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A STUDY OF THE GENESIS OF A GRAY BROWN PODZOLIC-PODZOL INTERGRADE SOIL PROFILE IN MICHIGAN

By

Donald Bruce Cann

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan
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ABSTRACT

A modification of the resistant mineral method used by Marshall and Haseman was applied to a study of the genesis of a Gray Brown Podzolic-Podzol intergrade in Michigan. Changes introduced in the method were (1) the use of quartz, instead of zircon, as the resistant reference mineral, (2) the determination of quartz with a Geiger counter x-ray spectrometer and (3) the use of the coarser fractions of the soil.

Quartz was determined quantitatively on the coarse, fine and very fine sand fractions of the soil, using a Norelco Geiger counter x-ray spectrometer. The method developed eliminates the use of an internal standard used by previous workers and is time saving. It was found that the choice of a quartz standard was important.

Calculation of the volume of parent material necessary to produce one cubic centimeter of the present horizons gave a volume change factor for determining the original volume and weight of each horizon. The gains and losses for the solum were thus computed.

Results show that about 85 percent of the soluble material originally present has been removed from the profile. There was a total loss in weight of the solum, but a 20 percent gain in volume which occurred largely in the A_{1p}, A_{2p} and B_p horizons. Marked increases in

organic matter in the B_p and in organic matter and clay in the B_{21GBP} seem to indicate that both of these are illuvial horizons. Losses of soluble material, silt and clay and the small volume change of the B_{1GBP} horizon, compared with the horizons above and below, give support to the conclusion that it is an eluvial horizon and that two processes are occurring simultaneously during profile development.

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I. INTRODUCTION

The study of the evolution of the present day characteristics of soils from the original unweathered material has not developed as rapidly as studies in other branches of soil science. There are several reasons for this. Observation of soils in many places and under many different conditions required considerable time, but the acquired knowledge emphasized the need for an orderly arrangement or classification of soils based on their characteristics and manner of development. Soil survey workers, fully cognizant of the practical viewpoint, were aware also of the necessity for soil genetic studies, but in most cases, had neither the time nor facilities to carry on the work.

Until 1942, the study of soil genesis lacked two important factors necessary to all scientific studies, namely, a quantitative method of measuring soil development and its duration in time. In this year Marshall and Haseman[32] published the results of a quantitative study of soil development in which the change in mineral composition of the various soil layers with depth was assessed against a selected mineral known to be resistant to weathering. Certain assumptions were necessary and some of these might not be valid in the light of present knowledge. Nevertheless, this is the only quantitative method for studying soil genesis that has appeared in the literature and its usefulness is now becoming apparent.

The purpose of the present investigation was to apply the Marshall and Haseman technique to the study of a Gray Brown Podzolic - Podzol intergrade soil of Michigan in an attempt to determine its genesis and mode of formation. An "intergrade" is the term applied to a soil showing characteristics of more than one major soil group. In this case, a profile typical of the true Podzol soils has apparently developed in the A_2 horizon of a soil belonging to the Gray Brown Podzolic Group. Cline[12] has observed this condition in New York state and Gardner[16] has studied the occurrence of the "double profile" in Michigan.

In the present study, two innovations in the Marshall and Haseman technique were introduced. Quartz was used as the reference resistant mineral instead of zircon as proposed by Marshall and Haseman. The Geiger counter x-ray spectrometer was used to determine quartz and other soil minerals.

II. REVIEW OF LITERATURE

The literature dealing with the study of soil formation consists of contributions from many phases of soil science. Early workers were interested in the effects of single factors such as climate, vegetation, or parent material on soil formation and the work was largely descriptive. Later, this work was supplemented by contributions from the study of soil organic matter, soil colloids, base exchange and the structure of the clay minerals. More recently, particularly in the last decade, the trend has been toward a mineralogical approach. Much of this work has been qualitative and little attention has been given to the development of sound quantitative methods.

One of the earlier studies on the evolution of soils was that of Griffiths et al.[18], who observed the effects of vegetative changes on soil profile development in central New England. Here, one hundred years of pasture and tillage had been followed by eighty years of white pine. The pine, in turn, was followed by forty years of hardwood forest. With increasing time under pine, the dark brown cultivated layer became thinner and organic matter accumulated. At forty years some profiles showed a trace of leached A_2 horizon and at eighty years, a recognizable true Podzol profile had developed. During the first ten years under hardwood occupation, most of the organic matter accumulated under pine disappeared, leaving a thin A_1 horizon. The B horizon deepened and became darker in color. One of the very noticeable features was the change in the consistency of the B horizon under pine and again under hardwood. Under the young pine there is a wide variation of consistency from loose to tough, with a greater proportion loose to friable. With increasing age the soils become more compact and tenacious. Once the pines are removed, the soil under the young hardwoods again loosens up. The hardwoods have a decided effect on the soil, changing the structure found under pine to nearly one hundred percent crumby structure under the older hardwood groups.

Hesselman[21] showed that the presence in a forest stand of species rich in basic buffers often determines the character of the upper part of the soil profile, as to whether it will become a mull or raw humus type. Larch litter is acid and rich in acid buffers, but is much richer in basic buffers than either pine or spruce litter. The effect on the soil may be indirect, affecting the role of micro-organisms in their decomposition of humus.

Lunt[29] also attempted to correlate soils in New England with forest vegetation. He concludes that the type of forest vegetation is conditioned by the soil. He pointed out that a good mull develops under a thrifty hardwood stand and occurs as a result of favorable soil conditions.

Lundblad[27] showed that parent material containing calcium carbonate was not necessary for the formation of Brown Forest soils except where they were formed under "acclimatic" conditions. He noted a different type of organic matter in the humus horizon of the Brown Forest than in the Podzol soil and assumed that a different type of weathering was responsible. Later[28] in confirmation of the Mattson theory of isoelectric weathering, he considered the Podzols to have developed through an extreme type of acid weathering, the typical Brown Forest soils through a mild acid weathering, with the "acclimatic" Brown Forest soil taking a middle course between the two.

Chandler[9] found that the colloidal material in the A horizon of the Podzol had a considerably higher silica-sesquioxide ratio than the corresponding fraction of the Brown Podzolic soil which he studied, but the ratio in the B horizons of the two soils was the same. The organic content of the colloidal material from the A_1 horizon was high. The content of olivene, hypersthene and hornblende remained high in the A horizon of the Brown Podzolic soil, but these minerals were severely weathered in the A horizon of the Podzol.

Deb[14] studied the movement of iron oxides in Podzol soils and showed that iron may move in any one of six different forms. He found that the amount of humus necessary to peptize iron oxide sol varies considerably with the source of the humus and the concentration and pH of the iron oxide. The ratio of humus to ferric oxide was constant for each kind of humus over a wide range of concentrations. From Deb's work it is evident that any iron oxide sol formed by weathering in the upper horizons of Podzols should be fully peptized by the humus in soil solution. Deb concluded that the precipitation of iron oxide sol in the B horizon was not due to exchangeable calcium alone or to colloidal flocculation of humus protected sols or to chemical precipitation of complex salts. He thought it would be necessary to postulate a microbiological mechanism for the precipitation of iron.

In a somewhat similar study, Bloomfield[4] showed that an aqueous extract of pine needles brought ferric and aluminum oxides into solution and the iron was reduced to the ferrous state under neutral aerobic conditions. The ferrous iron, and possibly the aluminum were present in the form of organic complexes. The ferrous complex was not readily decomposed under alkaline conditions and, at pH 8.0, relatively large quantities of iron remained in solution. This seemed to be in agreement with the ideas advanced by Stobbe.[45]

Some observations made by Burges and Drover[5] on Australian soils indicated that half of the calcium carbonate in a profile was removed in fifty years. A distinct A horizon was developed in 300 years, at 1000 years a B horizon was noticeable and at 2000 years the soil had all the characteristics of an iron Podzol. Measurements were made on old beach lines whose age had been established.

Cline et al.[12,15,36] have reported on a series of profile studies on the soils of New York, based on the hypothesis that on calcareous parent materials in that state, soil development follows a sequence from Brown Forest, through Gray Brown Podzolic to Brown Podzolic and Podzol soils. The profile becomes increasingly acid in the upper part and the mull humus layer of the Brown Forest soil is gradually replaced by a strongly acid matted mor. The A_2 horizon thickens and in the Gray Brown Podzolic stage, there is evidence of a double profile developing. The structure of the B horizon changes. Microscopic studies revealed that clays were concentrated on the aggregates in the lower horizons and these had been translocated by water. Silicate clays played the dominant role in the mobile fraction of the Gray Brown Podzolic soils, while oxide clays appeared to be dominant in the Brown Podzolic soils. Physical and chemical studies showed that clay deposition followed the carbonate layer downward.

These workers pointed out that the thickness of the eluviated zone and the depth of clay accumulation in the solum was related to the loss of bases as a function of time and permeability of the profile.

In a more recent study, Cline[13] showed that when the A_2 horizon of the Gray Brown Podzolic soil became strongly acid, yellowish iron films appeared on the primary particles in the upper part of the A horizon. This was interpreted as the first sign of incipient Podzol development. When the entire solum had become strongly acid, a weak Podzol profile appeared above the Gray Brown Podzolic B horizon. Illite clays dominated all horizons. In the southern part of the state, Gray Brown Podzolic soils occurred on both acid and calcareous materials, but showed no evidence of incipient Podzol development within a degrading Gray Brown Podzolic solum. It would appear from this that climatic factors were responsible, at least in part, for the formation of double profiles.

A similar sequence of soil development was reported by Stobbe[45] who investigated the morphology of the Gray Brown Podzolic and related soils of Eastern Canada. Stobbe believed that Gray Brown Podzolic soils were not formed by the podzolization process. He cites as evidence the high pH, high base saturation, accumulation of clay and lack of organic matter in the B horizon and the fact that podzolic degradation may take place in the upper part of the solum.

Possibly the process differs in degree rather than kind. Stobbe pointed out that calcareous materials liberated iron and aluminum at a higher rate than non-calcareous materials, hence sesquioxides may be liberated before all the free calcium carbonate is removed.

In a study of some Podzolic soils in the northern Great Lakes area, Nygard and his co-workers[40] observed that Podzol characteristics were superimposed on other soils in the region, but advanced no theories as to how this had occurred.

The characteristics of Podzolic soils in northeastern United States have been described by Lyford[30]. Some of these soils appear to be polygenetic, having a leached horizon and one of deposition in the place where the normal A_1 and A_2 horizons would have occurred. Such soils were observed to appear only on calcareous parent materials north of the Wisconsin terminal moraine, but on non-calcareous materials south of it.

The occurrence of double profiles has also been reported by Allen[3]. These profiles occur on till of both Mankato and Cary age, but development is more advanced on the Cary till.

A further study of the morphology of double profiles was made by Gardner and Whiteside[16]. They believed that the upper part of the profiles had been developed from uniform materials - in other words, the profiles were genetic.

The time required for the change from Gray Brown Podzolic was regarded as less than post-Mankato time since, as Allen pointed out, the profiles also developed in Mankato drift. Gardner and Whiteside believed that two processes were operating simultaneously, the formation of the upper horizons being accelerated by the climatic conditions.

Johnsgard[24] suggested that the height of rise of capillary water above the water table may have considerable effect in determining the type of soil that will develop. He showed that a sandy Podzol had a marked depletion of hornblende, augite, actinolite and feldspars throughout the solum, whereas a Half-Bog soil did not show any marked change in these minerals. Cady[6] studied soils developed from similar parent material under different vegetation. He concluded that the relative abundance of easily weathered minerals in the Brown Podzolic A horizons indicates a lesser intensity of podzolization under hardwood than under spruce-hardwood. Hornblende and pyroxene are readily decomposed under conditions of strong podzolization, while epidote, magnetite and garnet are little affected.

In a search for a mineral sufficiently resistant to be useful as a weathering index, Mickelson[39] found that only zircon and tourmaline would meet the requirements and these were present in significant quantity only in the coarse silt fraction. He concluded from a calculation of the hornblende/garnet ratios that garnet fragments decompose readily. This does not agree with the work of Cady. Mickelson also used the percentage composition of the mineral suite to compute his zircon/tourmaline ratios. It would have been more accurate to use the total amount or grams of constituent, since percentages change with weathering and loss of other minerals.

In 1942, Marshall and Haseman[32] described a quantitative method for evaluating soil formation by the use of heavy mineral studies. Using zircon as the index mineral, they evaluated weathering losses from the solum by comparison of the zircon in the solum with that in the parent material. They used the size distribution of zircon as a test of whether the profile had developed from the underlying material. It was necessary to assume that the resistant minerals had not undergone any decomposition and that they had not been translocated in the profile. One of the objections to the use of zircon is that it may occur rarely in some soils and in amounts difficult to measure. Other more common and abundant minerals might serve as well. Marshall and Haseman pointed out that the coarser soil fractions might be useful as indicators in soil genetic studies. Their results showed that profile development extends to a greater depth than is normally supposed. Further studies by Humbert and Marshall[22] showed that the presence of ferrous ions in silicate structures causes a rapid breakdown when these are exposed to weathering agencies, due to oxidation of the iron.

Matelski and Turk[35] reported studies on the heavy mineral fraction of some Michigan Podzols. They found that organic matter was an effective weathering agent in the B horizon and that heavy minerals in the B horizon suffered greater decomposition than in the A or C horizons. They suggested that more accurate results are obtained by subjecting the entire fine sand fraction to heavy mineral analysis rather than just a small portion.

Mick[38] in a study of Michigan soil profiles gave an excellent review of previous mineralogical investigations by various workers. He found that hornblende was the most abundant heavy mineral in the drift. Mick expressed the hypothesis that, in certain profiles, the calcite of the lower horizons has changed to dolomite and supported this with magnesium analyses of the lower horizons. He discussed the evolution of a St. Clair profile and the changes taking place during development, but his method of calculating these changes is open to criticism, since he assumed that heavy mineral count percentages were weight percentages. This will affect, to some extent, the calculated gains or losses of constituents and thus create a false impression of the course of soil development.

The mineralogical composition of a heath Podzol has been described by van der Marel[46], who pointed out that the potassium content of the feldspars decreased from the lower zones upward, especially through the A_2 horizon.

He considered that this indicated a selective process in podzolic weathering as regards the kind of feldspar being decomposed. Silica gel increased from the surface downward and aluminum hydroxide gels flocculated at a greater depth than the iron hydroxide gels. This work is somewhat similar to that of Graham[17] who showed that the weathering rates of the plagioclase feldspars increased with increasing calcium content. Graham considered albite as being extremely resistant to weathering.

Rolfe[44] has studied the mineralogical characteristics of fourteen major soil profiles. He found that the micas showed a definite weathering sequence and could be used as a basis for a weathering criterion. He believed that podzolization is essentially a process of iron oxide removal rather than one of mineral decomposition. He pointed out that dispersion of free iron oxides at a low pH is a function of the type of humus and therefore the production of a leached layer depends on the type of vegetative cover. Rolfe recognized two types of double profiles - one caused by a change in the weathering regime and the other resulting from two depositions of soil material in one profile. He concluded that there is an intimate relationship between the vegetation and the mineral content of the soil

The choice of quartz as the standard mineral against which weathering losses were to be assessed led to a review of methods for determining this mineral. Microchemical methods for the determination of quartz were tried and found to be unsatisfactory and mineralogical methods were necessarily tedious and not accurate enough for the purpose. The recent application of the Geiger counter x-ray spectrometer to the determination of minerals seemed to offer a solution to the problem.

Quartz has been determined by x-ray methods for a number of years, using the camera technique, but the usefulness of this method as a quantitative procedure has been limited by the many variables that exist in the preparation, mounting, exposure and interpretation of results. The Geiger counter x-ray spectrometer eliminates or minimizes many of these variables.

The first method suitable for routine quantitative mineralogical analyses with x-rays was published by Clark and Reynolds[11] in 1936. These workers were among the first to develop the internal standard method. A pure crystalline powder known not to be present in the mixture was added to the unknown in a definite ratio and the diffraction pattern measured by a suitable apparatus - in this case a circular reflection camera. The ratio of the density of a line of the substance sought to that of a nearby line of the standard was determined photometrically.

Following the publication of this paper, a number of workers applied the technique to mineral analysis. Hellman et al.[20] reported on a quantitative procedure for the estimation of montmorillonite and in 1944 MacEwan[31] reported further work along this line.

Whiteside[47] applied the Clark and Reynolds procedure to the study of loess. This was the first application of the use of an internal standard with soil materials. Whiteside used ammonium chloride as an internal standard and introduced an innovation in the rotating sample method by filling the sample tubes only partially full in order to promote random orientation of the particles. Quartz, feldspar, calcite and dolomite were determined quantitatively.

In 1947 Jeffries[23] published an excellent description of the Geiger counter x-ray spectrometer and its use in determining essential soil minerals. He showed results of the qualitative analysis of the very fine sand, silt and clay fractions of several soils.

Carl[7] pointed out the limitations of the camera technique and described quantitative methods using the Geiger counter x-ray spectrometer. He observed that the method was rapid, non-destructive, and practically independent of particle size, locked grains or minor surface coatings. Some later workers seem to disagree with this statement.

A quantitative method for the analysis of heavy metal carbides with the x-ray spectrometer was described by Redmond[43]. He describes two methods for mounting the sample and emphasizes that the spectrometer must be standardized from day to day.

The use of the x-ray spectrometer for organic quantitative analysis has been described by Christ, Barnes and Williams[10]. They found widely variable results when particle size was reduced below 0.2 microns and pointed out that their method is valid only if the particle size distribution of the unknown is essentially the same as that of the standard used. They also found that crystal orientation could be overcome by mixing carbon black with the sample.

During 1948, Alexander, Klug and Kummer[2, 25, 26] published several papers dealing with investigations into the x-ray spectrometer operation and theory. They showed that the intensity of the diffracted rays were a function of the particle size, number of particles present and the proportion of particles favorably oriented. Their results seemed to indicate that good reproducibility was dependent on the particle dimensions being less than five microns. Later, Alexander and Klug[1] developed the mathematical relationships applicable to the quantitative analysis of powder mixtures with the x-ray spectrometer. They were able to show that experimental measurements of quartzite and fluorite mixtures fell on the theoretical intensity-concentration curves derived by mathematical analysis of the factors involved.

Most investigators up to 1948 had not used any standard procedure for sample preparation and mounting.

McCreery[37] introduced a method for preparing mounts especially for the x-ray spectrometer. Essentially, the material is tamped gently into a hollow cell backed by a glass plate. The surface is smoothed off and covered with another glass plate. The cell is then turned over and the original glass cover removed, exposing a smooth surface for irradiation.

Among the first workers to apply the Geiger counter x-ray spectrometer to the quantitative mineralogical analysis of soils were Phillippe and White[41]. They used the McCreery technique and sodium fluoride as an internal standard. These workers expressed the belief that the range in particle sizes introduced by grinding the samples may have some effect on the reproducibility. Phillippe and White give a good description of the spectrometer and recorder operation.

Pollack[42] reported a study of the x-ray diffraction of sixteen common silica minerals and the effects of various factors on the reproducibility of results. Pollack used the McCreery technique and later made some changes in the method which decreased the standard error of the results. He investigated the effects of grinding and preparation of the sample and thought that the difficulty in obtaining reproducibility lay in the technique of preparing the sample and variations between different quartz varieties.

III. APPARATUS AND MATERIALS

A. The Geiger-counter X-ray Spectrometer

The instrument used in this investigation was a Norelco Type 42202 Geiger-counter x-ray spectrometer manufactured by the North American Phillips Company, Inc. of New York. It consists of a basic x-ray production unit having an x-ray tube with a tungsten filament and cooper target. A nickel filter .0007 inches thick filters out all but the cooper K-alpha radiation.

A wide range, high and low angle Geiger-counter goniometer is mounted on the unit and carries the collimating slits and sample holder. The principles of operation have been described by Jeffries[23].

The emergent beam was collimated by a slit having an angular aperture of one degree. This exposed about two-thirds of the focal area of the sample to the x-rays at the angle (26.60° 2θ) at which the 3.35 A. spacing of quartz was measured. At larger angles, a smaller proportion of the focal area is exposed to the beam. The diffracted beam entering the Geiger-counter tube was defined by a slit having a width of .003 inches. A scatter slit with a four degree aperture was used between the receiving slit and the Geiger-counter tube to insure that only rays diffracted by the sample entered the tube. The sample holder and Geiger-counter tube are motor driven and synchronized so that an angle of 2θ is always maintained in scanning. The goniometer was run at a scanning speed of one degree per minute and the x-ray tube was operated at 30 kilovolts and 15 milliamperes. A warming up period of thirty minutes was allowed before x-raying the samples. The intensity of the diffracted beam received by the Geiger counter tube was electronically recorded by a Brown automatic recorder as peaks on a graph. The height of the peaks above the recorder background is proportional to the intensity of the diffracted beam.

B. Soil Profile Investigated

The soil used in this study was a profile of the Marlette loam. The sampling site was located 200 yards east of the northwest corner of the northeast quarter of the northwest quarter of Section 33, T14N, R13E, Sanilac County, Michigan. Here, the Marlette loam is developed on gently rolling topography outside the Port Huron moraine. The original vegetation consisted of maple and mixed deciduous cover, but the site of the sample is now under sod.

The parent material of the Marlette loam is a calcareous loam till, thought to be of Cary age, and the profile shows the presence of carbonates at a depth of about 36 inches. The soil is well drained and comparatively free from large stones. The annual precipitation in this area averages 35 to 40 inches. The upper part of the profile shows well developed Podzol characteristics and the Marlette loam is a good example of the Gray Brown Podzolic-Podzol intergrade found in Michigan. A detailed description of the profile is given below.

Profile Description

H Horizon	Depth in Inches	Description
A_{1p}	0 -- 2.5	dark gray* (7.5YR4/0) silt loam; weak crumb structure; pH 7.5
A_{2p}	2.5-- 4.0	light grayish brown (7.5YR6/2) loam; very weak crumb structure; pH 5.5
B_p	4.0-- 9.0	strong yellowish brown (10YR5/6) loam; weak crumb structure; pH 5.7
A_{2GBP}	9.0-- 13.5	brown to dark orange yellow (10YR6/6) loam; weak fine granular structure; pH 6.0
B_{1GPB}	13.5-- 18.0	brown to dark orange yellow (10YR6/6) loam; subangular blocky structure; pH 6.0
B_{21GBP}	18.0-- 27.0	strong yellowish brown (10YR5/6) loam; medium blocky structure; clay coatings on particles; somewhat mottled; pH increases with depth from 6.5 at 23 inches to about 8.0 at 27 inches
B_{22GBP}	27.0-- 36.0	strong yellowish brown (10YR5/6) loam; medium blocky structure; pH 8.0
C	36.0-- 72.0	strong yellowish brown (10YR5/6) loam; calcareous; pH 8.0

* ISCC - NBS color names are used herein.

IV. EXPERIMENTAL PROCEDURE

A. Preliminary Investigation

The desire to use quartz as a reference mineral made it necessary to investigate the applicability of the x-ray spectrometer to its quantitative determination. Previous workers[25, 10, 42] have pointed out the significance of particle size in obtaining reproducibility. Carl[7], however, observed that results were independent of particle size.

A preliminary investigation was carried out to determine the significance of particle size on the diffraction intensity of quartz. A clear crystal of geode quartz, furnished by the Department of Geology, Michigan State College, was ground to pass a 325 mesh (44 microns) sieve. This material was then fractionated by sedimentation into 2-10, 10-20, 20-50 and greater than 50 microns fractions. Samples of each fraction were then x-rayed and the resulting intensities recorded.

Mounting and measuring the sample. The McCreery method[37] as modified by Pollack[42] was used in mounting the samples. Aluminum slides or lozenges approximately 40 millimeters square and 1 millimeter thick, having a rectangular hole 10 by 20 millimeters were used to hold the sample. This provided a maximum focal area of 200 square millimeters. The opening was covered on one side with a piece of glass, slightly larger than the opening, firmly bound to the surface with scotch tape. The sample was spread into this cell by tapping the material off a spatula until the cell was filled to excess. The material was then tamped into place by working the edge of the spatula over the surface. The surface was levelled off with a razor blade, more material spread on and the process repeated two or three times. Finally, the surface was levelled, covered with a glass plate taped to the slide, the slide turned over and the original glass plate carefully removed. This resulted in a smooth surface for exposure to the x-rays. The slide was placed in the spectrometer and the intensity of the rays diffracted by the 3.35 A^o spacing of quartz was recorded. The goniometer was allowed to run two or three degrees (2θ) on either side of the peak intensity of quartz and the intensity was measured with the angle 2θ both increasing and decreasing.

Thirty six measurements were made on each slide, 12 each on the center, left and right sections, by shifting the slide in the appropriate direction in the spectrometer. Thus it was possible to measure the variability within the slide resulting from preparation technique. In order to measure reproducibility, slides of each fraction were measured on different days. A discussion of the results is given in Chapter V.

B. Preparation of Soil Sample

One hundred gram samples of each soil horizon were treated with hydrogen peroxide to remove organic matter. After filtration and washing, the washed sediment was transferred to shaker bottles and diluted with water. The suspension was made just alkaline to phenolphthalein and shaken overnight. The sands were separated from the silt and clay by washing on a 300 mesh sieve. The dried sands were weighed and fractionated by sieving into coarse and medium sand (2 - .25 millimeters), fine sand (.25 - .10 millimeters) and very fine sand (.10 - .05 millimeters). Any fine material passing the 300 mesh sieve was added to the silt and clay fraction. The sand fractions were then treated for removal of free silica and iron and aluminum oxides by the method of Marshall and Jeffries[33].

Heavy mineral separations were made on portions of the fine sand and very fine sand, using tetrabromoethane of specific gravity 2.90. A further separation of the light fraction of the very fine sand at a specific gravity of 2.70 was made by diluting the tetrabromoethane with nitrobenzene.

For x-ray analyses, samples of the cleaned sand fractions were ground in a steel mortar to pass a 300 mesh sieve. This material was used directly in the preparation of slides.

C. Analytical Determinations

Mechanical analysis. Determination of the silt and clay content was carried out on the material washed through the 300 mesh sieve after separation of the sands.

Bulk density determinations were made on core samples from each horizon.

Organic matter and solution loss. Organic matter and solution loss were determined on separate samples of the air dry soil. Organic matter was determined by treatment with hydrogen peroxide. The residue from this determination was treated with 0.2 normal HCl. The loss in weight after washing and drying was regarded as solution loss.

Mineralogical examination. A qualitative examination of the minerals present in the very fine sand fraction was made with the petrographic microscope. An examination of the coarser sand fractions was also made.

X-ray spectrometer analysis. After preliminary investigation, it was decided to attempt to measure feldspars as well as quartz, since these minerals gave strong diffraction intensities in a region conveniently near that of quartz. It was also decided to make the measurements without the use of an internal standard, as used by previous workers, by comparing the peak heights of the unknown directly with those of known standards. This method saves considerable time in preparation of the samples and standards and in the calculation of the results. The feasibility of such a procedure has been advocated by Klug et al.[26] when the unknown contains more than 60 percent quartz.

Consequently, standards were prepared of pure quartz, pure anorthite, pure albite and pure orthoclase. Check mixtures containing 80 percent quartz and 20 percent albite and 70 percent quartz and 20 percent albite were also prepared. Calcium carbonate was used as the diluent where necessary. The pure quartz used is the standard and in the mixtures was the 2 - 10 micron fraction used in the preliminary investigation mentioned under A above.

Slides were prepared in the manner described above for mounting and measuring the sample and the standards were x-rayed. The goniometer was run at a scanning speed of one degree per minute and was allowed to range from 26 degrees (2θ) to approximately 28.80 degrees (2θ), which was sufficient to record the diffraction intensities of both the quartz and the feldspars. Four slides of each sample were prepared and two determinations were made on two sections of each slide, making a total of sixteen determinations per sample.

The soil samples prepared for analysis as described above were mounted and x-rayed in the same manner as the standards. The ratio of the heights of the peaks from the unknowns to those of the pure minerals above the background was taken as a measure of the amount of mineral present.

The ratio of height of the peaks obtained from the soil samples to that obtained from the 100 percent standards was calculated as percent quartz or feldspar respectively. Attention was focussed largely on the quartz determinations and the pure quartz standard was run each day at the beginning and end of other determinations in order to check the constancy of the apparatus and the reproducibility of the results.

V. RESULTS AND DISCUSSION

A. Results of Preliminary Studies

The effects of the particle size of quartz on the intensity of the diffracted x-rays are summarized in Tables I, II and III. Table I shows the mean peak heights obtained from each size fraction run on different days, in order to check the variability of the apparatus and the reproducibility of the results. The peak heights in Table I are the means of 36 determinations made on each size fraction.

TABLE I

MEAN PEAK HEIGHTS OF SIZE FRACTIONS

Particle size (microns)	First Day	Second Day
2 - 10	164.9	166.9
10 - 20	167.3	169.3
20 - 50	165.5	166.5
>50	135.0	197.1

The results indicate that particle sizes in the range 2 to 50 microns have about the same effect on the diffraction intensity of the x-rays. It should also be noted that the average of the peak heights for >50 microns obtained on different days is similar to those of the finer size fractions. It is known, however, that very small particle sizes, below about 0.5 microns, do show variability in their effects on the diffraction intensity.

In order to test the significance of the differences in peak heights between the different size fractions, Fisher's "t" value was calculated for (1) the difference between means of the same size fraction run on different days and (2) between the means of different size fractions run on the same day. These values are given in Tables II and III respectively. These values were calculated from the measurement of peak heights obtained with angle 2θ both increasing and decreasing. A value of t = 2 or greater is required for significance at the 5 percent level.

TABLE II

SIGNIFICANCE BETWEEN MEAN PEAK HEIGHTS OF SAME SIZE FRACTION RUN ON DIFFERENT DAYS

Particle Size (microns)	"t" values between means of size fractions							
	2 - 10u		10 - 20u		20 - 50u		>50u	
	Inc*	Dec*	Inc.	Dec.	Inc.	Dec.	Inc.	Dec.
2 - 10	.67	.12						
10 - 20			1.32	1.65				
20 - 50					.38	1.13		
>50							13.3	11.7

* Calculated from peak heights obtained with 20 increasing and decreasing respectively.

TABLE III

SIGNIFICANCE BETWEEN MEAN PEAK HEIGHTS OF DIFFERENT SIZE FRACTIONS ON THE SAME DAY

Particle Size (microns)	"t" values between means of size fractions							
	2 - 10 u		10 - 20 u		20 - 50 u		>50 u	
	Inc.*	Dec.*	Inc.	Dec.	Inc.	Dec.	Inc.	Dec.
2 - 10			.60	1.39	.16	.21	7.50	8.30
10 - 20					.26	.37	8.43	10.00
20 - 50							4.37	5.46

*Calculated from peak heights obtained with 2θ increasing and decreasing respectively.

The results indicate no significant difference in the effect of particle size on diffraction intensity between 2 and 50 microns. Above this there is considerable variation. Calculation by the author showed that there also was no significant difference between values obtained with 2θ increasing and with 2θ decreasing, except above the 50 micron particle size.

B. Determination of Quartz in Soil Fractions

The results obtained in the preliminary studies seemed to indicate that the method would be applicable to soils provided that the material was within a given size range. The 2 - .25 millimeter, .25 - .10 millimeter and the .10 - .05 millimeter fractions were prepared as described in Chapter IV and x-rayed. The mean peak heights, measured above the background, were calculated as percent of the mean peak height obtained from the pure quartz standard and the results considered as percent quartz in the fraction. The results are presented in Table IV.

TABLE IV

PERCENT QUARTZ IN SOIL SAND FRACTIONS

Soil horizon	Very fine Sand	Fine sand	Coarse* sand
A_{1p}	91.88	101.00	102.60
A_{2p}	91.08	99.86	102.74
B_p	85.10	97.01	92.18
A_{2GBP}	87.90	93.97	90.88
B_{1GBP}	89.47	91.09	92.41
B_{21GBP}	81.23	89.40	90.11
B_{22GBP}	81.06	90.69	86.16
C	83.06	91.49	83.11

*Coarse and medium sand.

The percentage quartz recorded for both the A_{1p} and A_{2p} horizons of the fine and coarse sand fractions was over one hundred percent and the results in general would appear to be high. Several separate determinations on these two fractions consistently gave peak heights (intensities) greater than those of the pure quartz standard. It was first thought that the difference in particle size of the pure standard (2 - 10 microns) compared with that of the soil fraction (roughly 20 - 50 microns) might be responsible. This would have been in contradiction to the results obtained in the preliminary studies. Consequently, a sample of the 20 - 50 micron fraction of quartz used in the preliminary study was x-rayed. The peak heights obtained gave values similar to those of the 2 - 10 micron fraction.

Pollack[42] in his study of quartz varieties had obtained a lower value for geode quartz than for a sample of Ward's quartz (from Ward's Natural Science Establishment, New York) which he had used as a standard. Fortunately, a sample of the Ward's quartz used by Pollack was available and this was ground to pass a 300 mesh sieve and prepared for x-ray in a manner similar to the soil fractions.

The peak heights obtained from the Ward's sample were considerably higher than those from the geode quartz, previously used as a standard in this investigation. A sample of geode quartz also used by Pollack was checked against the geode sample used in this study and similar peak heights were obtained. It is not known why the geode quartz gives lower values and this might be the subject of some fruitful investigation.

It was believed that the Ward's quartz more nearly represented the desired 100 percent quartz standard and the values in Table IV were re-calculated on the basis of the mean peak heights obtained from the Ward's quartz. The results are presented in Table V.

TABLE V

REVISED PERCENT QUARTZ IN SOIL SAND FRACTIONS

Soil Horizon	Very Fine Sand	Fine Sand	Coarse* Sand
A_{1p}	67.43	74.13	75.23
A_{2p}	66.85	73.29	75.41
B_p	62.46	71.20	67.66
A_{2GBP}	64.52	68.97	66.70
B_{1GBP}	65.67	66.86	67.82
B_{21GBP}	59.62	65.61	66.14
B_{22GBP}	59.49	66.56	63.24
C	60.92	67.15	61.00

*Coarse and medium sand.

The percentage quartz is somewhat higher in the fine and coarse sand fractions than in the very fine sand, but decreases fairly regularly with depth in the profile in all fractions.

Table VI presents the results in a different manner and represents the percent of the soil weight contributed by the quartz from the respective fractions.

TABLE VI

QUARTZ IN SOIL FRACTIONS AS PERCENT OF TOTAL SOIL

Horizon	Coarse sand	Fine sand	Very fine sand	Total
A_{1p}	7.26	11.25	10.18	28.69
A_{2p}	7.70	11.59	11.35	30.64
B_p	7.23	9.69	7.76	24.68
A_{2GBP}	6.33	10.11	9.36	25.80
B_{1GBP}	6.07	9.31	10.69	26.07
B_{21BGP}	6.12	8.62	7.21	21.95
B_{22GBP}	5.98	8.74	8.75	23.47
C	5.90	8.96	8.49	23.35

Accompanying the determinations of quartz, the peak heights of the feldspars present in the soil fractions were recorded. Two principal peaks seemed to be evident and consistent throughout the analyses - one occurring at an angle of 27.50 degrees (2θ) and the other at 28.10 degrees (2θ). These correspond approximately to lattice spacings of 3.23 A. and 3.16 A. respectively. The peaks were taken to represent respectively the orthoclase and the plagioclase feldspars, but the identification of any particular feldspar was not possible, since the reflections from the various feldspars tend to overlap in this range.

The respective peak heights were measured and calculated as percent feldspar by comparison respectively with the peak heights obtained from pure orthoclase and pure albite. The results presented in Table VII may be regarded as comparative only since, in many cases, the amounts present were so small as to make accurate measurements questionable. It is possible also that other feldspars besides orthoclase, microcline or albite with nearly similar spacing may have been present and contributed to the peak height. However, some idea of the relative amount and distribution of the feldspars is brought out in Table VII.

TABLE VII

PERCENT FELDSPARS IN SAND FRACTIONS

Orthoclase Feldspars				Plagioclase feldspars		
Soil Horizon	Very fine sand	Fine sand	Coarse Sand	Very Fine Sand	Fine sand	Coarse sand
A_{1p}	7.63	8.56	2.23	5.80	5.50	1.68
A_{2p}	8.64	4.96	3.45	4.20	1.60	2.90
B_{p}	7.27	4.96	4.16	5.26	1.68	3.89
A_{2}GBP	8.05	5.17	4.03	6.33	2.91	4.96
B_{1}GBP	8.42	3.81	4.60	6.48	1.75	5.26
B_{21}GBP	6.33	4.88	2.45	5.34	3.89	5.19
B_{22}GBP	6.12	4.37	2.58	5.79	2.52	5.95
C	5.96	5.25	2.88	7.25	2.90	4.65

The figures in Table VII reveal a tendency for the feldspars to be more abundant in the finer fractions of the soil. The distribution throughout the profile is variable. The orthoclase feldspars tend to decrease with depth in all fractions, but the plagioclase feldspars show a somewhat irregular tendency to increase with depth in the profile. This probably reflects the greater ease of weathering of the plagioclases.

C. Results of Physical and Chemical Analysis

The results of physical and chemical determinations on the Marlette loam are presented in Table VIII. The mechanical analysis indicates that the profile has developed from material similar to that now underlying the solum and appearing as the C horizon. The high organic matter content in the B_p horizon indicates movement of organic material. The increase in bulk density with depth indicates that either considerable material has been lost from the original solum or there has been an increase in volume of the original material. As will be shown later, both of these processes occur. The silt and clay content varies irregularly with depth in the profile. A high silt content in the A horizons is accompanied by a high total sand content which modifies the texture. A high clay content occurs in the B_{21} horizon and this may be the result of soil development processes. It might be pointed out

TABLE VIII

COMPOSITION OF THE MARLETTE LOAM PROFILE EXCLUDING GRAVEL

Horizon	Bulk Density grams per millimeter	Organic Matter percent	Solution* Loss percent	Coarse sand 2-.25 millimeters percent	Fine Sand .25-.10 millimeters percent	Very Fine Sand .10-.05 millimeters percent	Silt .05-.002 millimeters percent	Clay .002 millimeters percent
A_{1p}	1.00	7.86	1.47	9.66	15.18	15.10	42.58	9.62
A_{2p}	1.02	2.81	0.65	10.21	15.82	16.98	44.63	9.55
B_p	1.04	5.40	1.84	10.69	13.62	12.42	40.59	17.28
A_{2GBP}	1.51	2.15	1.89	9.49	14.66	14.51	43.08	16.11
B_{1GBP}	1.66	1.75	1.10	8.95	13.92	16.29	42.45	16.64
B_{21GBP}	1.65	2.20	2.47	9.26	13.14	12.09	40.32	22.99
B_{22GBP}	1.75	1.34	3.92	9.46	13.13	14.71	42.19	19.17
C	1.87	1.01	14.93	9.67	13.34	13.93	44.17	17.88

*Solution loss determined after mechanical analyses here that the results in Table VIII, except bulk density, are based on the weight of oven dry soil from which the gravel greater than 2 millimeters has been removed. Bulk density determinations, however, include the gravel. Organic matter plus sand, silt and clay total one hundred percent. The effect of the gravel on the calculation of changes taking place during soil development will be discussed later.

D. Mineralogical Studies

A qualitative examination of the heavy minerals separated from the very fine and fine sand fractions was made to determine whether or not any particular mineral was more abundant than others. Table IX gives the percentage of heavy minerals found in the fractions, the best yields being obtained from the very fine sand.

TABLE IX

PERCENT HEAVY MINERALS IN SAND FRACTIONS

Horizon	Very fine sand	Fine Sand
A_{1p}	3.78	0.50
A_{2p}	1.16	0.40
B_p	3.90	0.60
A_{2GBP}	2.32	0.50
B_{1GBP}	2.68	0.50
B_{21GBP}	2.34	0.80
B_{22GBP}	2.00	0.70
C	2.22	0.90

As is the case in many Michigan soils, the heavy mineral suite was dominated by hornblende. This material varied widely in its degree of weathering, from the dark green slightly altered mineral to grains partially altered to chlorite. The hornblende was less abundant in the A_p horizons than deeper in the profile, but there appeared to be little difference in its abundance in the various horizons below the A_{2p} layer.

The other accessory minerals observed were augite, hypersthene, diopside, epidote, tourmaline, rutile, leucoxene, garnet and zircon. Opaque minerals included ilmenite and magnetite.

An examination of the whole coarse sand fraction from the C horizon gave some indication of the origin of the parent material. The fraction contained fragments of mica schist, fossiliferous limestone, quartzite, syenite and some sandstone. Quartz and feldspars were the dominant minerals. The variability of the quartz was particularly noticeable. It occurred as sharp, angular transparent to translucent grains and in subangular, frosted forms. Both rose quartz and the smoky variety were present and a small percentage of the particles were spherical in shape as though wind blown.

In the separated finer fractions and the unseparated coarser fractions, the micas were conspicuously absent. A few fragments of muscovite and biotite were observed, but they were widely scattered throughout the fractions. A count of the zircon in the heavy mineral fraction of the very fine sand showed that it ranged from 3.97 to 7.25 percent, these extreme values occurring in the B_{21} and B_{22} horizons respectively. The zircon content of the other horizons was quite uniform, varying from 4.40 to 5.40 percent of the heavy mineral suite.

VI. APPLICATION OF ANALYTICAL DATA TO THE STUDY OF SOIL DEVELOPMENT

It is intended in this section to apply the results obtained from x-ray and analytical determinations to a study of the formation and movement of materials in the profile of the Marlette loam. As in the Marshall and Haseman technique, a resistant mineral - in this case, quartz - was used as a standard against which net gains or losses in the profile were assessed. The method involves certain basic assumptions, namely,

(1) that the profile has developed from material similar to that now regarded as the C horizon and

(2) that the quartz originally present has not been weathered, formed or translocated in the profile.

The results of the mechanical analysis indicate that the present profile is genetic. The second assumption is not strictly true since all minerals eventually undergo weathering. Even zircon has been shown to weather under certain conditions[8]. However, in relation to other minerals in the profile, quartz may be regarded as being very resistant under the environmental conditions found in Michigan and the sand sizes are not regarded as being mobile under these conditions. In this study the total percent quartz found in the sand fractions of each horizon (Table VI) is used as a basis of calculating the gains or losses in the profile. The method of calculation is described below.

A. Method of Calculating Data

The changes in the profile 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. The steps involve 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.

From the percentage quartz in each horizon the amount of quartz per 100 cubic centimeters was calculated by multiplying the percentage quartz by the bulk density of the horizon. Using the C horizon as a standard, the number of cubic centimeters of parent material required to produce 1 cubic centimeter of the present horizon was obtained by dividing the grams quartz per 100 cubic centimeters of each horizon by this value for the C horizon. This gives a 'volume change' factor for each horizon.

The original weight of each horizon was found by multiplying the volume of each horizon (= depth in centimeters) by the volume change factor times the bulk density of the C horizon or parent material. This weight multiplied by the percentage of each constituent in the C horizon (Table VIII) gave the original weight of each constituent. The present weights were similarly calculated from the present weight and percentages of constituents in each horizon.

B. Results and Discussion

The volume change factors calculated for the Marlette loam by the method described above are presented in Table X, and the calculated net changes in weight of constituents for each horizon are shown in Table XI. The percentage net change is given in Table XII.

TABLE X

VOLUME CHANGE FACTORS FOR THE MARLETTE LOAM

Horizon	Percent Quartz in Soil	Grams of Quartz per 100 Cubic Centimeters	Volume Change Factor
A_{1p}	28.69	28.69	.66
A_{2p}	30.64	31.25	.72
B_p	24.68	25.67	.59
A_{2GBP}	25.80	38.96	.89
B_{1GBP}	26.07	43.28	.99
B_{21GBP}	21.95	36.22	.83
B_{22GBP}	23.47	41.07	.94
C	23.35	43.66	1.00

The grams of quartz per 100 cubic centimeters show considerable variation throughout the solum due to changes in volume taking place during soil development. The least change appears to be in the B_{1GBP} horizon.

The data in Table XI show the changes in weights of the horizons due to soil formation processes. Organic matter has increased in all horizons of the solum, but particularly in the A_{1p}, B_p and B_{21GBP} horizons. Since added organic matter comes principally from the surface, this indicates that translocation and deposition of organic colloidal material must have taken place in the profile.

About 85 percent of the soluble material has been lost from the solum, the percentage loss being highest in the A_{2p} and B_{1GBP} horizons. The sand fractions all show small losses in weight from the solum, but the actual percentage loss is, in general, below 5 percent. Such changes are negligible if it is considered that particle distribution through the original material was not strictly uniform. Thus small changes in the percentage of sand in the parent material might occur with change in depth or position.

There is a distinct loss of silt from each horizon. Some of the finer silt has undoubtedly weathered to clay minerals, but there seems to be definite evidence of translocation in the profile.

A considerable loss of clay has taken place from the surface, nearly 60 percent of the original clay plus whatever may have been formed having been removed from the

TABLE XI

ORIGINAL AND PRESENT CONSTITUENTS IN THE PROFILE, EXCLUDING GRAVEL

Horizon	Organic Matter			Solution Loss			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
A_{1p}	.07	.49	+ .42	1.16	.09	-1.07	.75	.61	- .14
A_{2p}	.05	.11	+ .06	.79	.03	- .76	.51	.41	- .10
B_p	.14	.72	+ .58	2.10	.24	-1.86	1.36	1.42	+ .06
A_{2GBP}	.18	.36	+ .18	2.75	.32	-2.43	1.79	1.59	- .20
B_{1GBP}	.23	.36	+ .13	3.45	.23	-3.22	2.23	1.85	- .38
B_{21GBP}	.35	.82	+ .47	5.23	.92	-4.31	3.39	3.45	+ .06
B_{22GBP}	.40	.54	+ .14	6.06	1.58	-4.48	3.93	3.82	- .11
Solum	1.42	3.40	+1.98	21.54		-18.43	13.96	13.15	- .81

TABLE XI (continued)

Horizon	Fine Sand			Very Find Sand			Silt		
	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
A_{1p}	1.04	.96	- .08	1.08	.95	- .13	3.44	2.68	- .76
A_{2p}	.70	.64	- .06	.74	.68	- .06	2.35	1.79	- .56
B_p	1.88	1.80	- .08	1.95	1.64	- .31	6.22	5.39	- .83
A_{2GBP}	2.46	2.46	----	2.57	2.43	- .14	8.16	7.22	- .94
B_{1GBP}	3.08	2.88	- .20	3.23	3.38	+ .15	10.23	8.82	- 1.41
B_{21GBP}	4.68	4.89	+ .21	4.88	4.51	- .37	15.48	15.04	- .44
B_{22GBP}	5.41	5.30	- .11	5.65	5.94	+ .29	17.93	17.06	- .87
Solum	19.25	18.93	- .32	20.10	19.53	- .57	63.81	58.00	- 5.81

TABLE XI (continued)

Horizon	Clay			Total			Volume			
	Original Weight grams	Present Weight grams	Net Change grams	Original Weight grams	Present Weight grams	Net Change grams	Original Volume Cubic Centimeters	Present Volume Cubic Centimeters	Net Change Cubic Centimeters	Percent Change
A_{1p}	1.39	.61	- .78	7.77	6.30	-1.47	4.15	6.30	+2.15	+45.54
A_{2p}	.96	.39	- .57	5.31	4.02	-1.29	2.84	3.95	+1.11	+39.08
B_p	2.52	2.29	- .23	14.07	13.26	- .81	7.52	12.75	+5.23	+66.22
A_{2GBP}	3.31	2.70	- .61	18.47	16.76	-1.71	9.88	11.10	+1.22	+11.23
B_{1GBP}	4.13	3.46	- .67	23.13	20.75	-2.38	12.37	12.50	+ .13	+ 1.01
B_{21GBP}	6.28	8.58	+2.30	35.06	37.29	+2.23	18.75	22.60	+3.85	+20.53
B_{22GBP}	7.27	7.76	+ .49	40.59	40.42	- .17	21.71	23.10	+1.39	+ 6.40
Solum	25.86	25.79	- .07	144.40	138.80	-5.60	77.22	92.30	+15.08	+19.52

TABLE XII

PERCENT CHANGE IN CONSTITUENTS, EXCLUDING GRAVEL

Horizon	Organic Matter	Solution Loss	Coarse Sand	Fine Sand	Very Fine Sand	Silt	Clay	Total
A_{1p}	+600.0	- 92.3	- 18.6	- .7	- 13.7	- 22.1	- 56.2	- 19.2
A_{2p}	+120.0	- 96.2	- 19.6	-8.6	- 8.1	- 23.8	- 59.3	- 24.3
B_p	+414.2	- 88.5	+ 4.4	-4.2	- 15.9	- 13.3	- 9.1	- 5.7
A_{2GBP}	+100.0	- 88.3	- 11.1	0.0	- 5.4	- 11.5	- 18.4	- 9.2
B_{1GBP}	+ 56.5	- 93.4	- 16.5	-6.5	+ 4.6	- 13.7	- 16.2	- 10.3
B_{21GBP}	+103.4	- 82.7	+ 1.7	+4.4	- 7.6	- 2.8	+ 36.6	+ 6.4
B_{22GBP}	+ 35.0	- 73.8	- 2.8	-2.0	+ 5.1	- 4.8	- 6.7	- .42
Solum	+139.5	- 85.6	- 5.8	-1.7	- 2.8	- 9.1	- .3	- 3.8

A_{1p} and A_{2p} horizons. There is a small percentage loss of clay from the B_p horizon, but the accumulation of clay in the B_{21GBP} horizon is very marked. This is the only horizon in the solum showing a distinct gain in weight. The increase in clay may be due, in part, to formation in place, but the losses in the solum above this horizon is evidence of translocation of considerable fine material. Further evidence of translocation of the clay may be found in examination of the structural units of the lower horizons. Here, fine clay may be detected on the walls of root channels and on cleavage faces.

There is a net loss in weight of the solum of 5.6 grams and a total volume increase of 15 cubic centimeters or 19.5 percent. Large volume changes occur in the A_{1p}, A_{2p} and B_p horizons where loosening of the soil by plant roots and the addition of organic matter is taking place. A volume change of 20.5 percent occurs in the B_{21GBP} horizon which may be attributed largely to microplastic movement of the clay. The very small volume change in the B_{1GBP} horizon is worthy of note. It would appear that additions and losses from this horizon are such as to offset any marked change in volume.

It was thought that a mechanical analysis of the sand, silt and clay on an organic matter-solution loss free basis might give a clearer picture of the changes in

TABLE XIII

ORIGINAL AND PRESENT CONSTITUENTS IN THE PROFILE, EXCLUDING GRAVEL*

Horizon	Coarse 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
A_{1p}	.71	.62	- .09	1.07	.94	- .13	1.23	.98	- .25
A_{2p}	.48	.38	- .10	.73	.65	- .08	.84	.68	- .16
B_p	1.28	1.33	+ .05	1.94	1.91	- .03	2.24	1.95	- .29
A_{2GBP}	1.67	1.48	- .19	2.54	2.32	- .22	2.93	2.73	- .20
B_{1GBP}	2.10	1.62	- .48	3.18	2.86	- .32	3.66	3.41	- .25
B_{21GBP}	3.19	2.85	- .34	4.82	4.96	+ .14	5.54	5.68	+ .14
B_{22GBP}	3.70	3.54	- .16	5.59	5.61	+ .02	6.42	5.98	- .44
Solum	13.13	11.82	-1.31	19.87	19.25	- .62	22.86	21.41	-1.45

* Original analyses performed by class in Soil Science. Results expressed on insoluble-organic matter free basis.

TABLE XIII (continued)

Horizon	Silt			Clay			Total		
	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
A_{1p}	3.33	2.66	- .67	1.35	.61	- .74	7.77	6.30	-1.47
A_{2p}	2.27	1.84	- .43	.93	.36	- .57	5.31	4.02	-1.29
B_p	6.03	5.36	- .67	2.45	1.99	- .46	14.07	13.26	- .81
A_{2GBP}	7.91	7.30	- .61	3.23	2.57	- .66	18.47	16.76	-1.71
B_{1GBP}	9.92	8.92	-1.00	4.04	3.58	- .46	23.13	20.75	-2.38
B_{21GBP}	15.04	14.51	- .53	6.12	8.46	+2.34	35.06	37.29	+2.23
B_{22GBP}	17.39	16.83	- .56	7.07	7.91	+ .84	40.59	40.42	- .17
Solum	61.89	57.42	-4.47	25.19	25.48	+ .29	144.40	138.80	-5.60

* Original analyses performed by class in Soil Science. Results expressed on insoluble - organic matter free basis.

the insoluble constituents in the mineral fraction of the soil. Such an analysis had been performed on this soil previously by students in Soil Science. The volume change factors obtained in the present investigation were used to calculate the net changes from these data and the results are presented in Table XIII.

It would appear that considerable soluble material was contained in the sand fractions. A net increase in clay in the solum indicates that some clay formation has taken place. The movement of materials is brought out more sharply in this table.

Some idea of the changes taking place in the feldspars may be gathered from the data in Table XIV. These data are comparative only as explained earlier and indicate a trend.

TABLE XIV

NET CHANGES IN FELDSPARS OF THE SAND FRACTIONS

Horizon	Orthoclase Feldspars		Plagioclase Feldspars	
	Net Change grams	Change percent	Net change grams	Change percent
A_{1p}	+ .028	+20.1	- .025	-18.9
A_{2p}	+ .009	+ 9.6	- .052	-53.5
B_p	+ .014	+ 5.5	- .087	-55.4
A_{2GBP}	+ .053	+16.1	- .038	-11.2
B_{1GBP}	+ .061	+14.6	- .074	-16.8
B_{21GBP}	- .025	- 3.9	- .036	- 5.6
B_{22GBP}	- .041	- 5.6	- .044	- 5.8
Solum	+ .099	+ 3.8	- .356	-13.3

The total feldspars show a net loss from the solum which is more evident in the plagioclase than in the orthoclase feldspars. The percentage gain or loss is small except in the A_{2p} and B_p horizons where the plagioclase feldspars have lost about 55 percent of their original weight. In general, the feldspars in the sand fractions do not appear to contribute very much to the net changes in the horizons.

Since the bulk density determinations include the gravel in the soil, it was thought that a comparison of the net changes, excluding gravel, should be made with the changes when gravel was included in the calculations. The composition of the soil when gravel is included is given in Table XV. The effect is to lower the percentage of constituents given in Table VIII, particularly in the A_{2p}, B_p and B_{22GBP} horizons where the percentages of gravel are high.

The net changes including gravel are shown in Table XVI and a comparison of the net changes with and without gravel is presented in Table XVII. The most significant changes, when gravel is included, are the apparent increase in the weight of gravel in the solum, especially in the B_{22GBP} horizon, and the reduction in total weight loss from the solum. As explained above, this may be due to irregular distribution of gravel in the original material. A high gravel content in some of the present horizons would thus appear as a large gain in weight and should not be interpreted as translocation or accumulation in the profile. This condition of heterogeneity is less likely to occur as the fractions become smaller in size. In the B_{22GBP} horizon the effect of gravel is to double the change in volume.

C. Suggestions for Further Study

The results obtained have revealed possible sources of error in this type of study and suggest additional lines of investigation that would be helpful in the interpretation of the data. The following suggestions are proposed as a guide for future work of this nature.

1. The whole soil, including gravel, should be studied. In soils containing considerable gravel, this may be an important factor in computing net gain or loss from the solum. The percentage of constituents should be calculated on the weight of the total oven dry soil.

2. A total chemical analysis of the soil would be useful in tracing the movement of the various chemical constituents.

3. An accurate quantitative determination of the feldspars would give information on the formation and movement of the clay. The x-ray technique developed in this study could be applied to the determination of the feldspars as well as to quartz.

4. The C horizon should be sampled at sufficient depth so that the true parent material will be obtained. This may only be revealed by subsequent analyses.

5. In the study of an intergrade it would be helpful if a profile of the zonal soils to which it is related could be studied. In the present case it would have been interesting to compare the intergrade with the profiles of a true Podzol and Gray Brown Podzolic soil.

6. The results obtained by this method might be compared with those obtained when zircon, determined chemically or mineralogically, was used as the resistant reference mineral.

7. The possibility of using the quartz/feldspar ratio to determine the volume change factors offers another method of approach.

TABLE XV

COMPOSITION OF THE MARLETTE LOAM PROFILE, INCLUDING GRAVEL

Horizon	Bulk Density grams per millimeter	Organic Matter percent	Solution* Loss percent	Gravel 2 millimeters percent	Coarse Sand 2-.25 millimeters percent	Fine Sand .25-.10 millimeters percent	Very Fine Sand .10-.05 millimeters percent	Silt .05-.002 millimeters percent	Clay .002 millimeters percent
A_{1p}	1.00	7.78	1.45	.83	9.56	15.06	14.97	42.20	9.60
A_{2p}	1.02	2.56	.59	8.48	9.34	14.48	15.54	40.86	8.74
B_p	1.04	4.90	1.67	9.54	9.67	12.30	11.24	36.72	15.63
A_{2GBP}	1.51	2.10	1.85	1.96	9.30	14.36	14.23	42.25	15.80
B_{1GBP}	1.66	1.66	1.04	4.81	8.52	13.23	15.52	40.41	15.85
B_{21GBP}	1.65	2.15	2.42	1.86	9.08	12.89	11.86	39.58	22.58
B_{22GBP}	1.75	1.23	3.59	8.20	8.68	12.05	13.50	38.74	17.60
C	1.87	.99	14.69	1.58	9.50	13.12	13.72	43.49	17.60

*Solution loss determined after mechanical analyses.

TABLE XVI

ORIGINAL AND PRESENT CONSTITUENTS IN THE PROFILE, INCLUDING GRAVEL

Horizon	Organic Matter			Solution Loss			Gravel		
	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
A_{1p}	.07	.49	+ .42	1.10	.09	- 1.01	.12	.05	- .07
A_{2p}	.04	.10	+ .06	.71	.03	- .68	.07	.34	+ .27
B_p	.13	.64	+ .51	1.89	.22	- 1.67	.20	1.26	+ 1.06
A_{2GBP}	.18	.35	+ .17	2.71	.31	- 2.40	.29	.34	+ .05
B_{1GBP}	.23	.35	+ .12	3.30	.23	- 3.07	.35	.99	+ .64
B_{21GBP}	.35	.81	+ .46	5.16	.91	- 4.25	.55	.69	+ .14
B_{22GBP}	.38	.50	+ .12	5.58	1.45	- 4.13	.61	3.31	+ 2.70
Solum	1.38	3.24	+1.86	20.45	3.24	-17.21	2.19	6.98	+ 4.79

TABLE XVI (continued)

Horizon	Coarse 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
A_{1p}	.73	.60	- .13	.98	.95	- .03	1.04	.94	- .10
A_{2p}	.47	.38	- .09	.64	.58	- .08	.66	.62	- .04
B_p	1.22	1.29	+ .07	1.68	1.64	- .04	1.77	1.49	- .28
A_{2GBP}	1.75	1.56	- .19	2.42	2.40	- .02	2.53	2.38	- .15
B_{1GBP}	2.13	1.77	- .36	2.94	2.75	- .19	3.07	3.22	+ .15
B_{21GBP}	3.34	3.38	+ .04	4.59	4.80	+ .21	4.82	4.42	- .40
B_{22GBP}	3.61	3.50	- .11	4.98	4.87	- .11	5.21	5.46	+ .25
Solum	13.25	12.47	- .78	18.23	17.99	- .24	19.10	18.53	- .57

TABLE XVI (continued)

Horizon	Silt			Clay			Total			Volume
	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	Change percent
A_{1p}	3.28	2.66	- .62	1.31	.60	- .71	7.53	6.30	-1.23	+56.33
A_{2p}	2.12	1.65	- .47	.86	.35	- .51	4.87	4.02	- .85	+51.92
B_p	5.59	4.86	- .73	2.27	2.08	- .19	12.87	13.26	+ .39	+85.31
A_{2GBP}	8.03	7.08	- .95	3.25	2.65	- .60	18.45	16.76	-1.69	+12.46
B_{1GBP}	9.76	8.38	-1.38	3.96	3.29	- .67	22.44	20.75	-1.69	+ 4.16
B_{21GBP}	15.24	14.76	- .48	6.17	8.43	+2.26	35.06	37.29	+2.23	+20.53
B_{22GBP}	16.53	15.66	- .89	6.69	7.12	+ .43	38.01	40.42	+2.41	+13.68
Solum	60.55	55.05	-5.50	24.51	24.52	+ .01	139.23	138.80	- .43	+23.97

TABLE XVII

NET CHANGE WITH AND WITHOUT GRAVEL

Horizon	Organic Matter		Solution Loss		Coarse Sand		Fine Sand		Very Fine Sand	
	With Gravel grams	Without Gravel grams	With Gravel grams	Without Gravel grams	With Gravel grams	Without Gravel grams	With Gravel grams	Without Gravel grams	With Gravel grams	Without Gravel grams
A_{1p}	+ .42	+ .42	-1.01	- 1.07	- .13	- .14	- .03	- .08	- .10	- .13
A_{2p}	+ .06	+ .06	- .68	- .76	- .09	- .10	- .08	- .06	- .04	- .06
B_p	+ .51	+ .58	-1.67	- 1.86	+ .07	+ .06	- .04	- .08	- .28	- .31
A_{2GBP}	+ .17	+ .18	-2.40	- 2.43	- .19	- .20	- .02	0.00	- .15	- .14
B_{1GBP}	+ .12	+ .13	-3.07	- 3.22	- .36	- .38	- .19	- .20	+ .15	+ .15
B_{21GBP}	+ .46	+ .47	-4.25	- 4.31	+ .04	+ .06	+ .21	+ .21	- .40	- .37
B_{22GBP}	+ .12	+ .14	-4.13	- 4.38	- .11	- .11	- .11	- .11	+ .25	+ .29
Solum	+1.86	+1.98	-17.21	-18.43	- .78	- .81	- .24	- .32	- .57	- .57

TABLE XVII (continued)

Horizon	Silt		Clay		Total		Volume Changes			
	With Gravel grams	Without Gravel grams	With Gravel grams	Without Gravel grams	With Gravel grams	Without Gravel grams	With Gravel Cubic Centimeters	Without Gravel Cubic Centimeters	With Gravel percent	Without Gravel percent
A_{1p}	- .62	- .76	- .71	- .78	-1.23	-1.47	+2.27	+2.15	+56.33	+45.54
A_{2p}	- .47	- .56	- .51	- .57	- .85	-1.29	+1.35	+1.11	+51.92	+39.08
B_p	- .73	- .83	- .19	- .23	+ .39	- .81	+5.87	+5.23	+85.31	+66.22
A_{2GBP}	- .95	- .94	- .60	- .61	-1.69	-1.71	+1.22	+1.22	+12.46	+11.23
B_{1GBP}	-1.38	-1.41	- .67	- .67	-1.69	-2.38	+ .50	+ .13	+ 4.16	+ 1.01
B_{21GBP}	- .48	- .44	+2.26	-2.30	+2.23	+2.23	+3.85	+3.85	+20.53	+20.53
B_{22GBP}	- .89	- .87	+ .43	- .49	+2.41	- .17	+2.78	+1.39	+13.68	+ 6.40
Solum	-5.50	-5.81	+ .01	- .07	- .43	-5.60	+17.84	+15.08	+23.97	+19.52

VII. CONCLUSIONS

In an investigation of this nature, conclusions can only be based on the net changes that take place in the profile. The processes by which such changes come about and the time required for their completion is not known, although often certain inferences and deductions can be made.

An examination of the data obtained from the Marlette loam profile reveals a rather marked change in the profile at the B_{1GBP} horizon. There may be two reasons for this. More recent material may have been deposited over older material of different composition or, there are two processes occurring simultaneously in the same profile.

The mechanical analyses show that the profile may be regarded as genetic and evidence of two processes occurring in the profile is found in the following facts.

The gains in organic matter through the solum indicate a movement of organic material from the A_{2p} to the B_p horizon. A trend is shown in the loss of soluble material, the percentage loss decreasing from the A_{2p} to the A_{2GBP} and increasing again in the B_{1GBP} horizon. The net loss of silt from the B_{1GBP} is the highest in the solum, although percentage-wise it is less than in the A_{1p} and A_{2p} horizons. There is little difference in the percentage loss of clay from the A_{2GBP} and B_{1GBP} horizons, but the increase in clay in the B_{22GBP} horizon indicates that movement into that horizon is taking place. The small volume change of the B_{1GBP} horizon is another factor that distinguishes it from other horizons. This may be due to net losses of clay to this horizon, only small additions of organic matter and little disturbing influence of plant roots.

It appears that, in addition to eluviation of the surface horizons and deposition in the B_p horizon, a second eluviation process is taking place below the B_p horizon which reaches its maximum in the B_{1GBP} horizon. This would support the contention of Gardner and Whiteside[16] that simultaneous processes involving the movement of different constituents and their deposition in different parts of the solum occur in soils with double profiles.

There is a possibility that the C horizon, as sampled, does not represent the true unweathered parent material, since small losses are recorded for the B_{22GBP} horizon. It would require further sampling and investigation to check this point, but it is believed that the sample obtained closely approaches the true parent material.

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