studied lie in a region where Podzols commonly develop on parent materials containing thirty-five to forty percent of clay.

In the comprehensive literature that has accumulated on Podzol soils, none of the references present data which are in accord with the characteristics of the Podzol soils occurring in the Maritime regions of Eastern Canada.

The hydromorphic soils of the greater parts of New Brunswick and Nova Scotia are characterized by a thick gray $A_2$ horizon which shows up prominently following cultivation. This feature occurs on all varieties and textures of parent materials, being particularly pronounced on clay loam material. The patterns of colors for cultivated fields are brown and gray with brown colors being characteristic of the better drained positions.

In the Caribou catena of soils the color pattern of cultivated soils is brown and black, in which the hydromorphic positions are black. The well drained soils possess a continuous bleached horizon typical of Podzol soils and all other characteristics appear identical with the better drained soils found in the other parts of the province. The Caribou soils occur in an area underlain by calcareous sedimentary rocks. Some connection therefore between the lime status of the parent rock and the absence of gray hydromorphic soils typical for most of the Maritime provinces might become evident on analysis.

## 2. LITERATURE REVIEW

The Podzols as a group have received a great deal of attention. From the earliest days of Soil Science the processes leading to their development have been studied extensively in Europe as well as in North America. Among the early studies, Aarnio[1] in Finland and Tamm[80] in Sweden conducted both field and laboratory research and on the basis of their work the Podzols were divided into what was called Humus Podzols and Iron Podzols.

These terms are still in use but in much of the subsequent work it has apparently been impossible to differentiate the soils of a particular region on that basis.

General as well as specific descriptions of Podzol profiles occurring in the literature agree on certain broad characteristics but differ considerably in many of the details. In the United States Department of Agriculture Yearbook, 1938, Byers et al[13] considered the process of podzolization to be comprised of two phases, namely, the accumulation of a peaty mat of organic matter on the surface and the eluviation of clays and iron compounds from an upper layer to lower layers with consequent whitening of the soil layer immediately beneath the surface organic matter. The translocated materialsare partly assorted and different ingredients are deposited in different horizons of the profile. The movement and deposition of organic matter together with a considerable quantity of iron and aluminum compounds takes place just below the bleached layer. The iron compounds are deposited next, while clays are carried still deeper by the filtering waters.

The number and arrangement of horizons of the Podzol profile consist of an upper horizon, frequently designated as the mor and commonly called $A_0$. Below this comes the top layer of mineral soil. In many cases this mineral horizon is dark in colour and is then designated as $A_1$. In most cases this horizon is absent. 50. pp. 63. On the other hand Nygard et al[62] stated that in the Podzol region of Minnesota a thin $A_1$ was present in most Podzols. In the state of New York Cline[20] indicated that the $A_1$ was absent in the well drained and moderately well drained positions but appeared in the imperfectly drained and more poorly drained positions where it may have a thickness of 3 to 6 inches. A similar observation was made by Lyford[48] for the Podzols of north eastern United States. He stated that in this area the $A_1$ horizon was rare on well drained Podzols but more common on Podzols that showed the effects of periodic or high water tables. In the soils of New Jersey, Joffe[36] showed the Podzol soils to possess an $A_1$ horizon having a depth range from 12 to 21 centimeters with an average of about 14 centimeters. However on the basis of their chemical attributes he did not consider them to be true Podzols. The Podzols occuring in Eastern

Canada are typically represented as having no $A_1$ horizon (14, 42, 84).

Below the $A_1$ or $A_0$ Comes the light coloured bleached layer or $A_2$, frequently referred to as the "bleicherde". Since this horizon is one of the most prominent horizons in the profile, its presence or absence and its degree of development is of prime importance in the classification of podzolic soils. Agreement is general that the $A_2$ horizon is present in Podzol soils and that the boundaries between it and the adjoining layers are usually sharp. This horizon varies considerable in thickness. According to Lyford[49] the $A_2$ varied from 2 to 5 inches thick. A description by Lundblad[45] showed a typical Iron Podzol in Sweden to have an $A_2$ with 7 centimeter thickness. In England however Davies and Owen[22] described a Podzol profile at Goldstone, Newport, Shropshire, as having an $A_2$ of 11 inches. In Eastern Canada, Stobbe and Leahey[79] stated that the thickness varied from one to twelve inches. McCool et al[57] in studies on soil profiles in Michigan gave a range in thickness of 3 to 24 inches.

The chemical characteristics of the $A_2$ horizon indicate that it has been subjected to acid weathering in most cases, and that there has been a considerable removal of organic matter and sesquioxides accompanied by a relative increase in silica. Its high degree of unsaturation and low base exchange capacity as compared with the $A_1$ horizon is typical for most Podzols (33 p. 265).

The B horizons of the Podzol have been designated in various ways. Marbut (50 p. 66) referred to the B as an "orterde" if not cemented. The early literature contains many references in which the first horizon occuring below the $A_2$ is referred to as the $B_1$ which in turn is followed by a $B_2$ and at times a $B_3$ horizon. All are horizons of accumulation and in many cases the $B_1$ contains the maximum accumulation of transported material. As defined at the present time this horizon is now designated as $B_{21}$ (78). The illuvial nature of this horizon is stressed by all soil workers. Russell (70 p. 518) stated that this horizon is enriched with organic matter, clay, and iron and aluminum hydroxides. He stated further that the zone of their maximum accumulation was often at its top. In addition to these materials some silica removed from the $A_2$ horizon may be deposited in the B horizon. This process is mentioned by Marbut[50] who quoted results obtained by Tamm in which a considerable amount of silica was removed in the formation of the gray horizon. The removal of substances from the upper horizons and their subsequent deposition in the B horizons was pointed out further by Mattson[53], Joffe[40], Lunt[47] and others.

In this connection the researches of Aarnio[1] as reported by Marbut (50 p. 78) are significant. It was demonstrated by laboratory methods that sols of different kinds of organic matter differed considerably in their protective and precipitating influences on collodial iron hydroxide and aluminum hydroxide. The weight relationships between organic matter and the inorganic colloids necessary for mutual flocculation varied considerably. It was shown that a given weight of aluminum hydroxide prepared by the method used by Aarnio, was precipated with a much greater weight of organic matter than was precipitated with iron hydroxide. It was concluded that the B horizon in soils with a very high percentage of acid organic matter contained under some conditions. a low percentage of iron but a relatively high percentage of alumina if there was alumina available. The concentration of the organic matter in the soil solution will be too high to permit the precipitation of iron. This process suggests the controlling factor in the development of the Humus Podzol on the one hand and the Iron Podzol on the other. Aarnio in the same experiment determined the precipitating effect produced by various electrolytes and it was concluded that Humus Podzols developed in regions where the sol contained a high percentage of organic matter and a low percentage of electrolytes. The Iron Podzols developed in soils where

the percentage of organic matter was relatively low and that of electrolytes high.

A result somewhat contrary to that of Aarnio has more recently been obtained by Deb[23]. His investigations showed that the ratio of humus to iron was much smaller than that obtained by Aarnio. His conclusions with respect to the effect of electrolytes and divalent bases were also at variance with many commonly accepted views. He stated that no evidence could be found to support the view that precipitation of iron from humus-protected sols was effected by exchangeable calcium in the B horizons of Podzols or that the adsorption of iron from complex salts of organic acids was influenced by the pH or amounts of exchangeable bases present in the soil. It was suggested that possibly the process governing the precipitation was of a microbiological rather than a collodial or chemical nature.

The occurrence of strictly Humus Podzols in a given region is emphasized principally in European literature. In the New England region of the United States, Lunt[47] stated that when the data for the silica sesquioxide ratio are compared with similar data reported elsewhere it appears that the strongly podzolized soils of New England would be classified as iron-humus profiles, for both iron and organic matter are low in the $A_2$ and high in the B.

Clay is one of the materials which accumulates in the B horizon. It has not yet been proven whether it is a transported product or if it has been formed in place. Richard and Chandler[69] indicated in their analysis of a well developed Podzol in the eastern part of the province of Quebec that the clay content of the upper part of the B horizon was higher than that of the $A_2$ and the lower part of the B. A review of data from Cann et al[14] shows that the $A_2$ horizons rather than the B horizons have the highest clay content. Data from other parts of Eastern Canada indicate that clay does not accumulate to any appreciable extent in the B horizons. In the Podzol profile described by Nygard et al[62] there was a marked accumulation of clay in the $B_{21}$ horizon. On the other hand Byers et al[13] stated that clays are moved from an upper layer to a layer below the one containing the concentration of organic matter and of iron. Data with regard to the fate of the clay fraction in the Podzol profile are lacking, although the statement is general that the removal and precipitation of this constituent is characteristic of podzolic soils.

The influence of relief of the land surface in soil formation is generally accepted as a major factor. This influence is expressed primarily by the effect of drainage, runoff and erosion and secondarily through variations in exposure to the sun and wind and in air drainage (78), Because of runoff, strongly sloping soils take in less water than do level soils and those in depressions receive water from surrounding slopes in addition to the rainfall.

It is recognized in all soil survey work that in an area of variable relief a certain sequence of soils will be found varying with the external and internal drainages of the soil and acting independently of other soil forming factors such as parent material or vegetation. Such a sequence of soils in which topography was the only genetic variable has been designated by Jeuny[32] as a toposequence. These sequences can be expected to differ in different regions accompanying the broader changes that take place in soil development. The same variations in sequences may be expected as those which occur in the normal profiles described for different regions. As indicated in the literature the variations in the normal profiles described for the Podzol soils vary considerably from one region to another. The associated imperfectly drained and poorly drained soils are seldom described.

Recently Cline[19] described the catenary relationship of the Podzol soils occurring in the State of New York. He indicated that the dominant yellowish-brown colours of the Podzol B horizon carry through the well, moderately well and imperfectly drained members. In the poorly drained positions the $A_0$ horizon of the better drained members was replaced by 3 to 6 inches of $A_1$ with gleyed horizons occurring immediately below. This sequence of horizons in poorly drained positions is not characteristic of the majority of soils occuring in the Eastern Canadian Podzol zone. In the latter the $A_0$ horizon is not replaced by an $A_1$ and the same sequence of horizons have developed as occur in the better drained positions. In the regions where the Caribou soils occur and in which the present study was carried out, the catenary relationships of the soils were more nearly like those described by Cline.

Some of the most complete studies carried out on a catenary basis are those reported by Mattson[53,54,55] and other Swedish workers[8,43]. The physical and chemical characteristics of the soils described showed a considerable range from the dry end to the wet end of the catena.

In southern Illinois, Norton and Smith[61] reported on the influence of topography on the profile character of certain mature podzolic soils. In this region the depth to the zone of clay accumulation decreased as the slope and drainage increased. Certain changes in texture, consistency and structure also coincided with changes in topographic position.

A different condition was reported by Lag[41] in Norway. In the Podzol soils of that region the $A_2$ horizon frequently extended to a depth of 60 centimeters. This layer however does not decrease with increasing grade. The effect of micro-relief was also evident in that the thickness of the $A_2$ horizon increased toward the depressions in the soil surface and decreased toward the slight elevations. Similar observations have been noted in the Podzol zone of Eastern Canada (84).

# 3. EXPERIMENTAL STUDIES

## 3.11 Location

The area selected for this study was located in the north western part of the province of New Brunswick, at a latitude of 47° 30' and longtitude 67° 30'. The site chosen was adjacent to the Stewart highway which runs diagonally across the north western part of the province joining the towns of St. Leonard and Campbellton.

## 3.12 Vegetation

This area is a rolling till plain covered by virgin and second growth stands of timber. In general the forest vegetation consists of mixed stands of hard-woods and softwoods (31) with a tendency for the various species to be segregated according to slope and drainage. Most frequently the pure hardwood growth occurs on the hilltops and upper slopes, a mixed growth of hardwoods and softwoods on the middle slopes and the pure softwoods on the lower slopes and in the valley bottoms (59).

In the well drained positions the predominant coniferous species are Picea rubra, Picea glauca, Abies balsamea and Pinus strobus. Picea mariana and Thuja occidentalis are to be found in imperfectly and poorly drained positions. The broad leaved tree species consist of Betula lutea, Betula papyrifera, Acer saccharum,

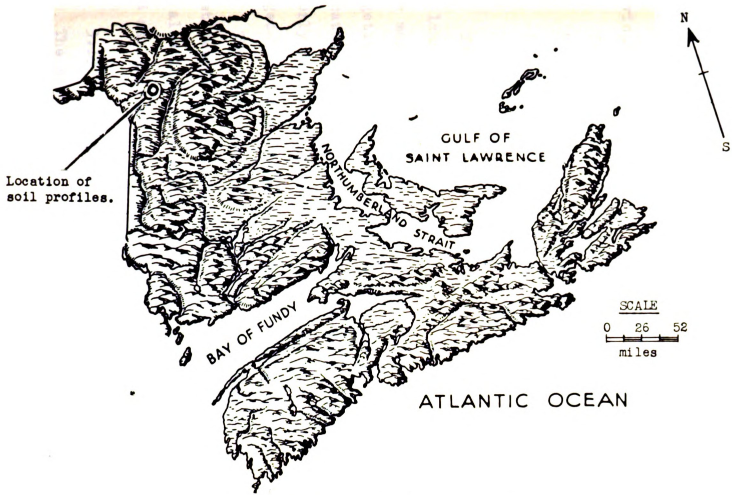


Fig. 1 Showing physiographic features of the Maritime Provinces and location of soil profiles.

*Fagus grandifolia* and *Populus tremuloides*. The Sugar Maple (Acer saccharum) occurs in pure stands in this region and also in association with Yellow birch (*Betula lutea*) and Beech (*Fagus grandifolia*). In a forest land classification (59) the area has been subdivided as follows:

| | |
|---|---|
| Softwood type | - 26.79% of the total area |
| Mixed wood type | - 46.01% of the total area |
| Hardwood type | - 10.88% of the total area |
| Non forested | - 16.32% of the total area |

In choosing a site for this study an attempt was made to locate pure stands of Sugar Maple since they offered the most satisfactory locations in which the factor of vegetation could be maintained as a constant. In all locations however, Black Spruce and Cedar occur in the poorly drained positions and therefore a variation in vegetation is unavoidable in these positions (See Figure 2).

The Sugar Maple stands are an open type of vegetation that permit the development of a ground vegetation that is also light demanding. It consists of woody shrubs and saplings of Sugar Maple and Beech.

### 3.13 Geology and Physiography

The northwestern portion of New Brunswick lies in the Appalachian region, sometimes called the Appalachian-Acadian region of Canada, and belongs to a larger unit

Figure 2. Showing vegetation, looking down the slope at the sampling site.

Figure 3. Showing vegetation looking up the slope at the sampling site.

usually referred to as the Appalachian Highlands or the Appalachian Mountain system which stretches from Alabama, U. S. A., in the southwest to Newfoundland in the northeast, a distance of 2000 miles (29).

This larger region, marked throughout by Palaeozoic deformation, is divisible into a number of physiographic provinces that show similar surface characteristics within themselves. In New Brunswick the Appalachian region is the northeast continuation of the New England Physiographic province. This region as a whole is an upland dissected by valleys and broken by broader lowland areas developed on belts of weak rocks.

The region has been classified as Pre-Carboniferous and may contain sediments belonging to the Devonian, Silurian or Ordovician. It stands at an elevation of 800 to 1000 feet above sea level and is developed on folded Palaeozoic strata (3). Its most striking feature is the flat topped character of its surface which is broken only by the valleys such as those of the Restigouche and its tributaries which are deeply entrenched in it. The folded rocks consist of calcarious or lime containing shales and slates that run from northeast to southwest (Figure 1) in the same general direction as the mountains of the rest of eastern North America.

The surface features of the region were modified by the ice age of the Pleistocene period. The till deposits which cover the entire surface are generally shallow and may have only slightly modified the general relief. In this region glacial erosion is so slight that the terrain has been considered by more than one geologist to have escaped glaciation (25). However it was glaciated and probably repeatedly. The till material is exclusively of local origin and appears to be very uniform in composition.

### 3.14 Climate

This region, although considered as part of the Maritime section of Canada, has a strongly continental climate with considerable variation in seasonal temperatures. January is generally the coldest month and July the warmest. The mean annual temperature for the month of January is 5°F. and for July 62°F. The mean annual temperature is 34°F. The average length of frost free period is 90 days. The mean annual precipitation is 35 inches and mean annual snowfall 110 inches. As a rule ten inches of snow is counted as the equivalent of one inch of rain, therefore in northern New Brunswick, over 30% of the precipitation falls as snow.

The climatic conditions occurring in this area compare favourably with conditions assumed by scientific workers as characterizing the podzol regions. Thus Joffe 39, p. 241) stated that according to Glinka the climatic conditions of the podzol zone, when a wide range of meterological data are averaged include a yearly rainfall of 19" to 21", and a mean annual temperature of 38.5°F. The podzol zone is generally to be identified with the humid temperate climatic zone and as pointed out by Joffe[39] podzols are found in North America in sections where the rainfall runs up to 41 inches annually with a mean annual temperature as high as 50°F. Cline[19] on the other hand stated the climatic limits of Podzols to be as follows; growing season 85 to 145 days, mean annual temperature 35° to 45°F., mean annual precipitation 40 to 60 inches with a precipitation during the growing season of 17 to 22 inches. Mean annual temperature and precipitation are slightly lower in this section of New Brunswick than the limits cited by Cline.

### 3.2 Method of Sampling

An effort was made to choose locations on virgin soils for sampling and observations. The choice of a long slope seemed preferable since it tended to minimize any effects that might have been due to erosion. The location selected had a slope of fourteen percent with an overall length of one eighth of a mile.

Changes in the character of the soil were observed from the top to the bottom of the slope. Test pits were dug at sites which represented each major profile. Since the profile characteristics differ only very slightly in the well drained positions, test pits were widely spaced over the upper part of the slope and more closely spaced towards the bottom of the slope. Four test pits were used to represent major profile differences. Of these, one was located at the crest of the hill, the second about two thirds of the distance down the slope, the third quite near the base of the slope and the fourth in the depression at the foot of the slope. These locations will hereafter be referred to as Profile 1, 2, 3 and 4 respectively, as shown diagrammatically in Figure 4.

At each location excavations were made with a spade to a depth sufficient to penetrate well into the parent material. In addition one excavation was made in the well drained position to a depth of 5 feet. At that depth bed rock was encountered. Bulk samples were taken from each major horizon of each profile, from the parent material of each profile, and from the 5 foot depth in the one location.

A series of core samples were then obtained surrounding the test pit by means of a core sampler described by Uhland and O'Neal[81]. The cutting head of the sampler is designed to hold an aluminum cylinder 3 inches in diameter and 3 inches long or three cylinders, each one inch long. Both types of cylinders were used in

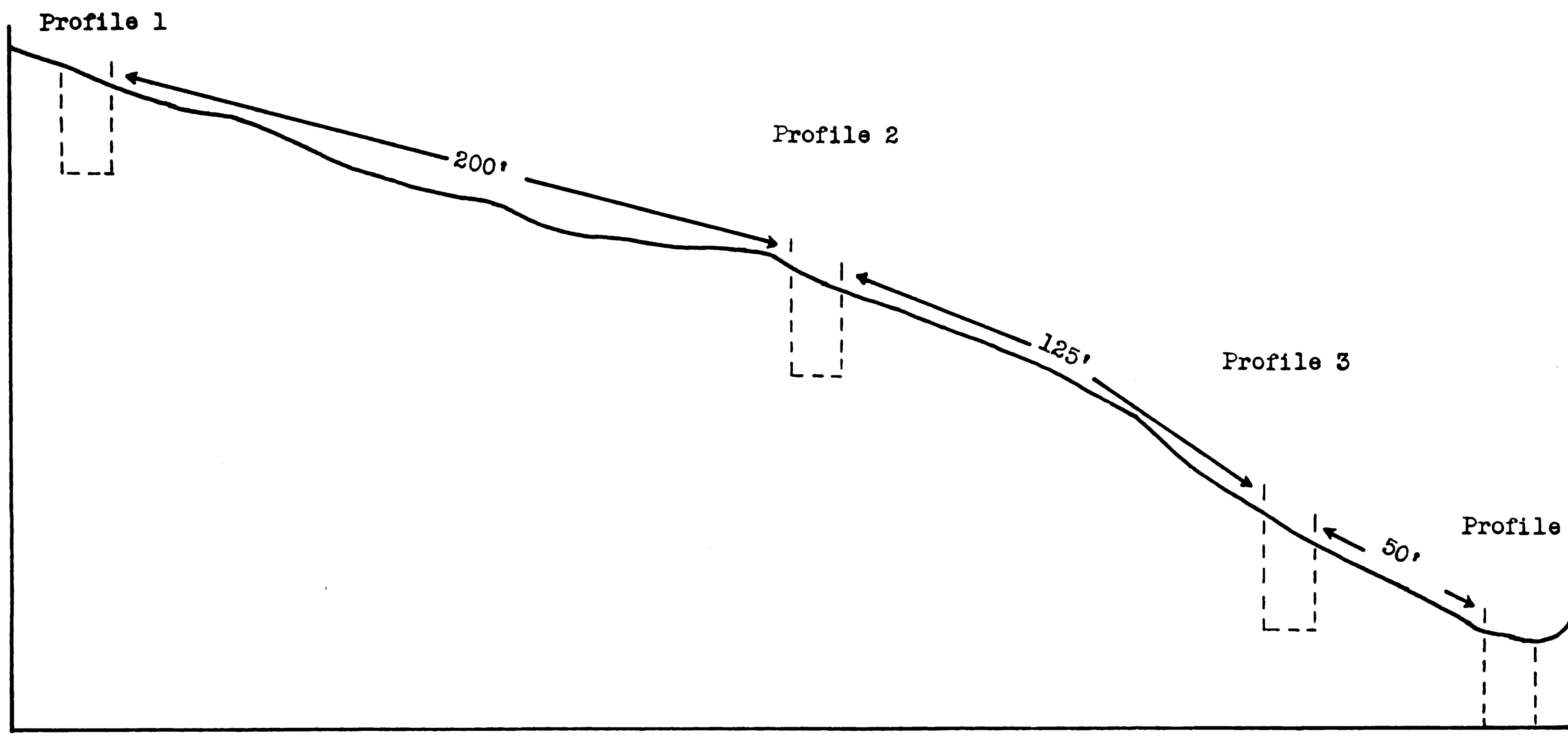


Fig. 4 Relative locations of profiles.

sampling the surface horizons. Considerable difficulty was encountered in sampling the parent materials and some of the lower horizons of the various profiles. The parent materials were quite compact and occasionally stony.

A total of ten core samples were obtained from each horizon of the profile at each of the four locations. As suggested by Uhland, a minimum horizontal interval of 8 inches was allowed between the cores taken from the same pit in order to prevent the outward impact of the sampler from compacting the soil of adjacent cores. A total of twenty pits were necessary for sampling at each profile location.

The core samples were placed in pint cartons and taken immediately to the laboratory for permeability studies and determination of bulk density.

### 3.3 Description of Soils

The following profile descriptions of the moist soil were taken at the time of sampling.

<u>Profile 1</u>

Aoo;-2-½ inches. This is the typical mor that is formed on the forest floor of well drained sites in this region. It consists of a loose layer of freshly fallen leaves and small twigs from the Sugar Maple, Beech and Yellow Birch.

Ao; -½-0 inches. A thin mat of moderately well decomposed organic material that contains a large amount of very fine roots which tend to hold the material together. The material retains some of its original structure and would probably be referred to as the 'F' layer by foresters.

$A_2$; o-2 inches. Yellowish grey *(10YR-7/2) silt loam. This horizon is not continuous. Its maximum thickness does not exceed two inches. The boundaries are sharp not only with the horizon above but also with that below. The structure is fine crumb with some tendency for greater development along the horizontal axis than along the vertical axis but a platy structure does not occur. It has a rather loose consistency.

$B_{21}$; 2-8 inches. Moderate brown (7.5YR-4/4) silt loam. The texture of this horizon is the same as that of the horizon above, being high in silt and relatively low in clay content. In colour this is the most distinctive horizon in the profile having a bright uniform colour that is produced under well drained conditions.

* ISCC-NBS colour names. Research Paper 1239, National Bureau of Standards, United States Department of Commerce, Washington, D.C.

The structure is fine crumb which again is similar to that of the horizon above. Consistency is very friable and the mass crumbles readily to loose aggregates. There are no particular physical features in this horizon which would characterize it as a horizon of illuviation. Lyford (45, p. 490) mentioned that this horizon may have a thin brownish black section just under the places where the bleicherde is thickest which he describes as a feature of the Humus Podzols. This is a characteristic feature of many of the soils in this region, but did not occur at this particular location.

$B_{22}$; 8-25 inches. Strong yellowish brown (10YR-5/6) loam. The silt content of this horizon is considerably less than that of the horizons above while the clay content of the two horizons are approximately equal. The colour is distinctly lighter than that of the horizon above and grades into that of the lighter coloured parent material below. The structure is coarse crumb and consistency is firm. This tendency to a stronger grade of structure increases with depth and continues into the parent material. The lack of a well defined structure is characteristic of the B horizons in this region. It is however the zone in which the finer tree roots are concentrated with possibly a larger number occurring in $B_{21}$ than in $B_{22}$.

C.; 25 inches plus. Light grayish olive (5Y-6/3) loam, containing some rounded cobblestones. The till material from which these soils are derived consists therefore of a heterogeneous mixture of coarse and fine materials. When dry it is very hard and very compact; moistening has a tendency to decrease the hardness but does not affect the degree of compaction. This characteristic of the parent material is common among the glacial tills of this region. The material is derived from rocks of sedimentary origin, presumably from the underlying calcareous shales and slates.

Profile 2

Aoo; -2½-1½ inches. A mat of relatively fresh leaves and twigs which contains a large number of small roots that tie the leaves together. No sharp boundary is present between this layer and the one below.

Ao; 1½-0 inches. This layer consists of well decomposed black organic matter, that is fluffy when moist and powdery when dry. It is synonymous with the H layer of the foresters.

A2; 0-1½ inches. Light grayish brown (7.5YR-6/2) silt loam. This is a discontinuous layer that shows variations in thickness within a radius of a few feet, the range being from 1 to 4 inches. The thickest portions are found directly beneath a decaying log or in a micro-depression. Boundaries are sharp between the horizon above and the horizon below. The structure is fine crumb and consistency is very friable. The results of chemical analyses indicate that the organic matter content is higher than is normal for this horizon, probably as a result of error in sampling. From a field examination there is no noticeable difference between this horizon and the $A_2$ horizon in profile 1.

$B_{21}$; 1½-5 inches. Moderate brown (5YR-3/4) silt loam. This is the most distinctive horizon in the profile and has a darker colour than the same horizon occurring in profile 1. The structure is fine crumb and consistency is loose or fluffy. This is the horizon in which most of the small tree roots are concentrated.

$B_{22}$; 5-9 inches. Strong yellowish brown (10YR-5/6) silt loam. Because of the difference in colour the boundary between this horizon and the one above is quite marked. The structure of the material is fine crumb and consistency loose. Colour is the only characteristic which differentiates the various parts of the B horizon.

$B_3$; 9-14 inches. Light olive brown (2.5Y-5/4) silt loam. This horizon has a colour intermediate between that of the $B_{22}$ and the parent material. The structure is coarse crumb and the consistency firm. Very few roots appear in this horizon. This is a subhorizon that did not occur in profile 1.

C. 14 inches plus. Light olive gray (5Y-6/2) silt loam. This material has the same characteristics as that described for Profile 1. It is hard and compact and contains many large shale fragments.

<u>Profile 3</u>

Aoo; 4-2 inches. This layer does not differ in any noticeable degree from that found to occur in profiles 1 and 2. The leaf material is relatively raw or undecomposed and small roots have developed throughout. Decomposition of leaf litter apparently is not completed for two or more years.

Ao; 2-0 inches. Black organic layer consisting of well decomposed material and developed into structural aggregates of 1 mm. size. The thickness of this horizon is variable and may attain a depth of 4 inches.

$A_1$; 0-2 inches. Brownish gray (10YR-3/1) silt loam. This dark mineral horizon gives rise to the dark coloured cultivated soils occurring in this topographic position. The thickness of the horizon varies and may be as much as 4 inches. This profile receives a greater amount of water through seepage and runoff than profiles 1 and 2 but no mottling is evident.

$B_2$; 2-7 inches. Moderate olive brown (2.5Y-4/4) silt loam. In comparison with profiles 1 and 2 the colour of this horizon is less pronounced and is strongly affected by the olive colour of the parent material. The structure is coarse crumb and consistency loose.

$B_3$; 7-11 inches. Light olive (5Y-5/3 silt loam. This horizon contains yellowish brown mottling throughout the soil mass. The structure is medium subangular blocky with a shiny coating on the surface of the structural aggregates. Consistency is hard or moderately compact but not as compact as the underlying parent material.

C.; 11 inches plus. Light grayish olive. (5Y-6/3) silt loam. This material is hard or very compact, a condition that seems to persist even when moisture content is high. Stone and shale fragments are plentiful.

Profile 4

Ao; 5-0 inches. This horizon consists of a mixture of raw and partially decomposed organic matter consisting of fallen logs, leaves and evergreen needles. The material occurs in layers about one inch in thickness which may represent yearly additions of organic debris. Fine tree roots are well distributed throughout the horizon.

$A_1g$; 0-3 inches. Olive gray (5Y-4/1) silt loam. The dark colour of this horizon indicates that some organic matter has filtered into the top of the inorganic material. Structure is coarse subangular blocky which retains its shape under moderate pressure. Yellowish brown mottling coats the aggregates as well as occurring within them. The designation as a gleyed horizon is done exclusively on the basis of the presence of yellowish brown mottling since colours normally associated with reduced conditions are masked by the original colour of the parent material.

G ; 3-10 inches. Light olive gray (5Y-5/2) silt loam. This horizon is more strongly mottled with yellowish brown stains than is the horizon above. Structure is not well defined but there is a tendency to the formation of weak medium subangular blocky aggregates. Consistency is hard or moderately compact.

C ; 10 inches plus. Light olive gray (5Y-6/2) loam. The parent material of this profile is very compact, and somewhat more stony than that of the other profiles. The permanent water table is apparently at some depth since this material dries out in the summer months and is only saturated during the wet season when a pit readily fills with water from channels in the till.

The principal characteristics of these four profiles are summarized in Figure 5. It will be seen that there was a marked tendency for the solum to become shallower

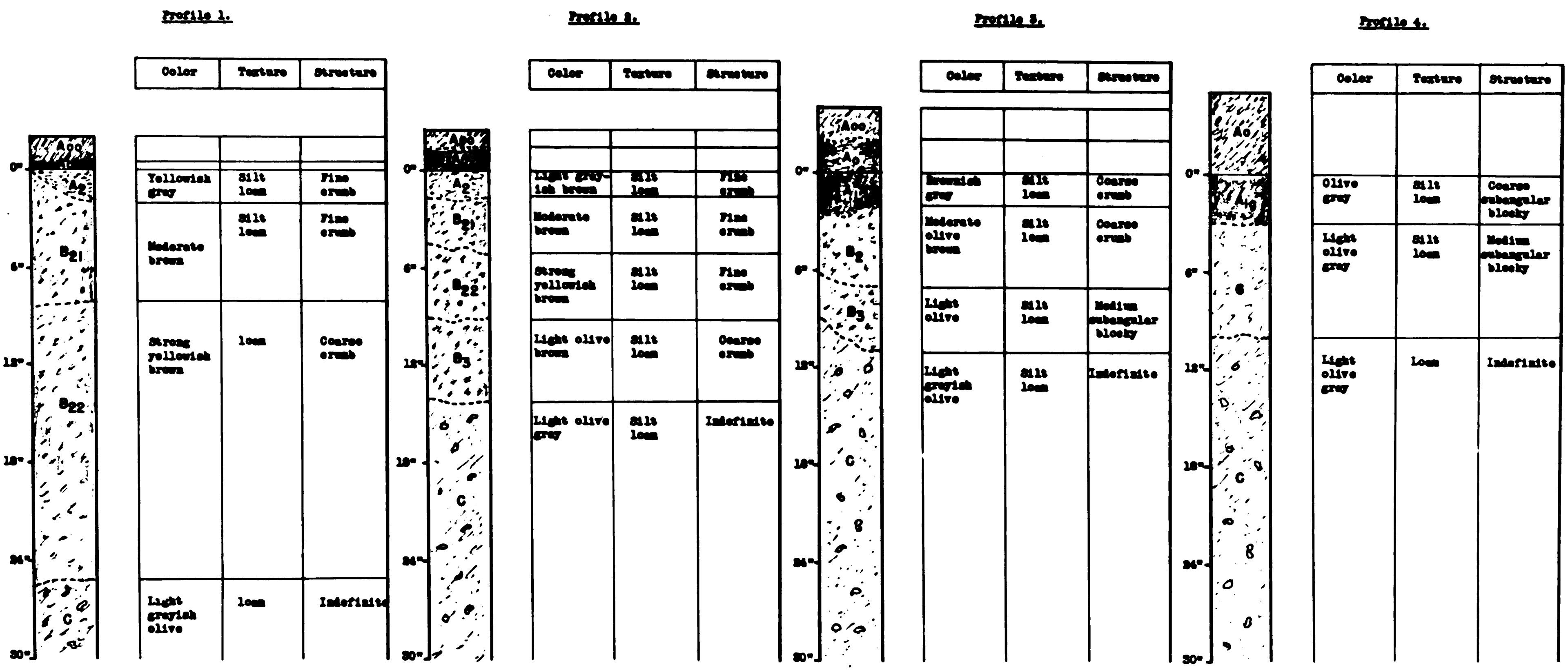


Fig. 5 Principal Characteristics of Profiles.

as on

the t

disap

an Aj

moist

It w

the

all

taken

were

as one approached the bottom of the slope, whereas the thickness of the organic horizons increased. The disappearance of the $A_2$ horizon and its replacement by an $A_1$ in profiles 3 and 4 indicate the effect that moisture has had on biological activity in this region. It will be shown later by chemical analyses data that the horizons of these profiles, designated as C are all acid in reaction. Some alteration has therefore taken place in the original parent materials since they were derived from calcareous sediments.

# 4. RESULTS AND DISCUSSION

## 4.1 Physical Properties

The variations found in soils are due to differences in their physical properties as well as in their chemical properties. Some of these physical properties such as colour and structure can be observed without the aid of instruments but some laboratory measurements are necessary for showing small differences which may be due to translocation of clay or volume changes within the profile.

### 4.11 Methods of analysis

The soil cores collected in the field were prepared for the determination of percolation rate as described by Uhland and O'Neal[81], with the exception that no determinations were made before the soils had been saturated with water.

An estimate of the volume of pores drained was obtained by placing the soil cores on a tension plate set at 60 cm. tension according to the method of Leamer and Shaw[48]. The soil cores were allowed to drain for 60 minutes after which they were dried in an electric oven at 105° Centigrade.

The bulk samples collected from the various horizons of each profile were air dried and screened through a 2 mm. sieve. These samples were used for all subsequent physical and chemical determinations.

Mechanical analyses were made in duplicate by the method of Olmstead et al[63].

Specific gravity of each sample was determined by means of a pycnometer. Porosities were calculated using the formula:

$$\text{Percent pore space} = 100 - \left(\frac{\text{Bulk density}}{\text{Specific gravity}}\right) 100.$$

4.12 Bulk Density and Specific Gravity

Bulk density determinations are used later for converting weight percentages into volume relationships. The values given in Table I are of interest as a basis for deductions to be made later in the discussion on chemical analysis.

The bulk densities varied according to the kind of horizon. The organic $A_0$ horizons had very low values and were the same for all profiles. The bleached $A_2$ horizons of profiles 1 and 2 had a higher bulk density than the horizons above and below. A less open type of structure and lower content of organic matter are both probably responsible for this tendency. In all profiles the bulk density increased sharply at the bottom of the solum and reached its maximum in the parent material.

The bulk density of the parent materials showed a progressive increase from profile 1 to profile 4. These

TABLE I

SUMMARY OF DATA ON BULK DENSITY AND SPECIFIC GRAVITY IN THE FOUR PROFILES

| Horizon | Bulk Density | Specific Gravity |
|---|---|---|
| **Profile 1** | | |
| $A_o$ | .14 | 1.06 |
| $A_2$ | .97 | 2.71 |
| $B_{21}$ | .76 | 2.49 |
| $B_{22}$ | 1.06 | 2.68 |
| C | 1.64 | 2.68 |
| Profile 2 | | |
| $A_o$ | .14 | 1.57 |
| $A_2$ | .99 | 2.48 |
| $B_{21}$ | .77 | 2.49 |
| $B_{22}$ | .86 | 2.56 |
| $B_{23}$ | 1.22 | 2.62 |
| C | 1.74 | 2.68 |

TABLE I (Continued)

| Horizon | Bulk Density | Specific Gravity |
|---|---|---|
| Profile 3 | | |
| $A_{oo}$ | .13 | 1.54 |
| $A_o$ | .17 | 1.68 |
| $A_1$ | .58 | 2.36 |
| $B_2$ | 1.13 | 2.60 |
| $B_3$ | 1.69 | 2.67 |
| C | 1.89 | 2.61 |
| Profile 4 | | |
| $A_o$ | .14 | 1.51 |
| $A_{1g}$ | .86 | 2.47 |
| G | 1.63 | 2.63 |
| C | 2.01 | 2.63 |

differences may be due to slight weathering and consequently losses of materials such as carbonates through leaching. The result is that in relation to topography the unweathered parent materials occurred at greater depths at the crest of the slope than they did at the foot.

In Figure 6 is shown the relation between loss on ignition, organic carbon and bulk density. When the data are treated statistically the correlation was -.877 ± .052 for carbon and -.673 ± .120 for loss on ignition. It is evident that it was the organic rather than the inorganic colloids that controlled the density of these soils.

The real specific gravities of soils vary with the kind and amount of minerals composing them and the amount of organic matter present. An average figure for the density of humus is 1.37 (7) and of mineral particles 2.65. All profiles with the exception of the $A_2$ horizon in profile 1 showed an increase in specific gravity from the surface horizon to the parent material.

### 4.13 Percolation Rate and Porosity

The rate at which water moved through the soil core was calculated by means of the following equation:

$$\text{rate, inches/hr.} = \frac{\text{No. ml. water/hr}}{\text{Volume of 1" core (ml)}}$$

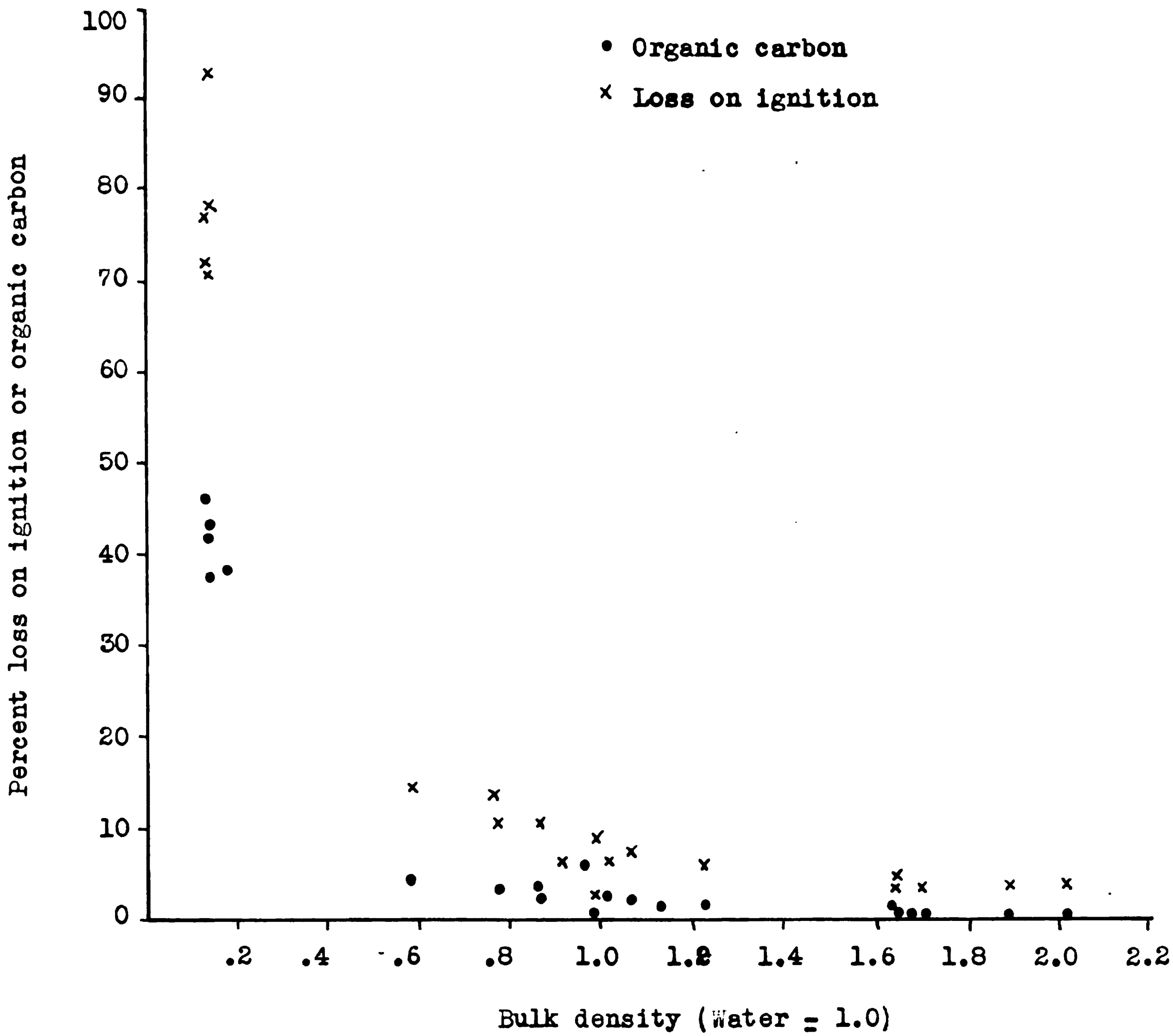


Fig. 6 Relation between loss on ignition, organic carbon and bulk density.

The figures thus obtained indicated the permeability of the horizons of the soil profile. Since the continuity of the pores have been destroyed between successive horizons there is no way of evaluating the movement of water for the profile as a whole. It may be assumed that it is the horizon with the slowest percolation rate that would have the greatest effect on the movement of water through the entire profile. On the other hand high percolation rates for some soil cores may be caused by cracks in the soil. This condition will be most evident in those cores which show high percolation rates but low values for percent pore space drained.

The data for percolation rate are given in Table II. A considerable range in values occurred between the samples within a given horizon as indicated by the variability of means. The most extreme ranges occurred principally in the surface horizons, that is the combined $A_0$ and $A_2$ horizons. Because of the difficulty of sampling thin horizons these two surface horizons were included in the same core.

Since saturated cores were used in this study, the relation between percolation rate and infiltration in which the latter refers to the entrance of water into soils under field conditions, can only be inferred. The rate of infiltration is a variable factor varying with

TABLE II

PERCOLATION RATE, PORE SPACE DRAINED AT SIXTY CENTIMETERS TENSION, TOTAL PORE SPACE, NON-CAPILLARY POROSITY AND CAPILLARY POROSITY

| Profile and Horizon | Depth | Percolation rate in./hr. | Pore space drained in one hr. at 60 cm. tension % | Total pore space % | Non-Capillary porosity % | Capillary porosity % |
|---|---|---|---|---|---|---|
| Profile 1 | | | | | | |
| $A_0 + A_2$ | -2" to 2" | 31.7 ± 19.3 | 21.9 ± 7.4 | 75.3 | 16.5 | 58.8 |
| $B_{21}$ | 2" to 8" | 17.6 ± 6.9 | 18.2 ± 2.1 | 69.5 | 12.6 | 56.9 |
| $B_{22}$ | 8" to 25" | 11.4 ± 6.1 | 15.2 ± 2.2 | 60.5 | 9.2 | 51.3 |
| C | 25" + | 2.5 ± 1.4 | 9.1 ± 2.8 | 33.9 | 3.1 | 30.8 |
| Profile 2 | | | | | | |
| $A_0 + A_2$ | -1½" to 1½" | 63.5 ± 52.0 | 22.7 ± 3.3 | 75.8 | 17.2 | 58.6 |
| $B_{21}$ | 1½" to 5" | 20.8 ± 7.0 | 21.3 ± 3.3 | 69.1 | 14.7 | 54.4 |
| $B_{22}$ | 5" to 9" | 14.5 ± 9.0 | 15.6 ± 4.8 | 66.4 | 10.3 | 56.1 |
| $B_3$ | 9" to 14" | 4.7 ± 4.3 | 9.8 ± 2.0 | 53.5 | 5.2 | 48.3 |
| C | 14" + | .6 ± .6 | 5.5 ± 2.1 | 35.1 | 1.9 | 33.2 |

TABLE II (Continued)

| Profile and Horizon | Depth | Percolation rate in./hr. | Pore space drained in one hr. at 60 cm. tension % | Total pore space % | Non-Capillary porosity % | Capillary porosity % |
|---|---|---|---|---|---|---|
| Profile 3 | | | | | | |
| $A_{oo}$ + Ao | 4" to 0 | 78.6 ± 46.8 | 30.3 ± 2.6 | 90.7 | 20.5 | 63.2 |
| $A_1$ | 0 to 2" | 58.4 ± 34.3 | 25.7 ± 6.0 | 75.5 | 19.4 | 56.1 |
| $B_2$ | 2" to 7" | 5.0 ± 5.7 | 7.4 ± 4.4 | 56.6 | 4.2 | 52.4 |
| $B_3$ | 7" to 11" | 2.5 ± 5.7 | 4.1 ± 2.3 | 36.8 | 1.5 | 35.3 |
| C | 11" + | .04 ± .02 | 3.1 ± 1.7 | 27.6 | .8 | 26.8 |
| Profile 4 | | | | | | |
| $A_o$ | 5" to 0 | 86.5 ± 51.8 | 23.0 ± 4.4 | 90.8 | 20.9 | 69.9 |
| $A_{1g}$ | 0 to 3" | 1.2 ± 1.2 | 4.3 ± 2.2 | 65.2 | 2.8 | 62.4 |
| G | 3" to 10" | .8 ± 1.4 | 2.8 ± 1.2 | 38.1 | 1.1 | 37.0 |
| C | 10" + | .1 ± .1 | 1.8 ± .3 | 23.6 | .4 | 23.2 |

changes in soil structure, the temperature of the air, water and soil, the moisture content of the soil and the degree of biological activity within the soil profile. Some of these factors vary seasonally and others vary during the course of a single storm. Despite these facts it is recognized that the relative amount of infiltration of water into soils is associated with their relative physical characteristics (26).

A comparison between profiles (Table II) shows that all possessed high percolation rates in the surface horizons and became progressively less with depth. The parent material had increasingly lower percolation rates and higher bulk densities toward the foot of the slope. The greatest effect on the water movement in these profiles is therefore the depth to the parent material. The thin sola of profile 3 and 4 limit the water movement to the surface horizons. In the case of profile 4 almost the entire hydrology of the profile is associated with water movement through the $A_o$ layer.

The choice of 60 centimeter tension in measuring the percent pore space drained, is used to conform to the minimum depth of tile placement in soil drainage work. Nelson and Baver[60] suggested 40 centimeter tension for the purpose of obtaining a simple index of water removal. This tension is sometimes used as a means of differentiating capillary and non capillary pore space, when the tension is applied for a sufficient length of time for the moisture value to come to an equilibrium.

By applying the capillary rise equation, $h = \frac{2T}{rdg}$, the size of the largest pore that would remain filled at any given applied suction can be calculated (71). In the present study a 60 centimeterstension drained all pores to a size of 0.025 millimeters.

The percentages of pore space drained in one hour at 60 centimeters tension are summarized in Table II. A comparison of the profiles shows that the upper parts of the solum drained readily under applied suction and reveals the open and porous nature of the B horizons of these soils. This tendency is less marked in profile 3, indicating that towards the bottom of the slope the physical condition of the soil changed considerably and that at the base of the slope, as in profile 4, the pore space which can be drained from the mineral layers approached that of the parent material.

The amounts of total pore space which are present in the various profile horizons are shown in Table II. All profiles showed a progressive decrease from the surface to the parent material.

If it can be assumed that the pore space drained in one hour at a tension of 60 centimeters differentiates between capillary and non-capillary porosity a more significant relationship between the various profiles can be established. In Table II calculations for non-capillary and capillary porosity have been based on that assumption. It may be seen that the pores which are available for drainage by gravitational forces are highest in the A and upper B horizons. Profiles 1, 2 and 3 showed a sharp decrease of non-capillary porosity with depth in the lower parts of the B horizons.

In the case of profile 4 water movement by this means was largely restricted to the $A_O$ horizon. A decrease in capillary porosity from the surface horizons to the parent material was also evident but was less striking than that of non-capillary porosity. In this characteristic the profiles are again similar and the most sudden decrease occurs between the base of the solum and the parent material. The permeability of the parent material was very slow. It has been found that soils with a non-capillary porosity as low as two percent of the entire soil volume are almost completely impervious to water (7).

4.14 Particle size distribution

The distribution of the soil separates, sand, silt, and clay, in the various profiles is given in Table III

TABLE III

PARTICLE SIZE DISTRIBUTION (PERCENT BY WEIGHT)

| Profile and Horizon | Gravel % | V.C.S. % | C.S. % | M.S. % | F.S. % | V.F.S. % | Silt % | Clay % |
|---|---|---|---|---|---|---|---|---|
| **Profile 1** | | | | | | | | |
| $A_2$ | 13.8 | 3.5 | 1.0 | 7.1 | 9.0 | 9.8 | 59.5 | 9.7 |
| $B_{21}$ | 10.8 | 3.9 | 1.1 | 5.5 | 7.5 | 7.7 | 63.9 | 10.2 |
| $B_{22}$ | 25.9 | 8.4 | 2.4 | 11.5 | 12.2 | 8.5 | 47.7 | 8.9 |
| C | 30.6 | 11.9 | 2.9 | 10.5 | 9.7 | 7.7 | 45.1 | 11.9 |
| 5' depth | 34.4 | 5.7 | 2.0 | 6.9 | 11.5 | 15.6 | 43.9 | 14.1 |
| **Profile 2** | | | | | | | | |
| $A_2$ | 7.9 | 0.5 | 0.5 | 3.0 | 6.0 | 8.7 | 69.9 | 13.1 |
| $B_{21}$ | 26.1 | 6.8 | 1.2 | 7.5 | 8.5 | 7.8 | 54.2 | 13.1 |
| $B_{22}$ | 17.6 | 5.3 | 1.8 | 8.7 | 11.0 | 9.2 | 52.4 | 11.2 |
| $B_3$ | 12.0 | 3.6 | 1.7 | 8.2 | 10.3 | 8.9 | 56.7 | 10.3 |
| C | 8.0 | 2.5 | 1.4 | 6.7 | 9.2 | 9.0 | 54.7 | 16.2 |

TABLE III (Continued)

| Profile and Horizon | Gravel % | V.C.S. % | C.S. % | M.S. % | F.S. % | V.F.S. % | Silt % | Clay % |
|---|---|---|---|---|---|---|---|---|
| **Profile 3** | | | | | | | | |
| $A_1$ | 7.7 | 2.1 | 0.8 | 4.2 | 9.0 | 15.0 | 60.2 | 8.0 |
| $B_2$ | 12.5 | 5.0 | 1.4 | 6.2 | 7.3 | 9.3 | 59.0 | 11.5 |
| $B_3$ | 13.8 | 3.0 | 1.5 | 7.2 | 8.9 | 10.1 | 56.5 | 12.4 |
| C | 20.7 | 3.0 | 1.5 | 7.5 | 8.9 | 9.1 | 52.3 | 17.4 |
| **Profile 4** | | | | | | | | |
| $A_{1g}$ | 2.8 | 1.7 | 0.8 | 4.7 | 7.6 | 8.2 | 52.0 | 24.7 |
| G | 20.5 | 4.8 | 1.7 | 8.0 | 8.7 | 8.2 | 51.6 | 16.8 |
| C | 13.9 | 5.3 | 2.2 | 9.9 | 11.7 | 11.2 | 41.5 | 12.8 |

and shown graphically in Figure 7. Although all profiles do not have the same depth of solum they are plotted to a depth of thirty inches and it is assumed that the parent material of a given profile has a uniform composition to that depth.

In a comparison between profiles it is evident that the silt fraction was the largest in each case and was relatively evenly distributed throughout the profile. Profile 1 showed the greatest variation in this constituent having considerably higher silt content in the surface 8 inches than in the lower horizons. This was to some extent true of profiles 3 and 4 although the differences were not as great.

Variations in the parent material are evident in comparing profiles 1 and 4 with profiles 2 and 3. It may be questioned whether these samples represented the true parent material. Since the samples for profiles 2, 3 and 4 were taken at an approximate depth of 24 inches it may be assumed that they were below the horizons at present undergoing Podzol development and that they represented normal variations within the parent material.

The percentages of sand occurring in the various horizons fluctuated in general with the changes in silt content. In profiles 2 and 3 the distribution of sand was relatively even throughout the profile. No explanation

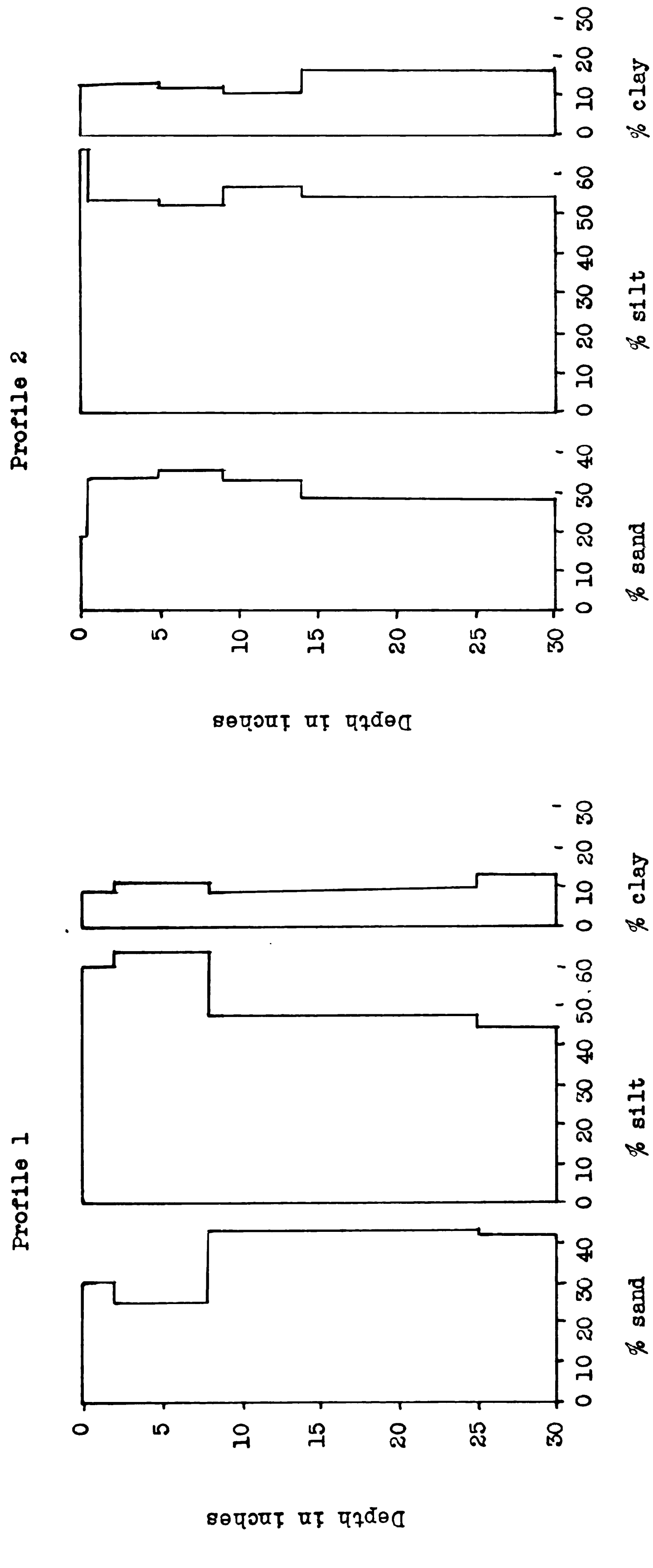


Fig. 7 Mechanical composition of profiles.

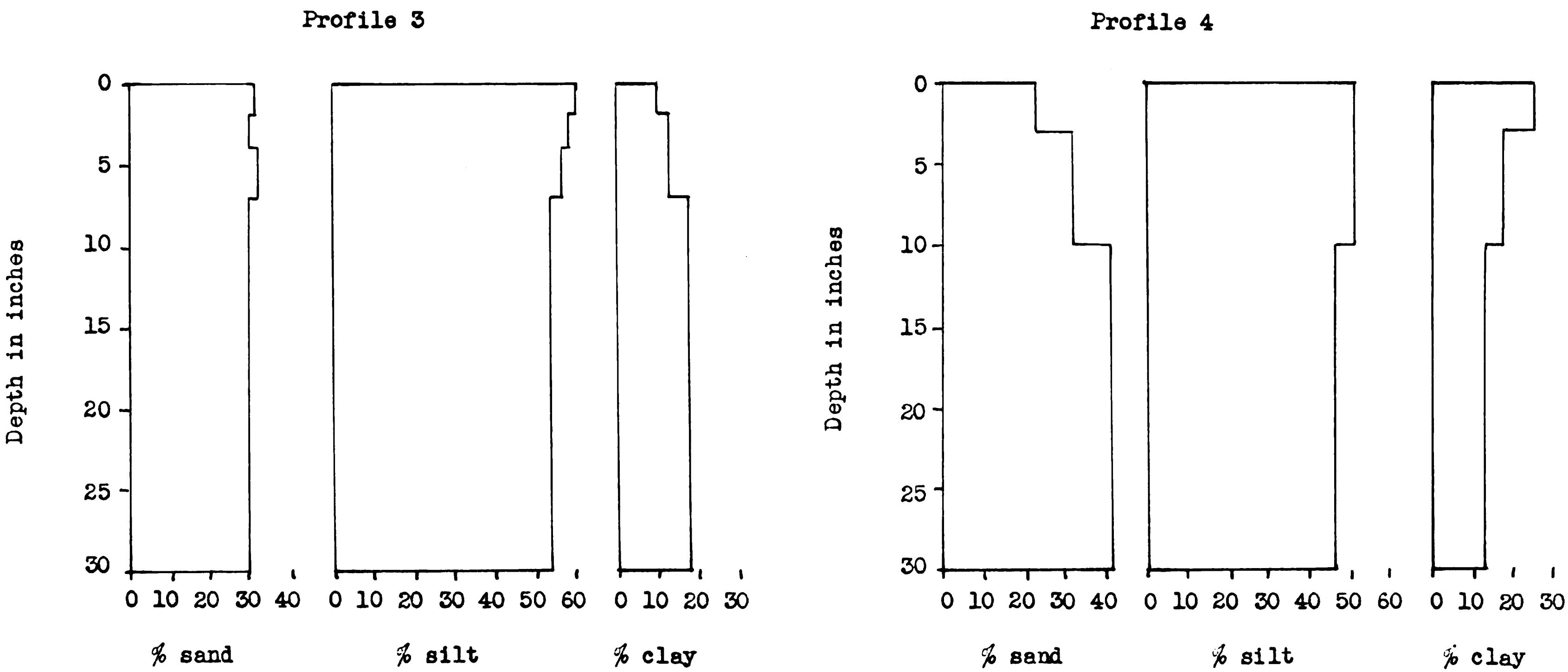


Fig. 7 Mechanical composition of profiles.

can be given for the variations occurring in profiles 1 and 4. It will be observed that the parent materials varied in sand content to a considerable degree and in the same manner as that of silt.

The percentage distribution of clay in these profiles is at variance with many published results. From an examination of profiles 1, 2 and 3, it is evident that there was no accumulation of clay in any of the horizons of the sola as the amount of clay in the parent material was higher in all cases. The lower clay content of the horizons of the solum as compared with the parent material is difficult to explain on the basis of the present study. If losses in this constituent have occurred it would be necessary to assume their complete removal in some form by percolating water. The highly acid condition of these soils will be referred to later but the accelerated weathering in acid soils may be responsible for the destruction of silicate clays as postulated by McCaleb and Cline[56].

The higher clay content in the surface horizons of profile 4 was probably due to surface deposition or weathering in place since the percentage was considerably higher than that in the parent material. Soils lying in this position in the landscape are subjectt to deposition of materials through geological erosion. If the clay had formed in place there would probably have been a decrease in the silt rather than in the sand fractions.

A comparison of these four profiles in a toposequence indicates that there is very little difference between them from the standpoint of particle size distribution except in profile 4.

The evidence of clay movement or accumulation in Podzol soils from various regions in the United States (77) is of interest when compared with profiles under consideration, on a regional basis. An analysis of the data (77) indicates that horizons of clay accumulation are common in Podzol soils of the western and central states but are not evident in those from some of the New England states. This condition is further confirmed by the data presented by Lunt[46] for Podzol soils occurring in New Hampshire. On the other hand Brown and Byers[12] showed that the Hermon soils which are considered to be typical Podzols in New England had a slight accumulation of clay in the $B_1$ horizon.

Data on Podzols as published by Robinson[70] gives evidence of mechanical eluviation in the Podzol soils in certain parts of England and Scotland and the conclusion is reached that there is generally a certain amount of mechanical eluviation in Podzol profiles.

## 4.2 CHEMICAL PROPERTIES

### 4.21 Analytical methods

The samples used for analyses were prepared in the following ways:

1. After passing through the 2 millimeter sieve the material was thoroughly mixed and used for the following determinations; soil reaction, easily soluble $P_2O_5$, and exchangeable bases.
2. 100 grams of each of the above samples were ground to pass through a .5 millimeter sieve. These samples were used for the determination of total nitrogen.
3. In the analyses of total amounts of other constituents an additional 50 gram sample of material that had passed the 2 millimeter sieve was ground until it passed through a 100 mesh sieve.

Soil reaction was determined by means of a glass electrode using a water-soil suspension having a consistency of smooth paste. No definite soil-water ratio was used.

Hygroscopic moisture was determined on duplicate 2 gram samples dried in an oven at 105 degrees Centigrade.

Loss on ignition was obtained by heating the sample in a muffle furnace at 650 degrees Centigrade for 1 hour.

Organic carbon was determined by the dry combustion method. The $CO_2$ was collected in 0.1 N $Ba(OH)_2$ solution. The percent organic matter was calculated by using the factor 1.724.

Total nitrogen was determined by the Kjeldahl method.

The total amounts of other constituents were determined according to methods approved by the American Association of Agricultural Chemistry.

The exchangeable cations and exchange capacities were determined in the leachate from neutral ammonium acetate.

The calcium was precipitated as the oxalate at pH 4.6 and titrated with .05 N. potassium permanganate.

The filtrate from the calcium determination was used for the determination of exchangeable magnesium. The magnesium was precipitated as magnesium ammonium phosphate, dissolved in sulphuric acid and determined volumetrically by back titrating with 0.1 N sodium hydroxide.

Exchangeable potassium was precipitated as the cobaltinitrite. The precipitate was titrated with standard .05 N potassium permanganate.

Exchangeable hydrogen was obtained by difference, that is, by subtracting the sum of the metal cations from the exchange capacity as determined by the ammonium absorption method.

The readily soluble phosphorus was determined colorimetrically by the modified Truog method. The extracting solution was .002 N sulphuric acid buffered at pH 3.0 with ammonium sulfate. The blue phospho-molybdate colour formed on the reduction of ammonium molybate by stannous chloride was read in a colorimeter and the readings compared with a standard graph.

### 4.22 Reaction, Exchange Capacity, Exchangeable Bases, Base Saturation and Easily Soluble Phosphorus

A consideration of the chemistry of these soils showed that the weathering processes by which they developed operated in a very acid medium. How the pH's of the various profiles varied with depth is shown in Table IV and Figure 8.

In all cases there was a general decrease in acidity with increasing depth and much the same pattern was exhibited by all the profiles. In this comparison the $A_o$ horizon has been included since it is the most acid horizon in each of the profiles.

The variations in acidity between profiles was most marked in the horizons below the $A_o$ horizon or below a depth of 5 inches. In the lower parts of the profiles the curves have a tendency to be parallel. In their relation to topography therefore the most acid mineral portions of

TABLE IV

REACTION, EXCHANGE CAPACITY, EXCHANGEABLE BASES, BASE SATURATION
EASILY SOLUBLE PHOSPHORUS

| Profile and Horizon | Reaction | Exchange Capacity m.e/100 gm. | Exchange Hydrogen m.e/100 gm. | Exchange Calcium m.e/100 gm. | Exchange Magnesium m.e/100 gm. | Exchange Potassium m.e/100 gm. | Base Saturation % | Easily Soluble Phosphorus p.p.m. |
|---|---|---|---|---|---|---|---|---|
| Profile 1 | | | | | | | | |
| $A_o$ | 4.25 | 83.56 | 50.77 | 21.81 | 2.68 | 8.30 | 39.24 | 53.5 |
| $A_2$ | 4.05 | 6.75 | 5.36 | 0.79 | 0.15 | 0.45 | 20.59 | 4.2 |
| $B_{21}$ | 4.45 | 26.28 | 23.27 | 0.51 | 0.29 | 2.21 | 11.45 | 8.6 |
| $B_{22}$ | 4.95 | 11.44 | 10.77 | 0.12 | 0.05 | 0.50 | 5.85 | 6.9 |
| C | 5.15 | 5.00 | 4.43 | 0.16 | 0.00 | 0.41 | 11.40 | 9.1 |
| Profile 2 | | | | | | | | |
| $A_o$ | 4.25 | 108.15 | 51.90 | 43.85 | 4.51 | 7.89 | 52.01 | 45.00 |
| $A_2$ | 4.40 | 19.21 | 12.19 | 5.40 | 0.69 | 0.93 | 36.54 | 5.40 |
| $B_{21}$ | 4.90 | 22.88 | 20.90 | 1.46 | 0.22 | 0.30 | 8.65 | 11.76 |
| $B_{22}$ | 5.15 | 13.54 | 12.24 | 1.01 | 0.08 | 0.21 | 9.60 | 13.61 |
| $B_3$ | 5.40 | 8.56 | 7.61 | 0.72 | 0.03 | 0.20 | 11.09 | 11.76 |
| C | 5.65 | 4.15 | 1.14 | 2.33 | 0.14 | 0.54 | 72.53 | 20.64 |

TABLE IV (Continued)

| Profile and Horizon | Reaction | Exchange Capacity m.e/100 gm. | Exchange Hydrogen m.e/100 gm. | Exchange Calcium m.e/100 gm. | Exchange Magnesium m.e/100 gm. | Exchange Potassium m.e/100 gm. | Base Saturation % | Easily Soluble Phosphorus p.p.m. |
|---|---|---|---|---|---|---|---|---|
| Profile 3 | | | | | | | | |
| $A_{oo}$ | 5.15 | 132.96 | 40.20 | 84.75 | 3.70 | 4.31 | 69.76 | 26.28 |
| $A_o$ | 5.45 | 122.39 | 54.53 | 63.20 | 2.26 | 2.40 | 55.44 | 6.48 |
| $A_1$ | 5.60 | 23.28 | 10.81 | 10.35 | 0.45 | 1.67 | 53.56 | 3.41 |
| $B_2$ | 5.70 | 20.97 | 15.98 | 3.84 | 0.15 | 0.95 | 23.55 | 10.44 |
| $B_3$ | 5.85 | 3.85 | 0.85 | 2.50 | 0.10 | 0.40 | 77.92 | 38.84 |
| C | 5.95 | 6.35 | 1.21 | 4.44 | 0.33 | 0.37 | 80.94 | 46.20 |
| Profile 4 | | | | | | | | |
| $A_o$ | 4.25 | 145.46 | 69.32 | 67.60 | 4.05 | 4.49 | 52.34 | 25.08 |
| $A_{1g}$ | 5.55 | 28.40 | 13.06 | 13.20 | 0.60 | 1.54 | 54.01 | 3.12 |
| G | 5.75 | 7.49 | 1.00 | 5.76 | 0.20 | 0.53 | 86.64 | 10.56 |
| C | 6.30 | 5.07 | 0.36 | 4.22 | 0.16 | 0.33 | 92.89 | 45.00 |

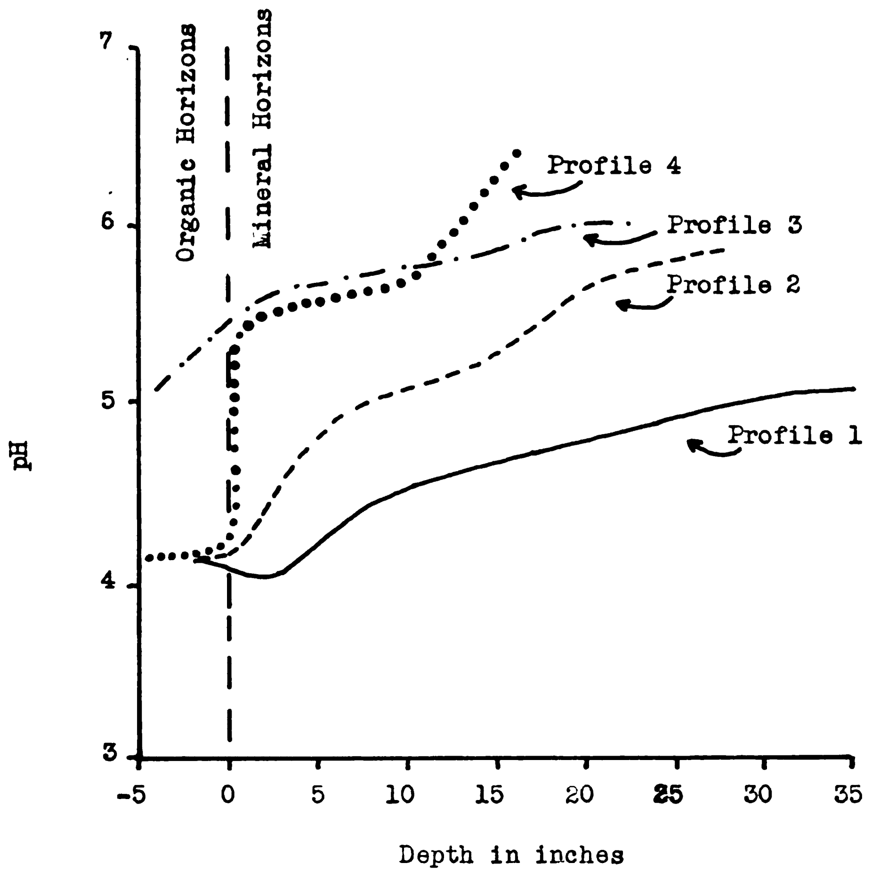


Fig. 8 Comparison of acidity, pH, in profiles as a function of depth.

the profiles occurred at the crest of the slope and became progressively less acid towards the foot. The acid water percolating through these soils has removed the carbonates from the mineral soil to a considerable depth. In profile 1 the material lying on the bedrock at a depth of 5 feet had a pH of only 6.75. These results agree with those reported by Bailey[6] for a number of Podzol soils in the United States.

Some investigators have used pH values as a measure of the approximate degree of base saturation or the degree of calcium saturation of the soil, where calcium is the predominant exchangeable metal ion. That the percentage base saturation at a given pH may differ in soils of similar origin has also been demonstrated (65).

The variability in the percentage base saturation of the profiles studied and the exchangeable calcium are shown in figures 9 and 10.

A comparison of figure 9 with figure 8 shows that base saturation values fluctuated more widely by horizons than did the pH values. There is little agreement in the shape of the curves with the possible exception of those for profile 4.

The high base saturation in the surface soil of these profiles (Table IV) was the most conspicuous feature with regard to the exchangeable cations. In the well

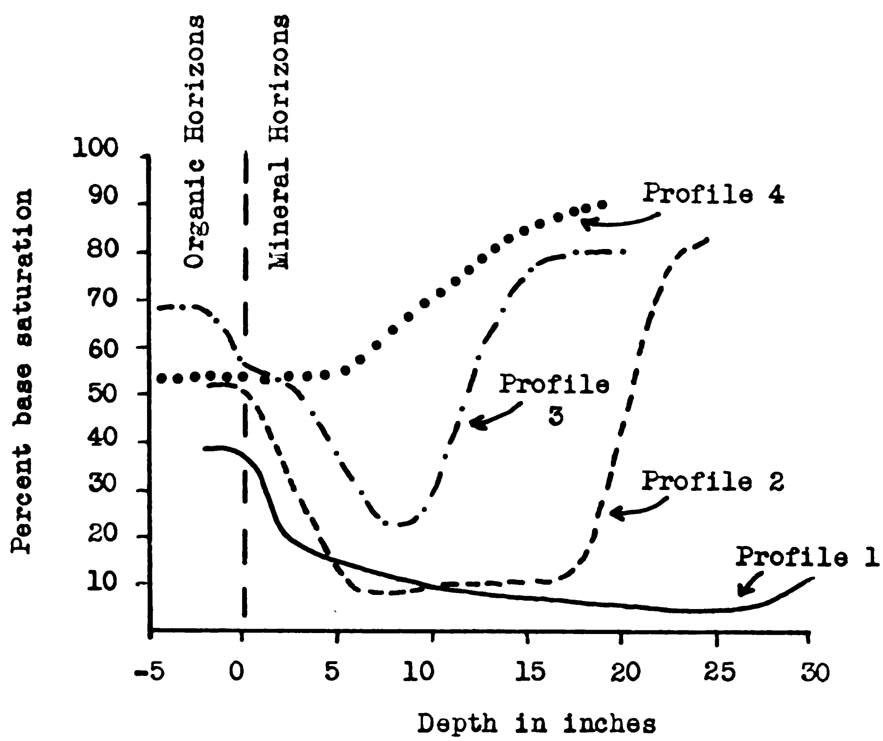


Fig. 9 Comparison of percent base saturation in profiles as a function of depth.

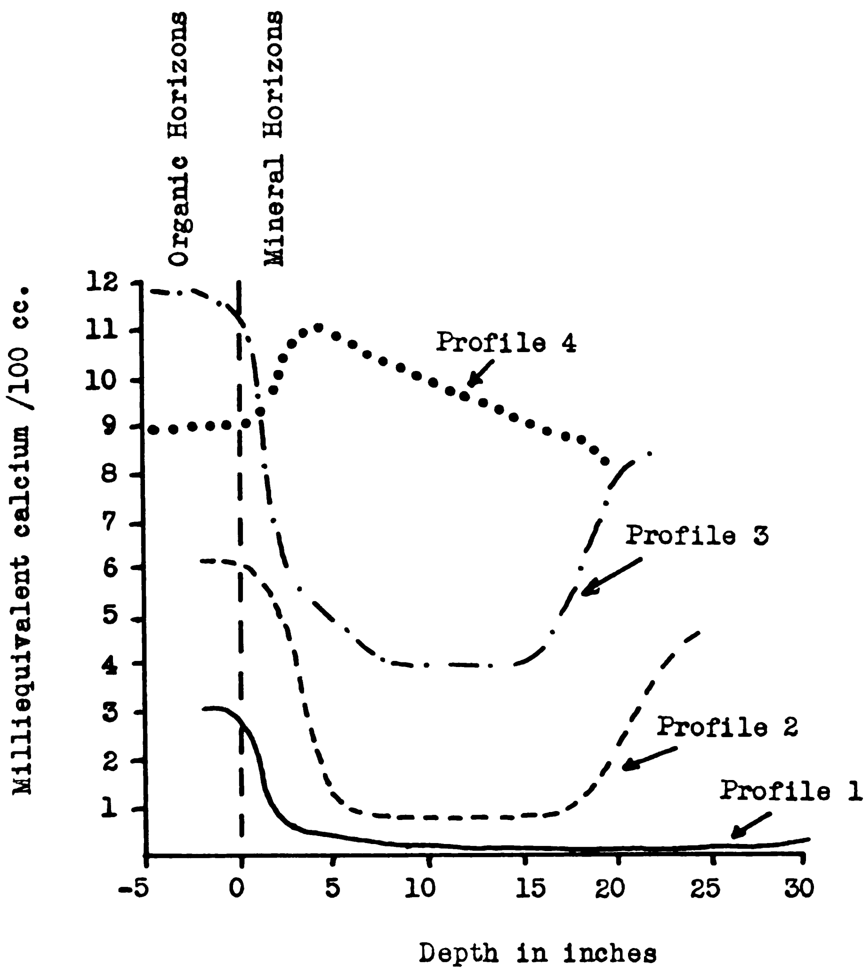


Fig. 10 Comparison of milliequivalents calcium in profiles as a function of depths on a volume basis.

drained positions the nutrients circulate in the profile by means of the vegetation and the content of bases, particularly calcium, contributed by leaves from deciduous trees may be relatively high. Chandler[16] has shown that hardwood vegetation in which the species sugar maple, basswood, beech and yellow birch are prominent contribute more calcium to the soil through their leaves than do mixed species or softwood trees. If this relationship holds in the region in which this study was conducted it should be expected that the exchangeable calcium should be greatest in those soils situated on the highest elevations and least in the soils near the foot of the slopes where the evergreen trees occurred in greater numbers.

The three better drained profiles 1, 2 and 3 show the lowest percent base saturation in the B horizon (Figure 9). This indicates that the B horizons in these profiles are not zones of accumulation of bases and that the occurrence of bases is not associated with the zones of illuviation of organic constituents. The lack of a more definite increase in base saturation in the lowest horizon of profile 1 would seem to indicate that leaching of bases occurred to a greater depth in this location than in any of the others.

The importance of calcium as affecting the base status of the various profiles is evident in figure 10.

With the exception of profile 4 the shapes of the curves are very similar to corresponding curves in figure 9. The higher calcium content in the organic horizons as compared with the B horizons may indicate that at least in the surface it may be associated with the organic matter. It will be noted further that in this surface horizon there was an increase in exchangeable calcium from profile 1 to profile 3.

Figure 11 in which the values for milliequivalents of calcium are expressed on the conventional weight basis is included for comparison. It is apparent from the appearance of these curves that the values for calcium expressed on a volume basis coincide more closely with the values for percent base saturation.

This result suggests the following conclusion. The expression of plant nutrients on a volume basis may offer some interesting possibilities in studies of plant nutrition. The milliequivalents of calcium per 100 cubic centimeters in the $A_0$ horizons of profiles 1, 2 and 3 increase directly with the milliequivalents of calcium per 100 cubic centimeters in the underlying mineral horizons. Since these three profiles were all sampled under sugar maple trees it appears that the base status of the mineral soil had a pronounced effect on the composition of the organic materials.

In the methods employed in this investigation it was

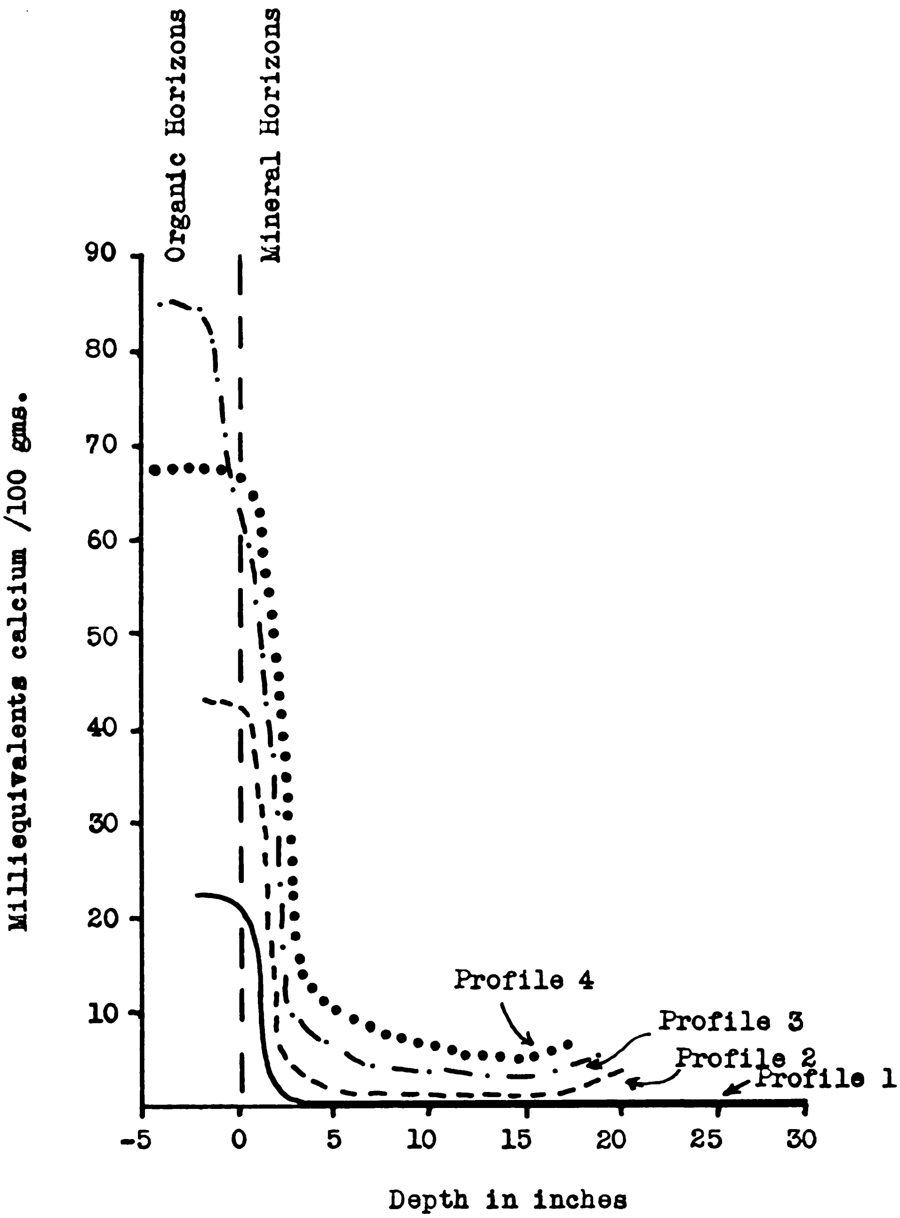


Fig. 11 Comparison of milliequivalents calcium in profiles as a function of depth on a weight basis.

stated that exchangeable hydrogen was obtained by difference. In these profiles the hydrogen cation predominates in the exchange capacity. The exchange capacity of the various profiles is shown in Figure 12 and exchangeable hydrogen in Figure 13.

Referring to Figure 12 it will be seen that in the upper horizons the variations between profiles are quite marked. If the curve of profile 1 is taken as the normal pattern for the well drained soils in this region, the drop in the exchange capacity in the depths two to four inches coincides with the $A_2$ horizon. This is followed by a relatively high exchange capacity in the $B_{21}$ horizon and a subsequent decrease to the parent material. In view of the fact that there is no accumulation of clay in this profile, the increase in exchange capacity of the B horizon may be attributed to the organic matter content, and the higher bulk densities of the mineral horizons.

The $A_0$ layers consisted of leaves and undecomposed forest litter, a material much different from the disseminated organic material in the B horizons.

The effect which decomposition of the organic matter has upon the exchange capacity is further exhibited in profile 3. The well decomposed organic material in the $A_0$ horizon has a higher base exchange capacity per gram than

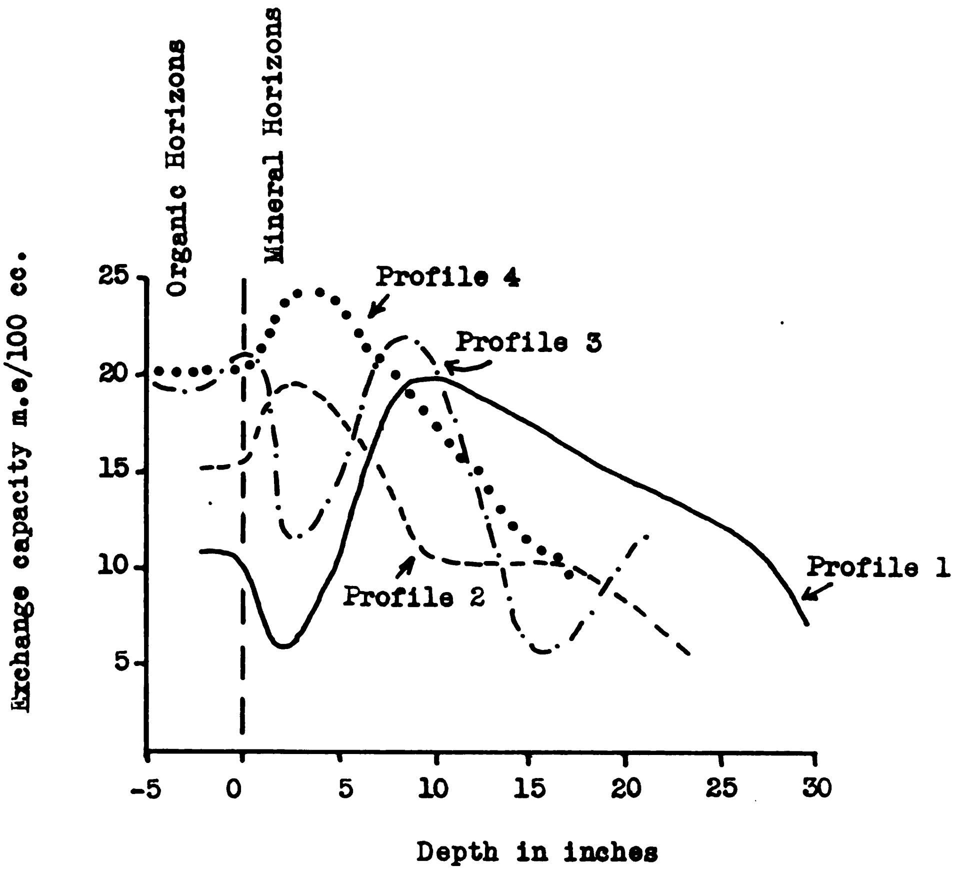


Fig. 12 Comparison of milliequivalents exchange capacity in profiles as a function of depth on a volume basis.

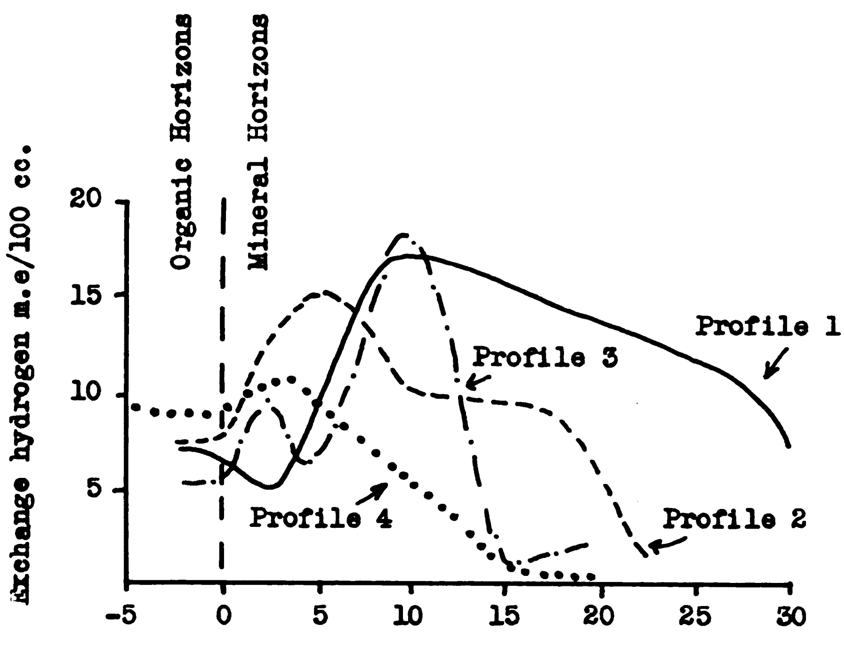


Fig. 13 Comparison of milliequivalents exchange hydrogen in profiles as a function of depth on a volume basis.

does the less decomposed organic matter in the $A_{oo}$ horizon. If one assumes that all the exchange capacity of these two layers is due to the organic material and that the loss on ignition is a fair estimate of the organic content, then their exchange capacities per 100 grams are 173 and 153 milliequivalents respectively.

Although there are variations between individual horizons in all four profiles, the profiles are similar in one important respect. In each one there was a mineral horizon which showed the highest exchange capacity per unit volume for that profile. (Figure 12). Since there was no zone of clay accumulation this increase must be attributed largely to the high bulk densities of the mineral horizons but it is partly due to the occurrence of well decomposed organic matter in the mineral soil.

The low quantities of exchangeable magnesium as shown in Figure 14 do not warrant any deductions as to comparisons between profiles. The same holds for potassium shown in Figure 15. These quantities were too small to have any significance on a comparative basis. It is of interest that there was an indication of more exchangeable potassium than magnesium in every horizon of every soil studied.

The distribution of easily soluble phosphorus shown in Figure 16 showed a trend that may bear some relation to drainage within the profile and consequently to its topographic position. In all profiles the content

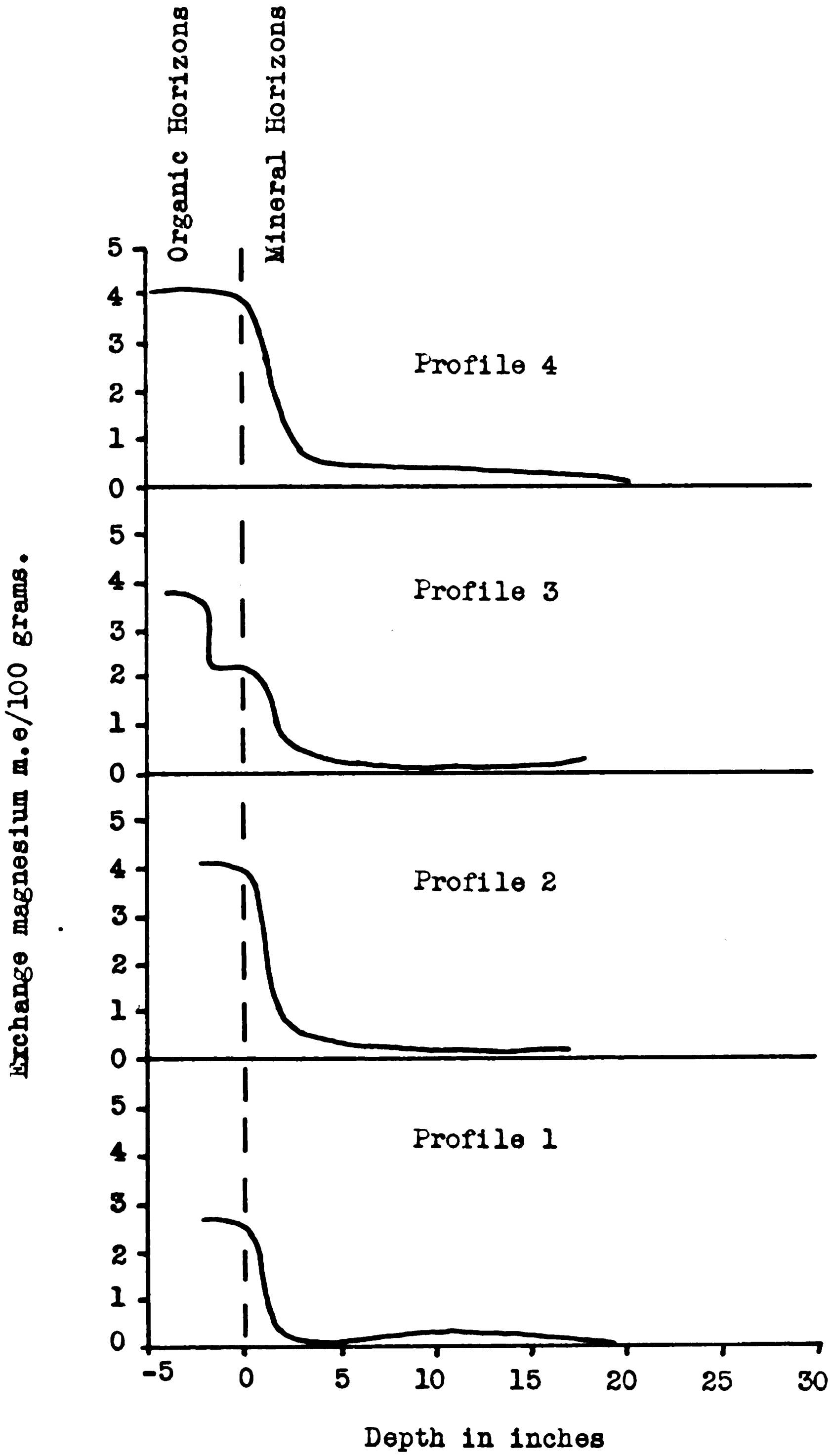


Fig. 14 Comparison of milliequivalents exchange magnesium per 100 grams, in profiles as a function of depth.

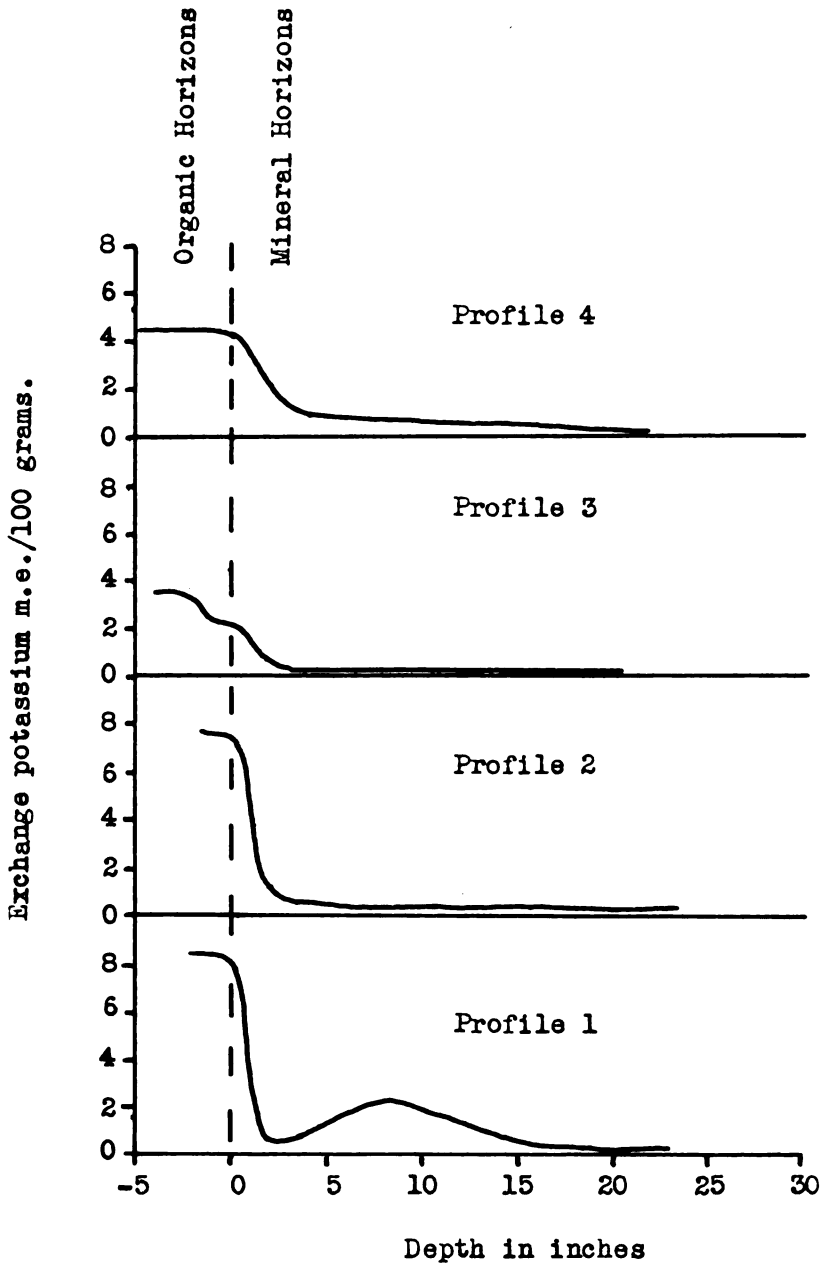


Fig. 15 Comparison of milliequivalents potassium per 100 grams, in profiles as a function of depth.

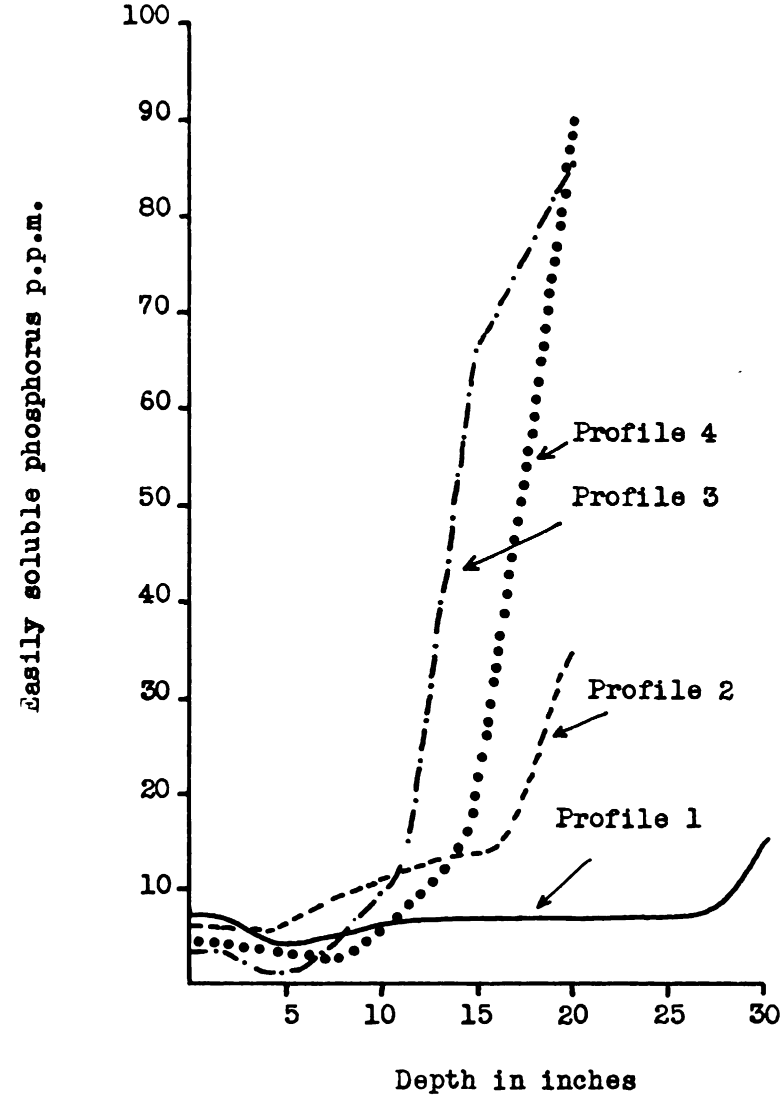


Fig. 16 Comparison of easily soluble phosphorus in profiles as a function of depth.

of easily soluble phosphorus was very low in the surface mineral horizons and much higher in the deepest mineral horizons. The contrastingly high values in the lower horizons of profiles 3 and 4 indicate the high contents of phosphorus that may occur in the more poorly drained positions.

### 4.23 Organic Matter and Nitrogen

In forested regions it is generally assumed that most of the organic matter added to soil is deposited on the surface in the form of leaf litter, branches and fallen logs. Upon decomposition by microorganisms certain intermediate products become mobile and are carried down into the profile.

Coile[21] determined the carbon content of these added organic materials and studied also the variability in base content with different species of trees. A high ratio of carbon to nitrogen provides a poor ration for bacteria. In addition high acidity retards bacterial decay but provides a medium that is quite suitable for fungal decomposition.

The data reported in Table V make it possible to study these profiles from the standpoint of organic matter, nitrogen and carbon. The loss on ignition is usually considered as having little diagnostic value and is included here as a comparison with the organic matter content. In general the figures parallel the differences in the organic matter content and in all cases they are higher than those for organic matter. Since carbonates are lacking in these soils it is to be expected that the relationship in these two constituents should be very close.

TABLE V

LOSS ON IGNITION, ORGANIC MATTER, NITROGEN, ORGANIC CARBON AND CARBON-NITROGEN RATIOS OF PROFILES EXPRESSED AS PERCENTAGE BY WEIGHT OF SOIL

| Horizon | Loss on Ignition % | Organic Matter % | Nitrogen % | Organic Carbon % | C:N |
|---|---|---|---|---|---|
| **Profile 1** | | | | | |
| $A_0$ | 70.64 | 65.40 | 1.69 | 37.92 | 22.4 |
| $A_2$ | 2.32 | 1.05 | 0.08 | .60 | 7.5 |
| $B_{21}$ | 13.36 | 10.75 | 0.33 | 6.22 | 18.8 |
| $B_{22}$ | 7.10 | 4.17 | 0.13 | 2.41 | 18.5 |
| C | 3.54 | 0.90 | 0.07 | .52 | 7.4 |
| **Profile 2** | | | | | |
| $A_0$ | 78.45 | 72.40 | 1.78 | 42.00 | 23.4 |
| $A_2$ | 5.87 | 4.36 | 0.21 | 2.52 | 12.0 |
| $B_{21}$ | 10.61 | 6.55 | 0.27 | 3.79 | 14.0 |
| $B_{22}$ | 6.36 | 3.65 | 0.15 | 2.11 | 14.0 |
| $B_3$ | 6.03 | 2.37 | 0.16 | 1.37 | 8.5 |
| C | 3.78 | 0.67 | 0.06 | .55 | 9.1 |

TABLE V (Continued)

| Horizon | Loss on Ignition % | Organic Matter % | Nitrogen % | Organic Carbon % | C:N |
|---|---|---|---|---|---|
| Profile 3 | | | | | |
| $A_{oo}$ | 87.56 | 79.70 | 1.72 | 46.23 | 26.8 |
| $A_o$ | 71.81 | 66.66 | 1.28 | 38.65 | 30.1 |
| $A_1$ | 14.13 | 7.65 | 0.33 | 4.41 | 13.3 |
| $B_2$ | 6.20 | 2.53 | 0.12 | 1.46 | 12.1 |
| $B_3$ | 3.21 | 0.33 | 0.02 | .19 | 9.5 |
| C | 3.46 | 0.24 | 0.04 | .14 | 3.5 |
| Profile 4 | | | | | |
| $A_o$ | 92.39 | 74.80 | 1.66 | 43.36 | 26.1 |
| $A_{1g}$ | 10.81 | 5.74 | 0.25 | 3.31 | 13.2 |
| G | 4.39 | 0.78 | 0.08 | .45 | 5.6 |
| C | 3.33 | 0.25 | 0.05 | .14 | 2.8 |

The distribution of the organic matter is the most distinctive feature of these profiles. Profile 1 which is the best drained of the group represents the zonal soil in this region.

The high organic matter content of the surface layer Ao was common to all profiles. The contrast between the $A_0$ horizon and the $A_2$ horizon was most marked in profile 1, and indicates that little of the organic fraction remained to become incorporated with the $A_2$ layer. In profile 2 some incorporation of organic matter occurred in this horizon either through error in sampling or as a result of macro-organic activity. The accumulation of organic materials in the $A_1$ horizons was evident in profiles 3 and 4.

The high content of organic matter occurring in the B horizon was evident in all profiles. In general it appeared that the upper part of the B contained a greater amount than the lower parts of this major horizon.

In its relation to topography the organic matter in the various profiles showed some rather marked trends. Considering the profiles in the sequence 1 to 4 the purely organic layers increased in depth in that order. In the surface mineral layer there was a marked decrease in profiles 1 and 2 and a lesser decrease in profiles 3 and 4. In the latter two profiles therefore the organic matter had accumulated nearer the surface of the profile. In the B horizons the organic matter was highest in profile 1 and decreased markedly to the G horizon of profile 4. Accompanying this decrease in quantity present in each of the subsoil horizons there was also a decrease in depth. It is evident therefore that in the better drained positions profile development had proceeded to a greater depth than in the more poorly drained positions.

The ratio of carbon to nitrogen showed as great a variation as the organic matter content. The carbonaceous nature of the material was most marked in the surface horizons. The ratio in the $A_2$ horizons of profile 1 and 2 was close to the frequently quoted figure for soils of temperate regions namely 10:1. The wide ratios which characterized the B horizons of profiles 1 and 2 indicate that considerable energy bearing material was still available.

Several reasons for this anomaly in regard to the ratio of carbon to nitrogen may be presented. The cause for the variation may be attributed to differences in composition of roots of plants as compared with their stems, branches and leaves, differences in the composition of the eluviated organic fractions, or the difference in the character of the microbiological processes at and near the soil surface and at lower depths. It seems reasonable to assume that the processes of decay taking place at the surface and in the upper portion of the soil profile would result in different residual materials from those occurring under widely different conditions at lower levels.

It has also been assumed by many workers that considerable translocation of organic matter takes place in the process of podzolization. This translocated material is colloidal in nature and is therefore an alteration product of microorganic activity. Some alterations should therefore be expected in its translocation through the profile.

It would appear from these results that the composition of the organic matter in the B horizons of the best drained profiles is not greatly different from that occurring in the $A_0$ horizon.

In view of the low base status of the horizons of the solum in these profiles it is improbable that the soluble organic matter has been precipitated at lower levels as a result of change in pH, as has been suggested by different workers.

The total nitrogen content in the $A_0$ layers was over one percent. This content dropped to a low figure in the mineral layers and particularly in the $A_2$ horizon since in well developed Podzol profiles it is the poorest part of the profile as a result of leaching. With the exception of the $A_2$ horizon there was a general decrease in nitrogen content with depth.

4.24 Total Silica and Sesquioxides

The composition of the horizons of the various profiles is presented in Table VI.

As is generally the case the $SiO_2$ content was high in the $A_2$ horizon, decreased in the B and increased again in the C horizon. This sequence held wherever an $A_2$ horizon was present, but when that layer was absent as in profiles 3 and 4 there was a general increase in silica from the surface to the parent material. [illegible]

[illegible]. The sample taken at a depth of 5 feet in profile 1 showed a silica content less than that of the C horizons of the various profiles. Two interpretations may be made of this fact, first that an accumulation of silica had occurred at the base of the solum or secondly that it represented normal variations in the silica content of the parent material. The latter supposition is probably more correct.

The changes in total sesquioxides and alumina showed a reverse trend to that of silica. The $A_0$ and

## TABLE VI

TOTAL CHEMICAL COMPOSITION OF THE PROFILES (PERCENTAGE BY WEIGHT)

| Profile and Horizon | Hygroscopic Moisture % | $SiO_2$ % | $Fe_2O_3$ % | $Al_2O_3$ % | $P_2O_5$ % | MgO % | CaO % | $K_2O$ % | Total % |
|---|---|---|---|---|---|---|---|---|---|
| Profile 1 | | | | | | | | | |
| $A_o$ | 9.34 | 23.37 | 0.26 | 4.12 | 0.13 | 0.41 | 0.94 | 0.54 | 100.41 |
| $A_2$ | 0.82 | 86.89 | 0.37 | 9.05 | 0.01 | 0.38 | 0.07 | 1.18 | 100.27 |
| $B_{21}$ | 5.08 | 60.48 | 1.69 | 25.98 | 0.05 | 1.22 | 0.12 | 1.20 | 104.10 |
| $B_{22}$ | 2.64 | 65.87 | 1.47 | 24.70 | 0.03 | 0.39 | 0.14 | 1.28 | 100.98 |
| C | 1.08 | 70.60 | 1.50 | 22.19 | 0.02 | 0.90 | 0.12 | 1.66 | 100.53 |
| 5' depth | 0.53 | 65.92 | 2.11 | 23.45 | 0.02 | 3.12 | 0.24 | 2.25 | 101.11 |

TABLE VI (Continued)

| Profile and Horizon | Hygroscopic Moisture % | $SiO_2$ % | $Fe_2O_3$ % | $Al_2O_3$ % | $P_2O_5$ % | MgO % | CaO % | $K_2O$ % | Total % |
|---|---|---|---|---|---|---|---|---|---|
| Profile 2 | | | | | | | | | |
| $A_o$ | 11.28 | 14.25 | 0.30 | 4.46 | 0.13 | 0.38 | 1.40 | 0.40 | 99.77 |
| $A_2$ | 1.38 | 80.46 | 0.64 | 12.57 | 0.02 | 0.47 | 0.23 | 1.26 | 101.52 |
| $B_{21}$ | 3.31 | 61.80 | 4.03 | 21.43 | 0.04 | 1.47 | 0.23 | 1.20 | 100.81 |
| $B_{22}$ | 1.83 | 63.48 | 3.43 | 24.45 | 0.03 | 1.33 | 0.25 | 1.30 | 100.63 |
| $B_3$ | 1.64 | 65.33 | 1.95 | 22.88 | 0.02 | 1.71 | 0.20 | 1.66 | 99.79 |
| C | 0.80 | 69.55 | 2.11 | 21.17 | 0.01 | 1.90 | 0.22 | 1.28 | 100.02 |

TABLE VI (Continued)

TABLE VI (Continued)

| Profile and Horizon | Hygroscopic Moisture % | $SiO_2$ % | $Fe_2O_3$ % | $Al_2O_3$ % | $P_2O_5$ % | MgO % | CaO O % | $K_2O$ % | Total % |
|---|---|---|---|---|---|---|---|---|---|
| Profile 3 | | | | | | | | | |
| $A_{oo}$ | 13.05 | 6.05 | 0.37 | 2.59 | 0.16 | 0.22 | 2.72 | 0.26 | 99.93 |
| $A_o$ | 14.57 | 14.32 | 0.41 | 10.08 | 0.28 | 0.50 | 2.50 | 0.42 | 100.32 |
| $A_1$ | 4.15 | 56.95 | 1.58 | 24.52 | 0.06 | 1.53 | 0.56 | 1.20 | 100.53 |
| $B_2$ | 1.55 | 63.05 | 1.69 | 24.02 | 0.03 | 1.59 | 0.39 | 1.39 | 98.36 |
| $B_3$ | 0.57 | 67.62 | 2.64 | 20.97 | 0.02 | 1.67 | 0.23 | 1.54 | 97.90 |
| C | 0.73 | 68.39 | 2.18 | 20.82 | 0.02 | 1.81 | 0.35 | 1.45 | 99.02 |

TABLE VI (Continued)

| Profile and Horizon | Hygroscopic Moisture % | $SiO_2$ % | $Fe_2O_3$ % | $Al_2O_3$ % | $P_2O_5$ % | MgO % | CaO % | $K_2O$ % | Total % |
|---|---|---|---|---|---|---|---|---|---|
| **Profile 4** | | | | | | | | | |
| $A_o$ | 12.47 | 3.42 | 0.11 | 1.36 | 0.11 | 0.15 | 2.33 | 0.24 | 100.11 |
| $A_{1g}$ | 2.46 | 59.36 | 1.88 | 24.14 | 0.04 | 1.55 | 0.59 | 1.76 | 100.13 |
| G | 0.85 | 69.20 | 0.86 | 21.50 | 0.02 | 1.68 | 0.33 | 1.64 | 99.62 |
| C | 0.52 | 69.26 | 1.58 | 20.52 | 0.01 | 1.72 | 0.30 | 1.39 | 98.12 |

and $A_2$ horizons contained relatively small amounts of these constituents. Since plants take up little of these compounds it can be expected that there will be little return of them to the $A_0$ layer. Some accumulations of sesquioxides probably occurred in the B horizons of profiles 1 and 2 and in the $A_1$ horizons of profiles 3 and 4. The increase over that occurring in the parent material was not large and was considerably less when compared with that of the sample at 5 foot depth.

It is evident from Table VI that of the total sesquioxides occurring in these soils iron oxide makes up a relatively small amount. Within each of the profiles the lowest quantities occur in the $A_0$ and $A_2$ horizons. The $B_{21}$ horizons of profiles 1 and 2 and the $A_1$ horizons of profile 4 all have higher values for iron than is found in their respective parent materials. If it is assumed that some accumulation has occurred in some of the B horizons it will also be necessary to assume that some losses have taken place in others since they have lower quantities than is found in the parent material.

The differences in iron content between horizons may not be significant within the range of the figures presented since it has been shown (73) that the losses of iron during sodium carbonate fusion of silicates and rocks may be considerable.

The characteristics of profile 4 are of interest from the standpoint of the process of gleying. Investigation of the literature on this subject reveals that the word is not always used in a very precise sense. In extreme cases notable deposits of hydrated ferric oxide may be formed, represented by bog iron ore formations, whereas in other cases there may be little iron deposition but some impedance is indicated by the greenish grey or bluish grey colours of the various horizons.

Various theories in regard to the mechanism of gley formation have been reported (9), (2), (13), some of which indicate that the role played by soil micro-organisms may be of great importance in this respect, since it is the creation of an oxygen deficit by some active agent which gives rise to reducing conditions.

The effect of reducing conditions in the soil is for the accessible trivalent iron to be reduced to the divalent condition. This change increases its solubility in the soil solution. The iron is therefore mobile while aluminum remains relatively immobile as it cannot be converted to a more soluble form by reduction. The movement of aluminum is therefore considered to be more characteristic of well drained soils than poorly

drained soils. Examination of the data for profile 4, Table VI reveals some increases in percentages of alumina in the B horizons of profiles 1, 2 and 3 and the $A_1$ horizon of profile 4. Iron on the other hand showed a decrease in the G horizon as compared with that occurring in the parent material. It would appear that in the poorly drained positions in this region some losses of iron do occur. These soils do not remain saturated for the entire year but dry out to some extent during the summer period. It is quite possible that the upper parts of the profile is subject to reducing conditions for only a part of the year and to normal oxidizing conditions for the remainder. These alternating effects may be responsible for the mottled appearance of the G horizon.

The derived data in Table VII shows the weight changes in the soil constituents expressed in the form of ratios of silica and sesquioxides calculated for the various horizons in the four profiles. This data reveal that the horizons showing the greatest amount of variability in these constituents were the $A_0$ and $A_2$. The composition of the B horizons and the parent material was relatively constant in respect to ratios of these constituents. Following the high ratios which were present in the $A_2$ horizons there was a narrowing of the ratios in the $B_{21}$ and $B_{22}$ followed by a slight increase in the parent material.

TABLE VII

RATIOS OF SILICA AND SESQUIOXIDES FOR GENETIC HORIZONS IN PROFILES

| Horizon | $Al_2O_3$ / $Fe_2O_3$ | $SiO_2$ / $R_2O_3$ | $SiO_2$ / $Al_2O_3$ | $SiO_2$ / $Fe_2O_3$ |
|---|---|---|---|---|
| Profile 1 | | | | |
| Ao | 15.8 | 5.3 | 5.6 | 89.8 |
| $A_2$ | 24.4 | 9.2 | 9.6 | 234.8 |
| $B_{21}$ | 15.3 | 2.2 | 2.3 | 35.7 |
| $B_{22}$ | 16.7 | 2.5 | 2.6 | 44.8 |
| C | 14.7 | 2.9 | 3.1 | 47.0 |
| 5' depth | 11.1 | 2.5 | 2.8 | 31.2 |
| Profile 2 | | | | |
| $A_o$ | 14.8 | 2.9 | 3.1 | 47.5 |
| $A_2$ | 19.6 | 6.1 | 6.4 | 125.7 |
| $B_{21}$ | 5.3 | 2.4 | 2.8 | 15.3 |
| $B_{22}$ | 7.1 | 2.2 | 2.5 | 18.5 |
| $B_3$ | 11.6 | 2.6 | 2.8 | 33.3 |
| C | 10.0 | 2.9 | 3.2 | 32.9 |

TABLE VII (Continued)

| Horizon | $\frac{Al_2O_3}{Fe_2O_3}$ | $\frac{SiO_2}{R_2O_3}$ | $\frac{SiO_2}{Al_2O_3}$ | $\frac{SiO_2}{Fe_2O_3}$ |
|---|---|---|---|---|
| Profile 3 | | | | |
| Aoo | 7.0 | 2.0 | 2.3 | 16.3 |
| $A_o$ | 24.5 | 1.3 | 1.4 | 34.9 |
| $A_1$ | 15.5 | 2.1 | 2.3 | 36.0 |
| $B_2$ | 14.2 | 2.4 | 2.6 | 37.3 |
| $B_3$ | 7.9 | 2.8 | 3.2 | 25.6 |
| C | 9.5 | 2.9 | 3.3 | 31.6 |
| Profile 4 | | | | |
| $A_o$ | 12.3 | 2.3 | 2.5 | 31.1 |
| $A_{1g}$ | 12.8 | 2.2 | 2.4 | 31.5 |
| G | 25.0 | 3.0 | 3.2 | 80.4 |
| C | 12.9 | 3.1 | 3.3 | 43.8 |

The evidence from many investigators with respect to the fate of the sesquioxides in Podzol soils is often conflicting. Deb[23] obtained results which fail to support the general assumption that the precipitation of iron in Podzol B horizons is due to flocculation by the divalent cations present in the exchangeable form.

The movement of iron from the A horizon and its precipitation in the B horizon is considered to be a fundamental characteristic of Podzol profiles. It has been suggested that iron may move as (a) a negatively charged humus - protected iron-oxide sol, or (b) a complex organic ion.

The question as to the amount of humus necessary in the soil solution to peptize the iron oxide has been studied by Aarnio[1] and Deb[23]. The data given by Aarnio suggests that the amount of humus required for peptization exceeds the amount of ferric oxide 2.5 times. Deb on the other hand found that the amount of humus necessary to peptize iron-oxide sol varied considerably with the source of humus and the concentration and pH of the iron-oxide sol, and that over a wide range of concentrations of iron-oxide sol full precipitation occurred with about 7 parts of humus per 100 parts of ferric oxide. Furthermore the amounts of humus required to peptize one half of the coagulated complex of humus and iron oxide was on the average about 10 parts of humus per 100 parts of ferric oxide.

These results would seem to indicate that any iron oxide sol formed by weathering in the upper horizons of Podzols will be fully peptized by the humus in soil solution and carried down the profile by percolating water.

The effectiveness of calcium in precipitating a humus-protected iron-oxide sol was also investigated by Deb[23]. On the basis of his experiments he concludes that "the precipitation of iron in the B horizons of Podzol soils is not due either to colloidal flocculation of a humus-protected iron-oxide sol or to the chemical precipitation of complex salts of iron and organic acids."

The losses of silica, sesquioxides and basic compounds from the soil have been mentioned by many workers but few data are published to indicate the extent of the losses. Analyses of the water from springs and rivers show that some of the silicon is washed out of the profile altogether and this appears to be true for the iron and aluminum also. Russell[72] presents figures from Rode that showed a considerable loss of silicon, iron and aluminum from the A and B horizons of a Podzol soil in Russia, and a net loss of iron and aluminum from the B horizons of a Swedish soil according to O. Tamm.

### 4.25 Total CaO, MgO, $K_2O$ and $P_2O_5$

The content of bases occurring in the profiles of Podzol soils is considered by some workers (46) (47) (36) to coincide to a certain extent with organic matter distribution. Although this tendency appears to hold for the available calcium and magnesium it is not so evident for the total percentage.of these elements. The data in Table VI show the amounts of CaO, MgO, $K_2O$ and $P_2O_5$ occurring in the selected profiles.

The quantity of calcium found in these soils was small and indicated that the portion which is designated as parent material had suffered considerable removal of bases. The calcium status was much lower than that of magnesium, a condition that was also reported by Lunt[47]. The magnesium content increased with depth in the profile whereas no such concomitant increase was evident in the case of calcium. No difference between the various profiles was shown by these constituents.

The content of phosphorus was extremely low and no particular trends could be detected in the distribution of this element. The same was true for potassium.

## 5. ESTIMATED NET CHANGES IN THE PROFILES STUDIED

The use of reference minerals as a means of evaluating net changes in soils brought about by soil development processes has been described by Marshall and Haseman[51]. Although these investigators used Zircon as the index mineral they pointed out that the coarser soil fractions might be useful as indicators in soil genetic studies. Recently Cann[15] studied the genesis of a Gray Brown Podzolic - Podzol Intergrade soil profile in Michigan using quartz as the resistant reference mineral. He showed the possibilities of using this mineral as a basis of calculating the gains or losses in the profile under the environmental conditions found in that region.

It is intended in this section to apply a similar method of calculation as that used by Marshall and Haseman[50] to the profiles used in this study in order to assess the formation and movement of materials, using silica as the standard reference material. A few basic assumptions will be necessary, namely,

(1) that the $SiO_2$ contents of the mineral layers have not been altered by soil formation and development and

(2) that the profiles have developed from material similar to that now regarded as the C horizon.

That the first assumption may not be entirely valid has been mentioned with reference to data quoted by Russell[72]. The loss of silica from the A and B horizons of these profiles would therefore affect the calculations particularly of the original weights of various constituents in the profile. These weights would be somewhat greater than that calculated in Table IX.

The selection of the C horizon as representing the true parent material may be questioned since it is acid in reaction and may therefore have lost some of its original carbonate content. This loss can not be great since the sample occurring at a depth of 5 feet had much the same chemical characteristics as that of the various C horizons.

In this study the total amount of $SiO_2$ found in each of the soil horizons was used as a basis of calculating the gains or losses in the profile. The profile changes due to soil development were calculated as grams of constituent gained or lost from a column one square centimeter in cross section to the depth of the solum. This involved the calculation of: (1) a volume change factor, (2) the original weight in grams of each constituent, (3) the present weight of each constituent and

(4) the difference between (2) and (3) to give the net gain or loss.

The volume change factor represents the number of cubic centimeters of parent material required to produce one cubic centimeter of the present horizon. This was obtained by multiplying the percentage of silica (by weight) in each horizon by the bulk density of the layer times one hundred and dividing each figure thus obtained by that of the C horizon.

The original weight of each horizon was found by multiplying the volume of each horizon (= depth in centimeters) by the volume change factor and by the bulk density of the C horizon. This weight multiplied by the decimal fraction (ie. %/100) of each constituent in the C horizon gave the original weight of each constituent. The present weights were calculated from the present weight and the decimal fractions of constituents in each horizon.

The volume change factors for the various horizons are given in Table VIII and the calculated net changes in weight of organic matter and of the soil separates are shown in Table IX. The grams of $SiO_2$ per 100 cubic centimeters (Table VIII) show a greater variation within each profile than when expressed as percent by weight. This variation is due to volume changes in the

TABLE VIII

VOLUME CHANGE FACTORS FOR PROFILE HORIZONS

| Profile and Horizon | $SiO_2$ % | $SiO_2$ per 100 cc Grams | Volume change factor |
|---|---|---|---|
| Profile 1 | | | |
| $A_2$ | 86.89 | 85.15 | .73 |
| $B_{21}$ | 60.48 | 45.96 | .39 |
| $B_{22}$ | 65.87 | 69.82 | .60 |
| C | 70.60 | 115.78 | 1.00 |
| Profile 2 | | | |
| $A_2$ | 80.46 | 79.65 | .66 |
| $B_{21}$ | 61.80 | 47.59 | .39 |
| $B_{22}$ | 63.48 | 54.59 | .45 |
| $B_3$ | 65.33 | 79.70 | .65 |
| C | 69.55 | 121.02 | 1.00 |
| Profile 3 | | | |
| $A_1$ | 56.95 | 33.03 | .25 |
| $B_2$ | 63.05 | 71.25 | .55 |
| $B_3$ | 67.62 | 114.28 | .87 |
| C | 68.93 | 130.28 | 1.00 |
| Profile 4 | | | |
| $A_{1g}$ | 59.36 | 51.05 | .37 |
| G | 69.20 | 112.80 | .81 |
| C | 69.26 | 139.21 | 1.00 |

**TABLE IX**

**ORIGINAL AND PRESENT CONSTITUENTS IN THE PROFILE**

| Horizon | Organic Matter | | | Very coarse sand | | | Coarse sand | | |
|---|---|---|---|---|---|---|---|---|---|
| | Original Weight grams | Present Weight grams | Net Change grams | Original Weight grams | Present Weight grams | Net Change grams | Original Weight grams | Present Weight grams | Net Change grams. |
| Profile 1 | | | | | | | | | |
| $A_o$ | | .46 | + .46 | | | | | | |
| $A_2$ | .05 | .05 | | .75 | .18 | - .57 | .17 | .05 | - .12 |
| $B_{21}$ | .08 | 1.24 | +1.16 | 1.20 | .42 | - .78 | .28 | .11 | - .17 |
| $B_{22}$ | .38 | 1.90 | +1.52 | 5.26 | 4.13 | -1.13 | 1.25 | 1.08 | - .17 |
| Solum | .51 | 3.65 | +3.14 | 7.21 | 4.73 | - 2.48 | 1.70 | 1.24 | - .46 |
| Profile 2 | | | | | | | | | |
| $A_o$ | | .51 | + .51 | | | | | | |
| $A_2$ | .03 | .21 | + .18 | .12 | .03 | - .09 | .08 | .02 | - .06 |
| $B_{21}$ | .04 | .51 | + .47 | .15 | .58 | + .43 | .10 | .12 | + .02 |
| $B_{22}$ | .05 | .31 | + .26 | .17 | .42 | + .25 | .11 | .15 | + .04 |
| $B_3$ | .09 | .36 | + .27 | .31 | .47 | + .16 | .21 | .28 | + .07 |
| Solum | .21 | 1.90 | +1.69 | .75 | 1.50 | + .75 | .50 | .57 | + .07 |

TABLE IX (Continued)

| Horizon | Organic Matter | | | Very coarse sand | | | Coarse sand | | |
|---|---|---|---|---|---|---|---|---|---|
| | Original Weight grams | Present Weight grams | Net Change grams | Original Weight grams | Present Weight grams | Net Change grams | Original Weight grams | Present Weight grams | Net Change grams. |
| Profile 3 | | | | | | | | | |
| $A_{oo}$ | | .52 | + .52 | | | | | | |
| $A_o$ | | .57 | + .57 | | | | | | |
| $A_1$ | .005 | .22 | + .21 | .08 | .05 | - .03 | .03 | .01 | - .02 |
| $B_2$ | .03 | .36 | + .33 | .45 | .76 | + .31 | .20 | .20 | |
| $B_3$ | .04 | .05 | + .01 | .57 | .48 | - .09 | .25 | .27 | + .02 |
| Solum | .075 | 1.72 | +1.64 | 1.10 | 1.29 | + .19 | .48 | .48 | |
| Profile 4 | | | | | | | | | |
| $A_o$ | | 1.33 | +1.33 | | | | | | |
| $A_{1g}$ | .01 | .37 | + .36 | .32 | .12 | - .20 | .12 | .05 | - .07 |
| G | .07 | .22 | + .15 | 1.63 | 1.47 | - .16 | .64 | .47 | - .17 |
| Solum | .08 | 1.92 | +1.84 | 1.95 | 1.59 | - .36 | .76 | .52 | - .24 |

TABLE IX (Continued)

| Horizon | Medium sand | | | Fine sand | | | Very fine sand | | |
|---|---|---|---|---|---|---|---|---|---|
| | Original Weight grams | Present Weight grams | Net Change grams | Original Weight grams | Present Weight grams | Net Change grams | Original Weight grams | Present Weight grams | Net Change grams |
| Profile 1 | | | | | | | | | |
| $A_o$ | | | | | | | | | |
| $A_2$ | .63 | .35 | - .28 | .57 | .45 | - .12 | .45 | .47 | + .02 |
| $B_{21}$ | 1.01 | .58 | - .43 | .92 | .85 | - .07 | .73 | .92 | + .19 |
| $B_{22}$ | 4.42 | 5.23 | + .81 | 4.01 | 5.53 | +1.52 | 3.19 | 3.89 | + .70 |
| Solum | 6.06 | 6.16 | + .10 | 5.50 | 6.83 | +1.33 | 4.37 | 5.28 | + .91 |
| Profile 2 | | | | | | | | | |
| $A_o$ | | | | | | | | | |
| $A_2$ | .39 | .16 | - .23 | .52 | .31 | - .21 | .53 | .44 | - .09 |
| $B_{21}$ | .47 | .58 | + .11 | .62 | .66 | + .04 | .62 | .61 | - .01 |
| $B_{22}$ | .54 | .76 | + .22 | .71 | .97 | + .26 | .72 | .80 | + .08 |
| $B_3$ | .98 | 1.25 | +. 27 | 1.29 | 1.63 | + .34 | 1.30 | 1.37 | + .07 |
| Solum | 2.38 | 2.75 | + .37 | 3.14 | 3.57 | + .43 | 3.17 | 3.22 | + .05 |

TABLE IX (Continued)

| Horizon | Medium sand | | | Fine sand | | | Very fine sand | | |
|---|---|---|---|---|---|---|---|---|---|
| | Original Weight grams | Present Weight grams | Net Change grams | Original Weight grams | Present Weight grams | Net Change grams | Original Weight grams | Present Weight grams | Net Change grams |
| Profile 3 | | | | | | | | | |
| $A_{oo}$ | | | | | | | | | |
| $A_o$ | | | | | | | | | |
| $A_1$ | .17 | .11 | - .06 | .20 | .25 | + .05 | .20 | .45 | + .25 |
| $B_2$ | .94 | .87 | - .07 | 1.11 | 1.01 | - .10 | 1.12 | 1.30 | + .18 |
| $B_3$ | 1.19 | 1.25 | + .06 | 1.40 | 1.55 | + .15 | 1.42 | 1.77 | + .35 |
| Solum | 2.30 | 2.23 | - .07 | 2.71 | 2.81 | + .10 | 2.74 | 3.52 | + .78 |
| Profile 4 | | | | | | | | | |
| $A_o$ | | | | | | | | | |
| $A_{1g}$ | .56 | .30 | - .26 | .65 | .49 | - .16 | .65 | .52 | - .13 |
| G | 2.90 | 2.30 | - .60 | 3.31 | 2.57 | - .74 | 3.34 | 2.47 | - .87 |
| Solum | 3.46 | 2.60 | - .86 | 3.96 | 3.06 | - .90 | 3.99 | 2.99 | -1.00 |

TABLE IX (Continued)

| Horizon | Silt | | | Clay | | |
|---|---|---|---|---|---|---|
| | Original Weight grams | Present Weight grams | Net Change grams | Original Weight grams | Present Weight grams | Net Change grams |
| Profile 1 | | | | | | |
| $A_o$ | 2.71 | 2.98 | + .27 | .76 | .46 | - .30 |
| $A_2$ | 4.34 | 7.39 | +3.05 | 1.22 | 1.28 | + .06 |
| $B_{21}$ | 18.95 | 21.84 | +2.89 | 5.35 | 4.02 | -1.33 |
| Solum | 26.00 | 32.21 | +6.21 | 7.33 | 5.76 | -1.57 |
| Profile 2 | | | | | | |
| $A_o$ | | | | | | |
| $A_2$ | 3.19 | 3.37 | + .18 | .96 | .68 | - .28 |
| $B_{21}$ | 3.77 | 4.19 | + .42 | 1.14 | 1.04 | - .10 |
| $B_{22}$ | 4.35 | 4.56 | + .21 | 1.31 | 1.04 | - .27 |
| $B_3$ | 7.85 | 8.80 | + .95 | 2.37 | 1.66 | - .71 |
| Solum | 19.16 | 20.92 | +1.76 | 5.78 | 4.42 | -1.36 |

TABLE IX (Continued)

| Horizon | Silt Original Weight grams | Silt Present Weight grams | Silt Net Change grams | Clay Original Weight grams | Clay Present Weight grams | Clay Net Change grams |
|---|---|---|---|---|---|---|
| Profile 3 | | | | | | |
| $A_{oo}$ | | | | | | |
| $A_o$ | | | | | | |
| $A_1$ | 1.27 | 1.77 | + .50 | .42 | .27 | - .15 |
| $B_2$ | 7.02 | 8.37 | +1.35 | 2.33 | 1.79 | - .54 |
| $B_3$ | 8.89 | 9.62 | + .73 | 2.95 | 2.20 | - .75 |
| Solum | 17.18 | 19.76 | +2.58 | 5.70 | 4.26 | -1.44 |
| Profile 4 | | | | | | |
| $A_o$ | | | | | | |
| $A_{1g}$ | 2.60 | 3.36 | + .76 | .73 | 1.67 | + .94 |
| G | 13.31 | 14.80 | +1.49 | 3.75 | 4.96 | +1.21 |
| Solum | 15.91 | 18.16 | +2.25 | 4.48 | 6.63 | +2.15 |

profile as a result of soil development.

It will be observed from Table IX that there has been a net increase in organic matter in all horizons of all profiles with the exception of the $A_2$ of profile 1 which shows no net changes. A comparison of the sola of the profiles indicates that profile 1 has a greater total net increase than any of the other profiles.

The sand separates show a considerable variation. In profile 1 there has been a net loss of the coarsest fragments with an increase in very fine sand and silt. Profiles 2 and 3 show a slight net gain in sand of all sizes whereas all horizons of profile 4 show a net loss. The greatest net gains are in silt and all horizons of all profiles show a net increase. Some change has therefore taken place in the coarse fragments of these soils followed by an increase in silt. An explanation for this change may be as follows. It was stated previously that the parent materials of these soils were derived from thinly bedded calcareous shales which have probably suffered considerable metamorphism as a result of diastrophic movements. Some alteration of the various minerals in the original sediment then probably occurred. In the region in which these soils are found physical weathering is probably the predominant process. The breakdown of these hard metamorphic rocks is chiefly through frost action and the comminution of coarse fragments may still be taking place in this way. This would account for the increases in the sand and silt fractions of the soils at the expense of the fractions coarser than one millimeter.

The clay content of these soils showed a net decrease in all profiles except in profile 4 which showed a net gain. It is evident therefore that in the zonal soils of this region clay destruction or eluviation is more active than clay formation and illuviation. The net increases shown in profile 4 are considerable. This increase may be due to depositional differences or possibly to clay formation. It is to be expected that soils in this position in the landscape could allow mobile products of weathering produced in the soils on higher ground to accumulate

The net gains or losses in weight of the sola of the various profiles are shown in Table X and the changes in volume in Table XI. All profiles show a net gain in weight. However when examined by horizons, only the $A_2$ horizons show a net loss of materials in these soils. Large volume changes occur in the $A_0$, $A_1$ and $B_{21}$ horizons where additions of organic matter are taking place. The loosening effects of plant roots and frost action are probably also important influences on the volumes of the soil horizons, even those still low

TABLE X

NET CHANGE IN WEIGHT OF HORIZON

| Horizon | Original Weight grams | Present Weight grams | Net Change grams |
|---|---|---|---|
| Profile 1 | | | |
| $A_{oo}$ | | .66 | + .66 |
| $A_o$ | | .71 | + .71 |
| $A_2$ | 6.08 | 4.98 | -1.10 |
| $B_{21}$ | 9.74 | 11.58 | +1.84 |
| $B_{22}$ | 42.49 | 45.77 | +3.28 |
| Solum | 58.31 | 63.70 | +5.39 |
| Profile 2 | | | |
| $A_{oo}$ | | .66 | + .66 |
| $A_o$ | | .71 | + .71 |
| $A_2$ | 5.83 | 5.03 | - .80 |
| $B_{21}$ | 6.89 | 7.82 | + .93 |
| $B_{22}$ | 7.95 | 8.74 | + .79 |
| $B_3$ | 14.35 | 15.49 | +1.14 |
| Solum | 35.02 | 38.45 | +3.43 |

TABLE X (Continued)

| Horizon | Original Weight grams | Present Weight grams | Net Change grams |
|---|---|---|---|
| Profile 3 | | | |
| $A_{00}$ | | .66 | + .66 |
| $A_0$ | | .86 | + .86 |
| $A_1$ | 2.40 | 2.95 | + .55 |
| $B_2$ | 13.19 | 14.35 | + 1.16 |
| $B_3$ | 16.71 | 17.17 | + .46 |
| Solum | 32.30 | 35.99 | + 3.69 |
| Profile 4 | | | |
| $A_0$ | | 1.78 | + 1.78 |
| $A_1$ | 5.67 | 6.55 | + .88 |
| G | 28.94 | 28.98 | + .04 |
| Solum | 34.61 | 37.31 | + 2.70 |

TABLE XI

NET CHANGE IN VOLUME OF HORIZONS

| Horizon | Original Volume Cubic Centimeters | Present Volume Cubic Centimeters | Net Change Cubic Centimeters | Per cent Change |
|---|---|---|---|---|
| Profile 1 | | | | |
| $A_{oo}$ | 0 | 5.08 | ± 5.08 | ∞ |
| $A_o$ | 0 | 5.08 | ± 5.08 | ∞ |
| $A_2$ | 3.70 | 5.08 | ± 1.38 | ± 37.29 |
| $B_{21}$ | 5.94 | 15.24 | ± 9.30 | ±156.56 |
| $B_{22}$ | 25.90 | 43.18 | ±17.28 | ± 66.71 |
| Solum | 35.54 | 73.66 | ±38.12 | ±107.25 |
| Profile 2 | | | | |
| $A_{oo}$ | 0 | 5.08 | ± 5.08 | ∞ |
| $A_o$ | 0 | 5.08 | ± 5.08 | ∞ |
| $A_2$ | 3.55 | 5.08 | ± 1.73 | ± 51.64 |
| $B_{21}$ | 3.96 | 10.16 | ± 6.20 | ±156.56 |
| $B_{22}$ | 4.57 | 10.16 | ± 5.59 | ±122.32 |
| $B_{23}$ | 8.25 | 12.70 | ± 4.45 | ± 53.93 |
| Solum | 20.13 | 48.26 | ±28.13 | ±139.74 |

TABLE XI (Continued)

| Horizon | Original Volume Cubic Centi-meters | Present Volume Cubic Centi-meters | Net Change Cubic Centi-meters | Per Cent Change |
|---|---|---|---|---|
| Profile 3 | | | | |
| $A_{00}$ | 0 | 5.08 | + 5.08 | ∞ |
| $A_0$ | 0 | 5.08 | + 5.08 | ∞ |
| $A_1$ | 1.27 | 5.08 | + 3.81 | +300.00 |
| $B_2$ | 2.79 | 5.08 | + 2.29 | + 82.08 |
| $B_3$ | 11.04 | 12.70 | + 1.66 | + 15.03 |
| Solum | 15.10 | 33.02 | +17.92 | +118.67 |
| Profile 4 | | | | |
| $A_0$ | 0 | 12.70 | +12.70 | ∞ |
| $A_1$ | 2.81 | 7.62 | + 4.81 | +171.17 |
| G | 14.40 | 17.78 | + 3.38 | + 23.47 |
| Solum | 17.12 | 38.10 | +20.89 | +121.38 |

in organic matter.

Similar calculations were made for $Al_2O_3$, $Fe_2O_3$, CaO, MgO and $K_2O$. Those are shown in Table XII. A net increase in alumina has taken place in each profile, the increases being greatest in profiles 1 and 3. The $A_2$ horizons are again the only horizons showing a net loss. These gains in alumina are difficult to explain since it has been generally assumed that aluminum is a relatively mobile cation in acid soils. A gathering of aluminum by the vegetation from a volume greater than that assumed for the solum in each soil might account for this increase. The much greater amounts of $Al_2O_3$ than $Fe_2O_3$ in $A_o$ horizons would indicate that this is probable. The chemical composition of the gravel fractions in these profiles - not included in the chemical analyses which were made on the less than two millimeter fractions - might be responsible for some of the observed differences, if those gravel fractions are disintegrating to sand and silt sizes. In addition if, as seems probable, the layers chosen as the parent materials of each profile are also partly weathered then these increases may be only apparent rather than real. More detailed investigations extending to greater depths in carefully selected profiles representative of the zonal and hydromorphic soils in this area are

# TABLE XII

## ORIGINAL AND PRESENT CONSTITUENTS IN THE PROFILE $Al_2O_3$, $Fe_2O_3$, CaO, MgO, $K_2O$

| Horizon | $Al_2O_3$ | | | $Fe_2O_3$ | | | CaO | | |
|---|---|---|---|---|---|---|---|---|---|
| | Original Weight grams | Present Weight grams | Net Change grams | Original Weight grams | Present Weight grams | Net Change grams | Original Weight grams | Present Weight grams | Net Change grams |
| **Profile 1** | | | | | | | | | |
| $A_{oo}$ | | .01 | + .01 | | +.002 | +.002 | | .01 | +.01 |
| $A_o$ | | .02 | + .02 | | .001 | +.001 | | .006 | +.006 |
| $A_2$ | 1.34 | .45 | - 89 | .09 | .01 | -.08 | .007 | .003 | -.004 |
| $B_{21}$ | 2.16 | 3.00 | + .84 | .14 | .19 | +.05 | .01 | .01 | |
| $B_{22}$ | 9.42 | 11.30 | +1.88 | .63 | .67 | +.04 | .05 | .06 | +.01 |
| Solum | 12.92 | 14.78 | +1.85 | .86 | .873 | +.013 | .067 | .089 | +.022 |
| **Profile 2** | | | | | | | | | |
| $A_{oo}$ | | .01 | + .01 | | .002 | +.002 | | .01 | +.01 |
| $A_o$ | | .03 | + .03 | | .002 | +.002 | | .009 | +.009 |
| $A_2$ | 1.23 | .63 | - .60 | .12 | .03 | -.09 | .01 | .01 | |
| B21 | 1.45 | 1.67 | + .22 | .14 | .31 | +.17 | .01 | .01 | |
| B22 | 1.68 | 2.13 | + .45 | .16 | .29 | +.13 | .01 | .02 | +.01 |
| B 23 | 3.03 | 3.54 | + .51 | .30 | .30 | | .03 | .03 | |
| Solum | 7.39 | 8.01 | + .62 | .72 | .934 | +.214 | .06 | .089 | +.029 |

TABLE XII (Continued)

| Horizon | $Al_2O_3$ Original Weight grams | $Al_2O_3$ Present Weight grams | $Al_2O_3$ Net Change grams | $Fe_2O_3$ Original Weight grams | $Fe_2O_3$ Present Weight grams | $Fe_2O_3$ Net Change grams | CaO Original Weight grams | CaO Present Weight grams | CaO Net change grams |
|---|---|---|---|---|---|---|---|---|---|
| Profile 3 | | | | | | | | | |
| $A_{oo}$ | | .01 | + .01 | | .002 | +.002 | | .01 | + .01 |
| $A_o$ | | .08 | + .08 | | .003 | +.003 | | .02 | + .02 |
| $A_1$ | .49 | .72 | + .23 | .05 | .04 | -.01 | .008 | .01 | +.002 |
| $B_2$ | 2.74 | 3.44 | + .70 | .28 | .24 | -.04 | .04 | .05 | +.01 |
| $B_3$ | 3.47 | 3.60 | + .13 | .36 | .45 | +.09 | .05 | .03 | -.02 |
| Solum | 6.70 | 7.85 | +1.15 | .69 | .735 | +.04 | .098 | .12 | +.022 |
| Profile 4 | | | | | | | | | |
| $A_o$ | | .02 | + .02 | | .001 | +.001 | | .04 | + .04 |
| $A_{1g}$ | 1.16 | 1.58 | + .42 | .08 | .12 | +.04 | .01 | .03 | + .02 |
| G | 5.93 | 6.23 | + .30 | .45 | .24 | -.21 | .08 | .09 | + .01 |
| Solum | 7.09 | 7.83 | + .74 | .53 | .361 | -.17 | .09 | .16 | + .07 |

TABLE XII (Continued)

| Horizon | MgO Original Weight grams | MgO Present Weight grams | MgO Net Change grams | $K_2O$ Original Weight grams | $K_2O$ Present Weight grams | $K_2O$ Net Change grams |
|---|---|---|---|---|---|---|
| Profile 1 | | | | | | |
| $A_{oo}$ | | .001 | +.001 | | .001 | +.001 |
| $A_o$ | | .002 | +.002 | | .003 | +.003 |
| $A_2$ | .05 | .01 | -.04 | .10 | .05 | -.05 |
| $B_{21}$ | .08 | .14 | +.06 | .16 | .13 | -.03 |
| $B_{22}$ | .38 | .17 | -.21 | .70 | .58 | -.12 |
| Solum | .51 | .323 | -.187 | .96 | .764 | -.196 |
| Profile 2 | | | | | | |
| $A_{oo}$ | | .001 | +.001 | | .001 | +.001 |
| $A_o$ | | .002 | +.002 | | .002 | +.002 |
| $A_2$ | .11 | .02 | -.09 | .07 | .06 | -.01 |
| $B_{21}$ | .13 | .11 | -.02 | .08 | .09 | +.01 |
| $B_{22}$ | .15 | .11 | -.04 | .10 | .11 | +.01 |
| $B_{23}$ | .27 | .26 | -.01 | .18 | .25 | +.07 |
| Solum | .66 | .503 | -.157 | .43 | .513 | +.083 |

TABLE XII (Continued)

TABLE XII (Continued)

| Horizon | MgO Original Weight grams | MgO Present Weight grams | MgO Net Change grams | $K_2O$ Original Weight grams | $K_2O$ Present Weight grams | $K_2O$ Net Change grams |
|---|---|---|---|---|---|---|
| Profile 3 | | | | | | |
| $A_{oo}$ | | .001 | +.001 | | .001 | +.001 |
| $A_o$ | | .004 | +.004 | | .003 | +.003 |
| $A_1$ | .04 | .04 | | .03 | .03 | |
| $B_2$ | .23 | .22 | -.01 | .19 | .19 | |
| $B_3$ | .30 | .28 | -.02 | .24 | .26 | +.02 |
| Solum | .57 | .545 | -.025 | .46 | .484 | +.024 |
| Profile 4 | | | | | | |
| $A_o$ | | .002 | +.002 | | .004 | +.004 |
| $A_{1g}$ | .09 | .10 | +.01 | .07 | .11 | +.04 |
| G | .49 | .48 | -.01 | .40 | .47 | +.07 |
| Solum | .58 | .582 | +.002 | .47 | .584 | +.114 |

needed to clarify the situation.

The changes in the weight of iron were less significant than in the case of aluminum. A very slight net gain was obtained in profiles 1, 2 and 3 and a net loss in profile 4. Although losses are indicated in the $A_2$ horizons of profiles 1 and 2 there are also losses in other horizons of the other profiles. It would appear that there has been little change in this constituent within the various profiles but they indicate different general trends in Zonal and Hydromorphic soils of the area.

The other cations namely calcium, magnesium and potassium are present in very small amounts. However all profiles show a small gain in calcium and a net loss of magnesium. As suggested for aluminum and iron the vegetation might affect the distribution of these cations to different degrees relative to the leaching effect of percolating waters. The C horizons, assumed as parent material, of each profile studied was acid in reaction and very low in total calcium and magnesium, even though the soils are believed to be formed from slightly calcareous rocks. Sufficient weathering must therefore have taken place in the horizons designated as "C horizon" to have reduced the calcium and magnesium to their present small quantities.

A net loss of potassium was shown in profile 1 with small net increases in the other three profiles. The loss of potassium may be expected in these well drained acid soils.

## 6. CONCLUSIONS: RELATION OF SOIL CHARACTERISTICS TO TOPOGRAPHY

This investigation of a toposequence of soils in an upland region in the province of New Brunswick revealed that the characteristics of Podzol soils occurring in this region are considerably different from those reported in many other parts of the country.

The soils studied were considered to belong to the Caribou catena, a group of soils also occurring in the State of Maine. The area was heavily wooded and much of the soil was still in a virgin state.

In cultivated soils striking differences were seen in the colours of the soils in the well drained positions as compared with those in the poorly drained positions. These colour characteristics were associated with horizon differences in the various profiles occurring on any given slope. The $A_0$ horizon increased in thickness with decreasing slope and reached its maximum in the poorly drained position. The $A_2$ horizon was replaced by an $A_1$ horizon near the foot of the slope and this layer became gleyed at a still lower position.

The influence of slope on profile development was further revealed in the depth of profile. The deepest profiles occurred at the crest of the slope and became progressively shallower towards the foot. Accompanying the decrease in depth of profile development were certain physical changes in the soil. This study showed that the percolation rate decreased with depth for each of the individual profiles and that the less permeable horizons came closer to the surface towards the foot of the slope.

The mechanical analysis data showed that the silt fraction made up fifty percent of the soil material in all profiles. A net gain in silt had taken place in all horizons as a result of soil development processes. A net loss of clay had occurred in profiles 1, 2 and 3, indicating a feature that may be characteristic of all zonal soils in that region. A net increase in clay had occurred in profile 4 which may have been the result of clay formation or alluvial deposition. Only the $A_2$ horizons showed a consistent net loss of materials in these soils.

All the profiles in this study were acid in reaction. A decrease in acidity from the surface to the parent material was noted in each profile, a difference of about one pH unit. The soils became less acid as the slope decreased and in profile 3 the surface $A_{oo}$ horizon had the same pH as the parent material of profile 1. In the poorly drained position this increase in pH was confined to the mineral horizons of the profile as the relatively thick $A_o$ horizon was strongly acid.

The exchangeable bases occurred in largest quantities in the surface organic horizons and in the parent materials. Calcium was the predominant cation and showed much the same relation to the slope as the soil reaction, that is an increase in calcium accompanying a decrease in slope. No particular trend could be discerned between the various profiles with regard to the exchangeable cations, magnesium and potassium. The soluble phosphorus on the other hand indicated a relationship with slope since there was an increase in the lower horizons from profile 1 to profile 4.

The analyses for total organic matter showed that in addition to the $A_0$ and $A_1$ horizons there was a marked accumulation in the $B_2$ horizons. A net increase in organic matter was obtained for all horizons of all profiles except the $A_2$ of profile 1 which showed no change. The net gains in the sola of the various profiles showed that organic matter did not change in relation to slope.

The carbon-nitrogen ratios of the $A_0$ horizons ranged from 22.4 to 26.8 and of the $B_2$ horizons from 12. 1 to 18.8. The higher values in the B horizons occurred in the profiles with the deepest development and the best drainage near the top of the slopes.

The data for silica and sesquioxides revealed a net gain in aluminum in all horizons of all profiles excepting the $A_2$ horizons which showed a net loss. The gains in the other horizons were relatively uniform and no particular zone of accumulation could be detected.

Iron was present in very small amounts and slight gains were obtained for all profiles excepting profile 4 which showed a net loss. It would appear therefore that small increases in iron content have taken place in the zonal soils of this region but does not seem to be confined to any one particular horizon in the profile.

The analysis of the data used in this study reveals certain possible sources of error that need further study. Within the region in which these soils occur there are other locations where the till deposits may be as much as fifteen to twenty feet in depth. These soils should reveal whether any unweathered parent material is present and how it compares with that used in the present study.

In order to test the validity of the use of silica as a resistant reference mineral the determination of Zircon, either chemically or mineralogically, might be used to compare with the results obtained by this method.

A mineralogical study particularly of the feldspars would provide information on the formation and movement of the clay. A comparison could then be made between the processes taking place in the zonal and Hydromorphic soils.

BIBLIOGRAPHY

1. Aarnio, B. Ueber die Ausfällung des Eisenoxyds und der Tonerde in Finnlandischen Sand und Grüsboden Geotekniska Meddelanden, Finland. 1915.

2. Albrecht, W. A. Calcium saturation and anaerobic bacteria as possible factors in gleization. Soil Sci. 51: 213, 1941.

3. Alcock, F. J. New Brunswick, Past and Present. Can. Geog. Jour. 27: 64-83, 1943.

4. Anderson, M. S. and Mattson, S. The properties of the colloidal soil material. U. S. Dept. Agr. Bull. 1452, 1926.

5. Association of Official Agricultural Chemists. Official and tentative methods of analysis. ed. 5. 1945. Washington, D. C.

6. Bailey, E. H. Hydrogen ion concentration of the important soils of the United States in relation to other profile characteristics. Soil Sci. 59: 239-262. 1945.

7. Baver, L. D. Soil Physics. Second Edition. John Wiley & Sons. New York. 1948.

8. Bengtsson, B., Karlsson, N., Mattson, S. The pedography of hydrologic soil series. Lautbr. Högsk. Ann. 11: 172-189. 1943.

9. Bloomfield, C. Experiments on the mechanism of gley formation. Jour. Soil Sci. 2: 196-211. 1951.

10. Bodman, G. B. Factors affecting the downward movement of water in soils. Am. Soil Survey Assoc. Bull. 17: 33-38. 1936.

11. Brown, Irvin C. and Thorp, James. Morphology and composition of some soils of the Miami family and the Miami catena. U.S.D.A. Tech. Bull. 834. 1942.

12. Brown, Irvin C. and Byers, H. G. Chemical and physical properties of certain soils developed from granitic materials in New England and the Piedmont and of their colloids. U.S.D.A. Tech. Bull. 609.

13. Byers et al. Formation of soil. Yearbook of Agriculture. U.S.D.A. 1938.

14. Cann, D. B., Lajoie, P. and Stobbe, P.C. Soil survey of Shefford, Brome and Missisquoi counties, Quebec. Canada Dept. of Agr. 1947.

15. Cann, D. B. A Study of the Genesis of a Gray Brown Podzolic-Podzol Intergrade Soil Profile in Michigan. Doctor of Philosophy Thesis, Michigan State College, 1954.

16. Chandler, R. F. Cation exchange properties of soils. Jour. Agr. Res. 59: 491-505, 1939.

17. Chandler, R. F. The time required for podzol profile formation evidenced by the Mendenhall glacial deposits near Juneau, Alaska. Soil Sci. Soc. Amer. Proc. 7: 454-459, 1942.

18. Chemical methods of soil analysis. Soil Sci. 59. 1945. 68. 1949.

19. Cline, Marlin G. Profile studies of New York soils. Soil Sci. 68: 259-272, 1949.

20. ______________ Major kinds of profiles and their relationships in New York. Soil Sci. Soc. Amer. Proc. 17: 123-127, 1953.

21. Coile, T. S. Composition of the leaf litter of forest trees. Soil Sci. 43: 349-355, 1937.

22. Davies, W. M. and Owen, G. Soil survey of N. Shropshire. Emp. J. Exp. Agr. 3: 1-11, 1934.

23. Deb, B. C. The movement and precipitation of iron oxides in podzol soils. Jour. Soil Sci. 1: 112-122, 1949.

24. Diagnostic Techniques for Soils and Crops. American Potash Institute. Washington 6, D. C. 1948.

25. Flint, R. F. Glacial Geology and the Pleistocene Epoch. John Wiley & Sons, New York. 1947.

26. Free, G. R., Browning, G. M., Musgrave, G. W. Relative infiltration and related physical characteristics of certain soils. U.S.D.A. Tech. Bull. 729, 1940.

27. Frei, Erwin and Cline, M. G. Profile studies of normal soils of New York. Micromorphological studies of the Gray-Brown Podzolic-Brown Podzolic soil sequence. Soil Sci. 68: 333-344, 1949.

28. Gardner, D. R. and Whiteside, E. P. Zonal soils in the transition region between the Podzol and Gray Brown Podzolic regions in Michigan. Soil Sci. Soc. Am. Proc. 16: 137-141, 1952.

29. Geology and Economic minerals of Canada. Economic Geology Series 1. Canada Dept. of Mines and Resources, Ottawa. 1947.

30. Glinka, K. The great soil groups of the world and their development. Edwards Bros. Ltd. Ann Arbor. 1927.

31. Halliday, W. E. D. Forest service bull. No. 89. Canada Dept. of Mines and Resources. Ottawa. 1937.

32. Jenny, Hans. Factors of soil formation. McGraw Hill Book Co. New York. 1941.

33. ________ Arrangement of soil series and types according to functions of soil forming factors. Soil Sci. 61: 375-391, 1946.

34. Joffe, J. S. The distribution of soluble and colloidal iron and aluminum in soils. Soil Sci. 26: 317-325, 1928.

35. ________ The process of podzolization. Soil Sci. 32: 303-323, 1931.

36. ________ The process of podzolization. Soil Sci. 33: 217-237, 1932.

37. ________ The process of podzolization. Soil Sci. 35: 239-257, 1932.

38. ________ Mature podzols. Soil Sci. 35: 313-331, 1933.

39. ________ Pedology. Rutgers University Press. New Brunswick, New Jersey. 1936.

40. ____________ A pedologic study of some soils in New Jersey. Soil Sci. 43: 221-238.

41. Lag, J. Illustration of influence of topography on depth of $A_2$ layer in podzol profiles. Soil Sci. 71: 125-127, 1951.

42. Lajoie, P. and Stobbe, P. Soil survey of Soulanges and Vaudreuil counties, Quebec. 1950.

43. Larsen, H., Mattson, S. The pedography of hydrologic soil series. Lantbr. Högsk. Ann. 9: 222-238, 1941.

44. Leamer, R. W., Shaw, Byron. A simple apparatus for measuring noncapillary porosity on an extensive scale. Jour. Am. Soc. Agron. 33: 1003-1008, 1941.

45. Lundblad, K. Studies on podzol and brown forest soils. Soil Sci. 37: 137-155, 1934.

46. Lunt, Herbert A. Profile characteristics of New England forest soils. Conn. Agr. Exp't. Sta. Bull. 342, 1932.

47. ________________ The forest soils of Connecticut. Conn. Agr. Exp't. Sta. Bull. 523, 1948.

48. Lyford, W. H. The morphology of the Brown Podzolic soils of New England. Soil Sci. Soc. Amer. Proc. 11: 486-492, 1946.

49. _____________ Characteristics of some podzolic soils of the north eastern United States. Soil Sci. Soc. Amer. Proc. 16: 231-235, 1952.

50. Marbut, C. F. Soils: Their genesis and classification. Lectures given to graduate school of the U.S.D.A. 1928 Soil Science Society of America 1951.

51. Marshall, C. E. and Haseman, J. F. The quantitative evaluation of soil formation and development by heavy mineral studies: A Grundy silt loam profile. Soil Sci. Soc. Amer. Proc. (1941) 7: 448, (1942).

52. Matelski, R. P. and Turk, L. M. Heavy minerals in some podzol soil profiles in Michigan. Soil Sci. 64: 469-487, 1947.

53. Mattson, S. and Gustafson, Y. The chemical characteristics of soil profiles. Ann. Agr. College. Sweden. V. 1: 33-68 (1934). V. 2: 1-30 (1935). V. 2: 115 (1935).

54. ___________, Karlsson, N. The pedography of hydrologic soil series. Lantbr. Högsk. Ann. 12: 186-203, 1944.

55. ___________ The pedography of hydrologic soil series. Lantbr. Högsk. Ann. 12: 119-129, 1944.

56. McCaleb, S. B. and Cline, M. G. Profile studies of normal soils of New York. Physical and chemical properties of Brown Forest and Gray Brown Podzolic soils. Soil Sci. 70: 315-328, 1950.

57. McCool, M. M., Veatch, J. O., Spurway, C. H. Soil profile studies in Michigan. Soil Sci. 16: 95-106, 1923.

58. Millar, C. E. and Turk, L. M. Fundamentals of Soil Science. Second Edition. John Wiley & Sons, Inc. New York. 1951.

59. Morison, M. B. Dominion Forest Service Bull. 91. Dept. of Lands and Mines. Ottawa. 1925.

60. Nelson, W. R. and Baver, L. D. Movement of water through soils in relation to the nature of the pores. Soil Sci. Soc. Amer. Proc. 5: 69-76, 1940.

61. Norton, E. A. and Smith, R. S. The influence of topography on soil profile character. Jour. Am. Soc. Agron. 22: 251-262, 1930.

62. Nygard, I. J., McMiller, P. R., Hole, F. D. Characteristics of some podzolic soils. Soil Sci. Soc. Amer. Proc. 16: 123-129, 1952.

63. Olmstead, L. B., Alexander, L. T., Middleton, R. E. Pipette method of mechanical analyses of soils based on improved dispersion procedure. U.S.D.A. Tech. Bull. 170, 1950.

64. Peech, M., et al. Methods of soil analysis for soil fertility investigations. U.S.D.A. Circ. 757, 1947.

65. Pierre, W. H., Scarseth, G. D. Determination of the percentage base saturation of soils and its value at definite pH values. Soil Sci. 31: 99-114, 1931.

66. Piper, C. S. Soil and Plant Analysis. The University of Adelaide, Adelaide, Australia. 1942.

67. Putnam, D. F. The climate of the Maritime Provinces. Canadian Geographic Journal 21: 134-147, 1940.

68. ____________ Canadian Regions. J. M. Dent & Sons Ltd. Toronto, 1952.

69. Richard, J. Aurele and Chandler, R. F. Jr. Some physical and chemical properties of mature podzols. Soil Sci. Soc. Amer. Proc. 8: 379, 1943.

70. Robinson, G. W. Soils, their origin, constitution and classification. Thomas Murby & Co. London, 1949.

71. Russell, M. B. Measuring structure and aeration. Soil Sci. 68: 25-35, 1949.

72. Russell, Sir E. John. Soil conditions and plant growth. Longmans, Green & Co. London, 1952.

73. Shell, Haskiel, R. Possible loss of iron during sodium carbonate fusion of silicates and rocks. Analytical chemistry. Vol. 26, No. 3: 591-593, 1954.

74. Slater, C. S. and Byers, H. G. A laboratory study of the field percolation rates of soils. U.S.D.A. Tech. Bull. 232, 1931.

75. Smith, G. D. Advantages and problems related to the field study of soil development. Soil Sci. Soc. Amer. Proc. 6: 78-82, 1941.

76. Smith, R. M., Browning, D. R., Pohlman, G. G. Laboratory percolation through undisturbed soil samples in relation to pore size distribution. Soil Sci. 57: 197-213.

77. Field and laboratory data on some podzol, brown podzolic, brown forest and gray wooded soils in northern United States and southern Canada. Soil survey Lab. Mem. No. 1. Beltsville, Md. 1952.

78. Soil Survey Manual. U.S.D.A. Handbook No. 18. U.S.D.A. Washington, 1951.

79. Stobbe, P. C. and Leahey, A. Guide for the selection of agricultural soils. Canada Dept. of Agr. Pub. 748. Ottawa. 1944.

80. Tamm, O. Markstein i det nordsvenska barr skogs-omradet. Medd. fr. Stat. Skogsfors. 17: 49, 1920.

81. Uhland, R. E. and O'Neal, A. M. Soil permeability determinations for use in soil and water conservation. SCS-TP-101. Washington, D. C. 1951.

82. Von Engeln, O. D. Geomorphology. The Macmillan Co. New York, 1949.

83. Whiteside, E. P. Clay formation and movement. Soil Sci. Soc. Amer. Proc. 9: 211-218, 1944.

84. Wicklund, R. E. and Smith, G. R. Soil survey of Colchester county, Nova Scotia. Report No. 3. Canada Dept. of Agric. Ottawa. 1948.

85. Winters, Eric. Interpretative soil classifications. Genetic groupings. Soil Sci. 67: 131-139, 1949.

86. ______________ The migration of iron and manganese in colloidal systems. Ill. Agric. Expt. Sta. Bull. 472, 1940.

87. Wright, H. C. Soil Analyses. Ed. 2. Thomas Murby & Co. London. 1939.

# Date Due

| | | | |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |