ABSTRACT

GENESIS MORPHOLOGY AND CLASSIFICATION OF MICHIGAN ALFISOLS AND PERUVIAN ENTISOLS

By Amaro Zavaleta

In order to compare and establish relationships between two Michigan soils of similar texture to four Peruvian soils; the Spinks and Lapeer series, developed in glacial calcareous till, in southern Michigan were studied and compared with the San Jose from volcanic materials, Loma Larga, Tesoro and Siguas series, from alluvials materials, broadly distributed on the Pampas La Joya, Siguas and Majes along the southern Peruvian coast. Pedogenetic studies were conducted oriented to a more complete understanding of the potentials of those Peruvian soils for agriculture and in comparison to Michigan soils now under cultivation.

Physical, chemical and mineralogical properties are presented as functions of depth and kind of horizons. Mechanical analyses and mineralogical analysis of the fine sand fraction by the Isodynamic Separator and petrographic microscope indicated the non-uniformity of the glacial till materials in the two Michigan profiles, and the heterogeneity of strata of materials in the Peruvian

profiles. The original materials of Lapeer contained a higher percentage of silt and clay than those of the other five profiles but the San Jose profile was more similar in texture to Lapeer than the other soils which were all more sandy. The textural differences were correlated with other physical and chemical characteristics.

Mineralogical analysis of the fine sand fractions of selected horizons indicated a similarity between Spinks and Lapeer series. Dissimilarity was found among the Peruvian profiles and marked differences in the mineralogical composition of the Peruvian and the Michigan soils.

Greater organic accumulations in the Michigan profiles, particularly near the surface are associated with the native forest vegetation and the current grain and hay production. In the Peruvian profiles the organic content is low throughout the profile and is more related to the arid environment and very sparse vegetation. The depth to which carbonates are leached is inversely related to the carbonate content of the original materials in the Michigan profiles. The free iron is affected by the content of clay and the organic matter in the Michigan profiles, their distribution in the Peruvian profiles are completely independent of those factors.

The clay bulge in the Spinks $B_t$ horizons (bands) is due to movement of clay out of the $A_2$ horizon and its accumulation in that horizon. The deep $B_t$ horizon analyzed contains discrete amounts of mica, vermiculite and kaolinite but no chlorite. The clay content in the surface horizon is probably partly due to depositional differences and partly to weathering in place. It is suggested that in pedogenesis vermiculite is being changed to chlorite, near the surface. The clay in the $B_t$ horizon of Lapeer is also in part illuvial and is represented by mica, vermiculite, kaolinite and interstratified vermiculite-chlorite. The vermiculite-chlorite was apparently forming from vermiculite in the parent material. It was confirmed that the presence of kaolinite is not pedogenic in these soils.

In the Peruvian profiles the distribution of clay is due to depositional differences and the kind and amount is variable in each soil. In order of decreasing abundance mica, feldspar, kaolinite, chlorite, vermiculite, montmorillonite, some interstratified vermiculite-chlorite, mica-chlorite, montmorillonite-vermiculite, and mica-vermiculite were identified. In the volcanic material the X-ray patterns do not correspond to any clay mineral known.

This material requires additional research in order to be characterized.

In the system proposed as a measure of the uniformity of parent material the use of particles considered strongly and moderately magnetic were useful in showing different original strata, but at the same time the distribution of the non-magnetic and slightly magnetic fractions, or their ratios, in the profile may show when the time of soil formation was enough to even out the differences inherited from the original parent material. These soils were classified according to the Seventh Approximation as follows:

Spinks: Sandy, siliceous, mesic; psammentic hapludalf; hapludalfs; udalf; alfisol.

Lapeer: Coarse loamy, mixed, mesic; typic hapludalf; hapludalfs; udalf; alfisol.

San Jose: Coarse loamy, ashy, nonacid, isothermic; typic torriorthents; torriorthents; orthents; entisol.

Loma Larga: Sandy, mixed, nonacid, isothermic; typic torripsamments; torripsamments; psamments; entisol.

<u>Tesoro</u>: Sandy, mixed, nonacid, isothermic; typic torripsamments; torripsamments; psamments; entisol.

<u>Siguas</u>: Sandy, mixed, nonacid, isothermic; typic torripsamments; torripsamments; psamments; entisol.

# GENESIS MORPHOLOGY AND CLASSIFICATION OF MICHIGAN ALFISOLS AND PERUVIAN ENTISOLS

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Soil Science

1967

To my wife and
little daughter

## ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitude to his Professor, Dr. E.P. Whiteside, who has given patient guidance and valuable assistance throughout the course of his studies. His allowance of freedom in selecting and carrying out the research and his perseverance in testing ideas during the study and in the preparation of the manuscript was the best teaching the author has ever encountered and for which he will be forever indebted.

He is particularly grateful to Dr. R.L. Cook, who kindly laid the path and facilitated his coming to the Department of Soil Science.

Special thanks are due to Dr. M.M. Mortland and Dr. K.V. Raman who taught and oriented him in the interpretation of the X-ray diffraction and clay analyses.

He is thankful to Dr. R. Ehrlich for his broad cooperation and assistance in identifying the minerals in the sand fraction.

His sincere appreciation goes to Dr. H.D. Foth, Dr. A.E. Erickson and Dr. B.G. Ellis for helpful suggestions during the course of this investigation.

Many thanks are extended to the Professors who contributed with their teachings to increase his knowledge in soils and related fields.

The author deeply appreciates the financial support of The Rockefeller Foundation who awarded him a scholarship during his graduate studies at this University and made it possible for him to carry on this research during the course of his regular studies and to the Agrarian University, La Molina, for granting him leave and thus enabling him to gain more knowledge.

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# INTRODUCTION

During the feasibility studies of the irrigation project of Majes-Lagunillas, I was impressed by the nature of soils that I saw in "Las Pampas de la Joya". Some of them present special morphological characteristics that at first glance seem unfit for irrigation purposes, and many soil scientists who are looking for soils are embarrassed. But when those soils are worked, facing the different problems that are present, it is possible to find many interesting explanations for the good yields with the most simple management system. With this in mind a study of the pedogenesis of the most representative soils of the area was planned.

The sequences of soils common in the area is represented by a group of four soils developed under similar major climatic conditions and on different parent material, two alluvial soils from "Las Pampas de la Joya and Siguas", repectively, one volcanic soil from "Las Pampas de la Joya" and one residual soil from "Las Pampas de Majes". Those three Pampas are located on the southern Peruvian coast, Arequipa Department.

In order to compare and establish relationships between two Michigan soils of similar texture to those Peruvian soils from different parent material, the Spinks and Lapeer series, developed in glacial till, were selected. It was considered that the study of such a group of soils could contribute greatly to a more complete understanding of the genesis of the Peruvian soils with potentials for agriculture and the Michigan soils now under cultivation.

The soils under research have not been studied in detail, particularly the Peruvian soils. Therefore, the following objectives have been undertaken in this thesis:

1) To characterize the physical, chemical and mineralogical properties of the major soil horizons or layers of each profile and to determine the nature of the processes which have resulted in the formation of those horizons.

2) To study the relationship between the characteristics of the Peruvian and the Michigan soils.

3) To compare the intensity of the processes of soil formation in the two areas.

4) To make special studies of the mechanical separates and their mineral composition.

5) To contribute a more complete understanding of the behavior of these soils.

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# CHAPTER I

# REVIEW OF LITERATURE

## A. The Gray-Brown Podzolic Soils

The name of Gray-Brown Podzolic soil, was proposed by Baldwin (1927), for a group of zonal soils in a humid cool temperate climate having a blocky illuvial B horizon of clay accumulation. His definition was adequate to distinguish these soils from those later called Gray Wooded and Soil Brun Acide, but the distinction between the Gray Brown soils and the Noncalcic Brown soils had not been made clear except in terms of the climates in which they are found (62).

Reporting on forested soils in New York, Cline et. al. concluded in relation to the genesis of the Gray-Brown Podzolic soils that in the climatic environment of that state, leaching of bases progresses with time. While carbonates are still present in the solum and the base status is very high, there is intense biological activity and little or no evidence of an illuvial B. A soil at this stage would be called a Brown Forest soil. As the removal of bases continues and the biological activities decrease somewhat, the structural aggregates in the B horizon become coated with thick layers of oriented clays indicating a translocation and accumulation of clay. A soil at this stage is considered a Gray-Brown Podzolic and is characteristic of a cool, humid temperate region. With continued removal of bases, the finer illuival B moves progressively deeper, biological activity decreases and a faint "bleicherde" layer forms directly below the leaf mat in what formerly was the A horizon. Immediately beneath this, and also in the former A horizon, a zone of sesquioxide accumulation developes comparable to that in well developed Podzols. This soil is considered as a Brown Podzolic. (46).

In an extensive review of research about the concept of Braunerde (Brown Forest soil), in Europe and the United States, Tavernier and Smith indicate that the Gray-Brown Podzolic soil climatically are found in somewhat warmer climates than the Podzols, or are restricted to young calcareous parent materials. The illuvial horizon characteristic of these soils shown an accumulation of silicate clays. This concentration of clays is probably due to their flocculation by the bivalent cations. With the continued leaching it is found that the B is destroyed and a Brown Podzolic or a Podzol tends to develop in the $A_2$ of the Gray-Brown Podzolic soil.

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The Spinks and Lapeer soils in Michigan are recognized as representatives of the Gray-Brown Podzolic great soil group. The former is developed in sand to loamy sand and the latter in sandy loam glacial till that was originally calcareous.

Veatch (70) separated the Podzol region of Northern Michigan from the Gray-Brown Podzolic region of southern Michigan by a line which follows approximately the southern limit of the native white pine in the native hardwood (sugar maple and beech) vegetation.

The members of the Gray-Brown Podzolic group are characterized by:

(1) A mull-like $A_1$ horizon.

(2) An $A_2$ horizon that may vary considerably in degree of development. It may be yellowish brown to brownish gray or gray. It differs from the $A_2$ of Podzols in that its boundaries are less abrupt, and it is of greater thickness in soils of a corresponding degree of development.

(3) A definite brown or brownish $B_2$ horizone which is appreciably finer in texture than any of the other horizons in the profile.

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(4) A $B_1$ horizon, which is often discontinuous, that is the transition from the lower $A_2$ to the $B_2$ horizon. The transition from the $B_2$ to the calcareous parent materials is generally distinct and quite sharp.

(5) The reaction of the $A_1$ and $A_2$ horizons commonly range from a pH of 5.4 to 7.5 but are in generally slightly acid. The $B_2$ horizon ranges from pH 6.8 to 7.8.

(6) The $A_1$ and $A_2$ horizons are moderately saturated with bases 35% to 85%, while the lower $B_2$ horizon is almost completely saturated.

(7) There is a very marked accumulation of sesquioxides in the B horizon but only a very slight or no accumulation in organic matter.

A modal and a number of intergrade types of Gray-Brown Podzolic soils have been recognized and defined on the basis of the degree of expression of the above characteristics.

The modal types of the Gray-Brown Podzolic soils may vary in the profile characteristics depending on the parent materials. In view of the calcareous nature and mixed lithology of the parent materials of many of these soils the main profile variations can be related to the texture of the parent materials and their natural drainage conditions. The range in textures and the associated profile differences may conveniently be divided into three segments: the fine, medium and coarse textured soils. In well drained conditions all these soils have well developed $A_1$, $A_2$ and $B_2$ horizons. The natural leaf litter generally decomposed before autumn so that the $A_0$ horizon is generally lacking. The $A_1$ horizon is on the average 3 to 4 inches thick, friable and gray brown in color. In the fine and medium textured soils it has a well developed medium granular structure, while in the coarse textured soils the structure is weakly developed, fine granular to crumb, and occasionally single grained. The reaction of this horizon varies from moderately acid to neutral, the colloids are moderately saturated with bases, and the organic matter and nitrogen contents are medium.

The $A_2$ horizon generally varies from 6 to 24 inches, and occasionally more in thickness. In the finer types the thickness of the $A_2$ generally varies from 6 to 10 inches, in the medium textured types from 8 to 18 inches, and in the coarser textured types from 12 to 24 inches. The color of the $A_2$ may vary from gray to pale brown, yellow brown and brown. The intensity of the brown coloration is generally greater in the coarser soils. In the medium textured soils in southern Michigan and Ontario the upper part, $A_{21}$, is more brownish than the lower part, $A_{22}$. In the coarser textured types the difference in color is generally more pronounced, while in the finer types the difference in color between the upper and lower $A_2$ is only very slight or not noticeable. The grayest part of the $A_2$ horizons occur just above the B horizon and not immediately below the $A_1$. The $A_2$ is friable when moist and the structure may vary from granular to weak platy. When dry the lower part of the horizon is often harsh, hard and somewhat vesicular. The reaction and the degree of base saturation of the $A_2$ is approximately the same as that of the $A_1$. However in some soil series there is a tendency for a slightly more acid condition in the $A_{22}$ subhorizon.

The $B_2$ horizon may vary in thickness from 3 to 15 inches. The thicker $B_2$ horizon generally occurs in the finer types and the thinner in the coarse textured soils. The relative thickness of $A_2$ and $B_2$ in the finer soils generally varies from 1:1 to 1:2; in the medium textured soils it is approximately 2:1 and in the coarse textured soils 3:1 to 4:1. In the coarse textured soils the depth to the $B_2$ horizon varies considerably, and the thickness of the $A_2$ and $B_2$ horizons likewise varies. In the medium and fine textured types the structure is moderately to well developed medium blocky or nuciform, while in the coarser types its development is weaker. The surface of the aggregates is generally coated with a thin, shiny, waxy film of colloidal material. The color of the $B_2$ varies from brown to yellowish brown. The $B_2$ texture is finer than of any other horizon in the profile, often by one textural class and occasionally by two classes. There is a marked increase of sesquioxides in the $B_2$ over their content in the $A_2$. The total base exchange capacity is also considerably greater, but there is very little, if any, accumulation of organic matter in the $B_2$. The base exchange complex is saturated, and the reaction is neutral to mildly alkaline, in the lower part of the $B_2$ horizon.

The $B_2$ is generally separated from the $A_2$ by a thin and frequently intermittent $B_1$ horizon. This horizon consists generally of crumbly brownish aggregates which are covered with a dull gray, fine sandy coating. Frequently gray sandy streaks or veins are interwoven throughout the mass of brownish aggregates. The morphological characteristics suggests that this is a desintegrating $B_2$ horizon. Chemical analyses of the brown cores of the aggregates show them to be similar in composition to the $B_2$ horizon, while the composition of the gray coatings is more like that of the

$A_2$ horizon. The changes from the $B_2$ to the lighter colored calcareous parent material is generally quite sharp (59).

Research studies of the clay skin material in the lower B horizon of Gray-Brown Podzolic soils in Wisconsin is quite different in several respects from the rest of the soil material in that horizon. Clay skins were found around roots in the horizon examined. This suggests that clay skins, regardless of how they have been formed, may have considerable influence on the growth of plants in this and in similar soils (10). Perhaps both clay and roots follow channels in the subsoil.

In Michigan, 1934 the so-called bisequa profiles were recognized by Veatch (74). These profiles consist of more than one zone of eluviation and more than one zone of illuviation.

Studies of the bisequa profiles showed that they are zonal soils of the transitional region between the Podzol and Gray-Brown Podzolic region in Michigan. These soils have upper $A_2$ and B horizons characteristic of a Podzol, while these are underlaid by what appear to be $A_2$ and $B_2$ of a Gray-Brown Podzolic profile. The Podzol horizons are more strongly expressed on coarse textured siliceous materials, and the Gray-Brown Podzolic horizons are best developed on the more calcareous and argilliaceous materials. The study concluded that all horizons in the double profile are genetic and are the result of either the simultaneous development of all the horizons, or the succession of a younger Podzol profile in the $A_2$ horizon of an older, thicker Gray Brown Podzolic Soil (74).

Results of a study of the Genesis of a Podzol-Gray-Brown Podzolic intergrade soil profile in Michigan show that: (a) there is a total loss in weight of the solum, but a 20% gain in volume, which takes place largely in the $A_1$, $A_{2p}$ and $B_p$ horizons; (b) about 85% of the soluble material originally present has been removed from the profile, (c) the principal constituent concentrated is organic matter in the Podzol B and silicate clay in the Gray-Brown Podzolic B. The authors concluded that the development of the bisequa is a result of simultaneous processes involving the movement of different constituents and their deposition in different parts of the solum (5) - Michigan Gray-Brown Podzolic soils.

Those soils have developed over calcareous glacial drift of Wisconsin, age composed principally of quartz, feldspars, clay minerals. The texture of the parent materials are moderately coarse to fine and the fabric or structure to unconsolidated and unstratified or stratified. Great soil

variations result from the varied textures, fabrics and mineralogical compositions of the materials left by the glaciers and their melt waters.

The topography and drainage of Michigan were greatly modified by glacial action, and these contribute to local soil variability. Naturally poorly drained and well drained soils occur within the Gray-Brown Podzolic region ( 2 ).

The humid climate of Michigan has resulted in the removal of the easily soluble constituents from the upper layers of most of the soils. Some constituents have been washed out of the surface horizons and deposited in the subsoil. The well-drained soils in the Gray-Brown Podzolic areas of southern Michigan have subsoils that are enriched by clay washed down from the overlaying horizons. These Bt horizons are finer textured than either the overlying or underlying horizons in the soil profile ( 2 ).

The annual temperature averages between 50° and 55°F., the average annual precipitation is between 30 and 35 inches. The average length of frost free period is between 140 and 160 days. Wide differences between winter and summer temperatures are common to the region. The prevalence of low winter temperatures affects soil temperatures to a considerable degree as indicated by the average depth of frost penetration, 30 inches. Loss of moisture into the atmosphere strongly influences the effectiveness of precipitation in soil formation directly and indirectly. The direct effect decreases the quantity of moisture available in and able to percolate through the soil while indirectly it determines the kind and quantity of vegetation that develops. The average relative humidity, local Noon, in July is between 50 and 55 at Lansing (2). The southern limit of native white pine coincides closely with the boundary between the Gray-Brown Podzolic and the Podzol regions (70).

Surface erosion and mass movement of surficial material will cause some removal and disturbance even on gentle slopes. Since much of the area beyond the borders of glaciation has considerable relief, these processes of disturbance or mixing are quite active and some of the resultant soils show only weak or moderate development even in the unglaciated areas in Central United States. Soils developed on recent alluvial materials or on very steep slopes where erosion has been more active may show very little development and so could be thought of as being much younger than those on more gently sloping upland surface. The thickest soils are usually found on the nearly level or gently sloping sites (2).

B. Genesis and Morphology of the Desertic Soils

Arid soils have been defined as those which will not support crop plants without irrigation (41). The following discussion will focus on the soil forming factors and processes responsible for the development of the soils in such a region. The factors of soil formation (13) in arid regions are the same as those in any other part of the world. The relative intensities of the various soil forming factors in arid regions, however, result in some pedologic processes that are quite characteristic of the region. Common to soils of such a region is the limited amount of water available for pedogenic processes, a factor that results in a lowering of the intensity of many of these processes. The consequent close relationship between well-developed soils and the parent material in arid lands is often not fully appreciated and thus gives rise to conflicting concepts for modal zonal soils for such regions (9).

In desertic regions the small quantities of moisture received limit leaching and restrict the production of vegetation. Under such conditions the soils formed have thin sola. The soluble salts are usually leached only to depths of 30 to 60 cms.

Higher temperatures increase evaporation rates and reduce the amount of water available for transpiration by plants. The higher temperatures accelerate weathering, and desert crusts are common on gravel and stone exposed on such surfaces.

The small moisture supply limits vegetative production. The vegetation is normally sparse, and the exposed ground surface ranges usually between 50 and 100 percent.

1. Textural B horizon development

Generally the quantity of moisture is insufficient to eluviate clay: but an increase in clay content is present in the subsoil.

If the parent materials are relatively low in alkaline earth carbonates and soluble salts, as the salts and carbonates are leached, weak to moderate carbonate horizons form at a depth of 37 to 75 cms., and the soluble salts even though low in total amount increase somewhat with depth below the maximum accumulation of carbonate. A thin light-colored A horizon and a distinct moderately strong textural B horizon form. The ratio of the clay in the Bt horizon to that in the A horizon ranges from 1.2 to 2.0 in the well developed zonal desertic soils.

In the most common situation the parent materials are moderate or high in alkaline earth carbonates and contain significant quantities of soluble salts. There is some translocation of salt and carbonate, causing an increase at depths of 37 to 75 cms. The highest concentrations of salt are in or below the horizons of maximum carbonate accumulation. However, the soil remains moderately to strongly calcareous throughout. A distinct textural B horizon forms with a clay increase ratio up to 1.5 to 2. The Bt is usually sodium affected at least in the lower part, indicating the influence of sodium in peptizing and increasing the mobility of clay thus suggesting that the soil formation has proceeded somewhat similar to that of the solonetz soils.

When the parent materials are high in alkaline earth carbonates and low in soluble salts, there is a translocation of carbonates as above; but only weak structural or no B horizons form.

The normal horizon sequence of zonal soils in desertic areas is: A, B, Bca, C; A, C; or A, B, Cca, C. The A horizons are thin, generally less than 10 to 15 cms., are light colored, usually platy, and with pronounced vesicular porosity in the topmost layers. Commonly the A horizons are bleached and lower in organic matter than the immediately underlying B horizon. The B horizons are thin, brighter, weakly to moderately developed, and have a characteristic very fine blocky structure in the upper part. The structure becomes coarser and less distinct with depth.

Within the desertic group of soils are important areas of Calcisols, Lithosols, and Rockland as well as saline and sodic soils (1).

Total clay contents suggest that eluviation of clay from the A and illuviation into the B horizon is common (12). However, the almost complete lack of oriented clay in the profile indicates that clay skins formed have been destroyed by natural turbations in the soil, as has been suggested previously (15), or that the content of bases or salts prevented clay dispersion and good orientation. The scarcity of evidence of an eluvial horizon and the persistence of the dry state of the surface layers have led to the conclusion that the $B_t$ horizons when present are due largely to clay formation in place, and are not illuvial (9). This theory has been supported by the observation of weathered pebbles in the B horizon of sierozem soils which exhibited relatively unweathered pebbles above and below that horizon (13).

Another method available to resolve the question of in situ or illuvial B horizon formation is the use of quantitative evaluation, by the index mineral method, of clay formation, clay migration, and volume change during development of soil materials in the profile. This might be used to determine where the non-clay has decreased in the profile and finally whether the pedogenic clay may have been translocated vertically in the profile (3 ).

2. <u>Clay Mineraology</u>

The mineralogy of soils in arid regions is, as in most other relatively little weathered soils from sediments, largely dependent upon the parent material. The soils from arid regions have not been shown to contain a predominance of expanding lattice minerals in their clay-size separates. Clay mineral studies of sierozems in Central Asia showed that in some soils kaolinite is predominate, while in other soils montmorillonite is predominant in the clay fractions (13). Twenty-five percent kaolinite and 70 to 80 percent mixed layer minerals were reported from the clay separate of six profiles developed in the Mojave Desert in California (9). Illite was the predominant clay in the B horizon of a Mohave profile in Arizona (12). A preponderance or illite and kaolinite was found in the clay fraction of the upper 60 inches of the profile. Below 60 inches, montmorillonite was found to be the dominant clay mineral in most cases (12).

Laboratory work (28) has demonstrated that montmorillonite can be formed at ambient temperatures in dilute suspensions if the pH value is kept above 7; below this pH value, an amorphous material formed. Assuming that clay minerals are forming in the soil solution, it is then feasible to hypothesize that montmorillonite could be forming in many of the alkaline arid soils. More likely, in view of the lack of uniformity observed in sola, is the explanation that the frequency distribution of minerals in the soil largely reflects that in the parent material and that each clay mineral in the soil can be considered secondary to a primary mineral in the parent material (31).

3. Movement of Iron

Soils of the arid regions are seen to be well oxidized, with only limited amounts of free iron present, and with little or no eluviation of free iron from the surface horizons of the profile (13).

4. Organic Matter Accumulation

The amount of organic matter in the sola is usually less that 1 percent due to sparsity of plant residues. The low effectiveness of the vegetation is further reduced by insect activity, the blowing away of the dry leaves and stems, the predominance of oxidizing decomposition processes due to high temperatures, and a corresponding restriction of formation of humic acids. The low C/N ratios are due to participation of bacteria that are more active in humus formation in arid regions than in humid regions. A high content of nitrogen in relation to carbon content in some arid regions could be due to the nitrogen-fixing blue green algae which are often present in crusts at the soil surface (22).

5. Caliche or calcic layer formation

The term caliche as used in this paper refers to hardpans cemented with calcium carbonate and silicates. The genesis of the calcic layer has been the subject of much discussion (25, 38, 51, 57). Divergence of opinion concerning the genesis of caliche or ca horizons is understandable in view of the varied nature of these layers. In each instance more than one pedogenic process may be involved. In general, studies in the more moist portion of the arid regions tend to favor a theory calling for the translocation of the carbonate from the upper to the lower part of the profile.

In drier areas several other processes appear more likely (13). There the current theories of caliche formation are summarized thus: deposition in small disconnected lakes and ponds by algae and inorganic processes; deposition along streams and intermittent streams by physical and/or organic processes; deposition by rising artesian waters either at surface level or the water table; deposition of carbonates by capillary rise of water from the water table; by descending surface waters following saturation of the soil zone, and by various combinations of the aforementioned methods (61).

Radiocarbon dating from three levels in a profile of a red desert soil, has revealed that the age of the carbon increases with depth. The indications are that in less than 9800 years a weak carbonate layer has formed by the eluviation of carbonate, probably as bicarbonate, from the upper layers of the profile, with subsequent carbonate deposition upon desiccation at a depth of from 38 to 44 inches in the soil (12).

It has been indicated, that with increasing time or soil maturity caliche becomes hard and strongly indurated. Calcium and aluminum silicates are more abundant near the upper surface of the caliche making up as much as 10 to 15 percent of the total, and that the silicates are responsible for the hardness (57). Contents of acid extractable silica (SiO[3]) in arid soils are highest in hard or indurated caliche layers and probably contribute appreciably to the cementation of the layer (61).

Under 10 inches of rainfall depth to silica-rich hardpan has been reported to correlate approximately with the permeability of the surface soil in parts of Western Australia (44). Soluble silicates are apparently quite mobile in arid regions.

Studies in arid regions of Southern Peru, have shown where volcanci ash or glass provide a rich source of relatively soluble silica, the cementation is more pronounced if gravel and cobbles make up a large part of the horizon (75).

6. Desert Pavement

The desert pavement and vesicular layer are prominent features of many of the major desert soils of the world, even though terminology is not everywhere consistent. The terms desert pavement and vesicular layer were used by Marbut (60). The coatings of pebbles of desert pavement have been called "patina" (57) "desert tan" (60), and protective crust (57), but for simplicity the term "desert varnish" of Gilbert (60) is used here for such coatings.

A gravelly mantle on desertic soils is characteristic and is commonly referred to as a desert or erosion pavement. Such a surface is stable and forms a protective covering against wind erosion of the soil surface. Erosion is normally active on surfaces lacking this pavement. The sparce cover of vegetation does little to reduce wind and water velocities. When grazed, trampling pulverizes the exposed surface between plants and erosion is accelerated. Erosion is a major factor in recharging surface soils with carbonates in arid regions through the movement and deposition of calcareous dusts by wind. The gravels become wind polished on their exposed surfaces in that process and are called ventifacts.

Since it is common to find mounds of soil material drifted around clumps of vegetation, it is likely that deflation does play a role in the pavement formation (41). Directly below the pavement, however, a characteristically porous, cellular or vesicular horizon often developes. This vesicular layer tends to be stone- and gravel-free. The presence of the gravelly layer over the gravel-free layer may be lithogenic in some areas (37). On the other hand, the gravel-free vesicular layer may have been developed from a gravelly parent material by the upward migration of the gravels. It has been shown that a vesicular layer similar to the natural vesicular structures can be formed by merely wetting and drying the soil. Gravel have been observed in the laboratory to move upward in a column on wetting and drying simultaneously, closed cellular pores form in the matrix. It appears quite plausible to conclude that air can become trapped under the gravels, as water infiltrates the soil, and can create large pores into which fine ones collapse, with the result that the gravel is eventually moved to the surface (60). Therefore, accumulation of gravel and stones at the surface to form a desert pavement is not due solely to removal of finer material by wind or water. This has led to a hypothesis for origin of the vesicular layer as a pedogenic horizon.

Desert pavements and vesicular layers are common on soils of several ages. They are most highly developed, however on the older soils. The age of the soils are usually related to land forms. Land forms are diverse within arid areas. Pediment surfaces, broad alluvial fans, valley fills, stream terraces, and pleateaus are common (60).

Age is indicated in places by strong $B_t$ horizons or thick formations of caliche or cemented pans.

C. The Desertic Soils of Southern Peru

A broad range of desertic soils occurs in this arid region. They include azonal Regosols, alluvial soils, Lithosols, and intrazonal Solonetz. In addition minor acreages of zonal soils are present. This soils region cuts across several separated geographic areas. These areas are distributed from the Pacific Ocean to the beginning of the Andean highlands in four pronounced strips: (1) immediate coastal terraces and lower slopes, without rains; (2) the upper slopes of the coastal hills rather constantly enveloped in fog and mists, and receiving from 1 to 8 inches of rain per year in irregular infrequent showers; (3) the valleys, ridges and pampas, a bright sunny area occupying much of the region and receiving showers occasionally at intervals of many years, and (4) the zone of steep valleys on the inner margin of the desert, where small but yearly rains get a verdant landscape in contrast to adjacent nude stretches to the west.

The soils under study lie in the third physiographic region in the Pampas de la Joya, Siguas and Majes on the Southern Peruvian Coast at latitude around 16° 40' S. and longitude 72° W. Those pampas are broad, nearly level plain with elevations between 1,200 and 1,700 meters above sea level. It is completely arid, having absolutely no natural vegetation of any sort in the entire region.

We can accept the climatological observations from the "Pampas de Majes" as reasonably representative of the three Pampas, La Joya, Siguas and Majes. At no time does the cloudiness exceed a value of 3 on a scale of 1-10. The area is nearly without rainfall but a very rare weak storm may bring some moisture. The annual minimum temperature is $1^{o}C$, the average maximum $33.6^{o}C$ and the annual average $26.6^{o}C$. The monthly temperature fluctuations are very small throughout the year, whereas the diurnal fluctuations are considerable. For the greater part of the year, the relative humidity is quite low, and the diurnal and monthly fluctuations are considerable. The regime of prevailing winds is South-Southeast (75). The date of this plain's formation is crudely estimated as Late Tertiary, with several abrupt interruptions due to volcanic activity (34).

The soils of the Southern Peruvian desert exhibit a particular pattern due mainly, in addition to the common factors of soil formation, to three factors which modify the soil process to an unusual degree, bringing about the formation of soils under an abnormally weak weathering regime, a weak organic and a very strong drift regime. Thus, those soils show rather weak profile development and soil differences are due more to inherited characteristics than to features acquired during soil development.

The dominant characteristics of the regional environment are: seismic and volcanic activity on parent materials formation and the Peruvian Current on climatic soil formation.

Considering the origin of the Pampas La Joya, Siguas and Majes, in some geologic time, this sector of the Peruvian coast has experienced repeated uplift and there has been some variation in the nature of the coastal drift sediments elevated by successive movements. At first this sector was under the ocean at the beginning of the uplift a great saline lake was formed; bounded by the Coastal Cordillera and the foothills of the Western Andes.

One striking feature of the area is in the geological pattern, the arrangement of four major volcanic masses, Ampato, Chachani, Misti, and Pichu Pichu in a remarkably straight line N. 45$^{o}$W. Jenks (1948, p. 175) suggested that these volcanoes are along a single line of weakness probably a major high-angle fault zone, with the northeast side raised as much as 1500m. above the southwest (35).

It is tempting to speculate that an interval of intensive but local volcanic activity in any particular watershed would lead to overloading of the lake basin, with volcanic tuff so that the pressure of the lake broke some weak points of the coastal Cordillera originating a drainage system represented by the discharging rivers Vitor, Siguas, and Majes. The tuff flows were spilled from the volcanoes from dispersed points onto the Pampas, and many valleys and neighbor basins were filled with successive tuff deposits. The initiation of a period of tumultuous fan-building with the formation of spectacular mudflows formed by convergence of debris-avalanches, breccia flows, and even "sand flows" account for the nature of transported parent material. Moreover, these soils associated with these tumultous mud-flow landforms have profiles that are far too young to relate to glacial times. A dry period produced the evaporation of the remaining water and saline concentration. As a result, the saline nature of the soils may have formed without any relation with the nature of the parent material. So on the Pampas we can identify volcanic tuff, alluvial and residual parent materials.

The major climatic regulator for the Peruvian Coast is a permanent anticyclone in the South Pacific; which advances parallel and along the Peruvian Coast and is deflected northwards up the coast towards the Equator. The water is cold and upwelling from the ocean depths; this cools the air and gives rise to a cold airstream that is responsible for a mean annual temperature far lower than that normal for these latitudes.

The landscape of the Peruvian coast is a desert which extends from the coastal cliffs up to the Western Andean

Cordillera. Along the coast there is a region of very low rainfall but high fog condensation that reaches its maximum near the summit of the coastal range.

From the point of view of soil formation, the environment is characterized by a moisture deficiency, high insulation, very high soil temperatures, and high evaporation rates when water is available. Under natural conditions, and under dry farming conditions, the intensity of both leaching and weathering is very low: under irrigation, the intensity of weathering in the soil accelerates markedly but the intensity of leaching is less affected owing to the high rate of evaporation. This disparity between weathering and leaching, induced through irrigation, sometimes leads to excessive accumulation of salts in the surface horizons of soils. Over much of the Peruvian desert landscape the organic regimen in the soils operates only weakly or has no significance, and the natural vegetation has not had much conditioning effect on soil processes. Thus, it may be appreciated how a major oceanic phenomenon is playing a significant role in soil formation. It is concluded that the inherited characteristics of the parent material, soil moisture and landform are the main factors to be considered in the classification of the Peruvian desert soils.

# CHAPTER II

## CHARACTERISTICS OF THE SOILS UNDER STUDY

### A. Profiles Selected

Four Peruvian soil profiles, similar in texture but different in parent material and two Michigan soils different in origin of parent material, but similar in texture to the Peruvian soils were selected. The Peruvian soils are represented by the Tesoro and Siguas (alluvials) San Jose (volcanic) and Loma Larga (residual) series. The Michigan soils are represented by the Spinks and Lapeer series developed from calcareous glacial drift (Wisconsinan). All are well drained soils.

The attached taxonomic chart Table 1, show the relationship among the soils investigated. The vertical arrangement of the parent materials is from the finest to the coarsest material.

The soils in each vertical column have the same kinds and sequence of horizons in the profile, except as noted, but differ in properties associated with differences in the character of the parent materials.

Table 1. Classification of the Michigan and Peruvian Profiles

| Parent Material | | | | | Soil Order | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Azonal | | | Intrazonal |
| Texture | Drift Lithology | Color | Fabric | Line | Alluvial | Gray-brn. podzolic well-drained | Reddish desert well-drained | |
| Sandy loam | Sandstone, limy & limestone 18-42" | moderate yellowish brown | unstratified | 1 | | Lapeer | | |
| Sandy loam | alluvial, sandy loam | lgt.gray. yellowish brown | stratified | 2 | Tesoro | | | |
| Loamy sand | moderate limestone | light yellowish brown | unstratified | 3 | | Spinks | | |
| Loamy sand | volcanic tuff | light grayish yellowish brown | stratified | 4 | | | | San Jose |
| Loamy sand | residual | moderate brown | stratified | 5 | | | Loma Larga | |
| Coarse sand | alluvial sand | light yellowish brown | stratified | 6 | Siguas | | | |

B. Soil Profile Descriptions

A soil pit, about 0.80 m. by 1.50 m. at the top and 2.00 m. deep was dug to describe and sample the major horizons of the soil profiles. The horizon designations and descriptions of each soil profile, except soil color names, were made according to those recommended in the Soil Survey Manual, Agriculture Handbook No. 18 and the 1962 supplement. The Soil horizons are also designated according to a proposed genetic or interpretative system (69), and these are shown in parentheses immediately below each Manual designation. The depths are the average for each horizon in the soil pit. Dry soil colors for the Peruvian and moist soil colors notations for the Michigan soils are reported according to the Munsell Soil Color Chart (50) and ISCC-NBS color names (65). Texture were determined by feel at the time of the field description and also based on mechanical anlyses of the samples.

Three core samples 4.8 x 16.9 cm. from each major horizon of the Peruvian soils, and six core samples 7.68 x 7.68 cm. for each major horizon of the Michigan soils were taken, in order to determine bulk density, moisture contents at various tensions, total porosity, and specific gravity.

For all physical, chemical and mineralogical analyses, a bulk sample of around 3 kilos was obtained by taking numerous subsamples from the walls of the pit for each major horizon, mixing them and then taking a representative subsample of the mixture.

Photographs of the six soil profiles are presented in Plates 1, 2 and 3.

1. Michigan Soils

a. Spinks profile:

Spinks soils are well-drained Gray-Brown Podzolic soils developed in calcareous or neutral loamy sands, sands or fine sands. They are distributed in Southern Michigan and Northern Indiana. They are developed on gently sloping to steep moraines and outwash plains. The natural vegetation was chiefly oaks and hickory trees. They are naturally well-drained. Surface runoff is slow to very slow. Permeability is very rapid. A representative profile from an alfalfa field located in the SE 1/4, of SW 1/4, of NE 1/4 of sec. 30, T.4 N.R. 1 W Meridian Township, Ingham County, Michigan, is as follows:

Plate 1. Color photographs of the Spinks (above) and Lapeer (below) profiles from Michigan

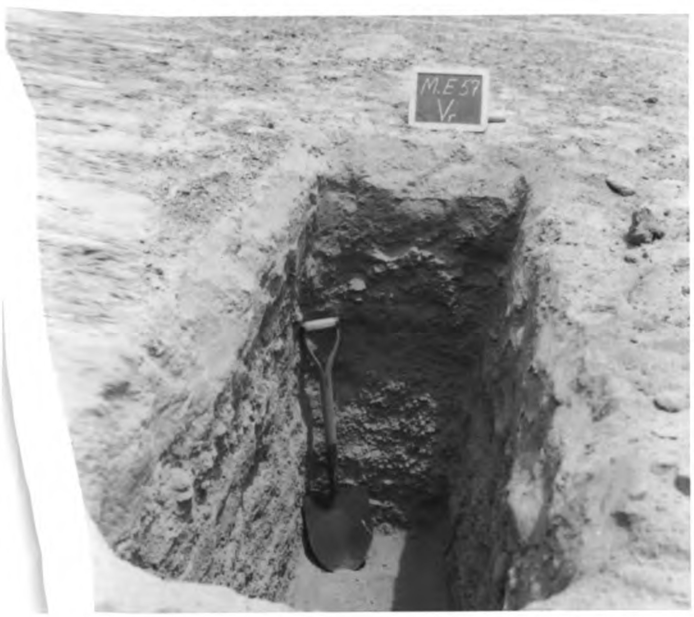

Plate 2. Color photographs of the San Jose profile (above) from volcanic materials and the Loma Larga series (below)


Plate 3. Color photographs of the two alluvial soil series, the Tesoro (above) and the Siguas (below), from Perú.

| Horizon | Depth cms | Description |
|---|---|---|
| Ap (Vp) | 0 - 20 | Sandy loam; grayish yellowish brown, to moderate yellowish brown (10YR 4/3); very weak, medium, granular structure; friable; medium acid (pH 5.8); 15 to 30 cms. thick; abrupt smooth boundary. |
| II $A_2$ (Em) | 20 - 46 | Loamy fine-sand; moderate yellowish brown (10YR 5/4); very weak, fine, granular, to single grain structure; very friable; neutral (pH 6.7); 25 to 38 cms. thick; abrupt, irregular to broken boundary. |
| III A'2 and $B_2t$ (Em & It) | 46 - 48 | Light grayish yellowish brown to light yellowish brown (10YR 6/3); fine sand A'2 horizons and light brown to strong yellowish brown (7.5YR 5/6) sandy loam B2t horizons. The B2t horizons which occur as thin, (0.5 to 10 cms.) bands or lenses are often wavy and discontinuous and they are increasing in |

| Horizon | Depth cms | Description |
|---|---|---|
| | | thickness with depth. These are separated by abrupt wavy boundaries. The A'2 horizons have single grain structure, while the B2t horizon have weak medium subangular blocky structure. Neutral; 50 to 100 cm. thick; clear wavy boundary. |
| C1 (Pu) | 169+ | Fine sand; light grayish yellowish brown to light yellowish brown (10YR 6/3); single grain structure; loose; neutral to calcareous. |

b. Lapeer Profile

The Lapeer soils include well drained Gray-Brown Podzolic soils, developed on sandy loam till calcareous at depths of 51 to 108 cms. They are broadly distributed in southern Michigan on nearly level to strongly sloping moraines and till plains. Slope gradient ranges from 1 to 18% or more. The natural vegetation is represented by hardwood trees including oaks, hickory, and in places, large proportions of beech and sugar maple. They are naturally well-drained.

Surface runoff is medium on milder slopes and rapid on the steeper ones. Permeability is moderate. A representative profile of Lapeer from an idle field of 1 percent slope located at SW 1/4, of SW 1/4, of NE 1/4. of sec. 19, T.4N. R. 1W, Meridian Township, Ingham County, Michigan as follows:

| Horizon | Depth cms | Description |
| --- | --- | --- |
| $A_p$ ($V_p$) | 0 - 28 | Loam; very dark grayish yellowish brown (10YR 3/2); moderate fine granular structure; friable; moderate in organic matter content; mildly alkaline (pH 7.8); 20 to 30 cms. thick; abrupt smooth boundary. |
| II $A_2$ (Em) | 28 - 41 | Fine, sandy loam; grayish yellowish brown to moderate yellowish brown; moderate, medium granular structure; friable; neutral (pH 6.7); 7 to 16 cms. thick; gradual wavy boundary. |
| III $B_t$ (It) | 41 - 72 | Clay loam; moderate yellowish brown (10YR 4/3); moderate medium subangular blocky structure; friable; neutral (pH 6.7); 15 to 25 cms. thick; clear wavy boundary. |

| Horizon | Depth cms | Description |
|---|---|---|
| III C (Pu) | 72 - 100+ | Fine sandy loam till; moderate brown (10YR 5/4); massive to weak, coarse subangular blocky structure; friable; calcareous. |

2. <u>Peruvian Soils</u>

The coordinate system used in citing location of profiles in the soil survey of La Joya, Siguas and Majes Pampas will be used here (75).

a. San Jose Profile

The San Jose series includes well-drained desert soil developed on volcanic material sandy loam. San Jose soils and Azucar series may be easily distinguished by color in the field. Azucar series are pinkish colored, composed largely of glass shards and pumice fragments and contains small amounts of oligoclase and biotite and rarely quartz. Over the surface there is an abundance of individual crystals of sanidine commonly colorless, or orthoclase usually white or pink. San Jose soils are white, free of hematite, harder than the former, and consist largely of secondary axiolitic and spherulitic growths of potash feldspar with relatively little glass. Contains quartz, oligoclase, and biotite fragments (75).

San Jose soils are broadly distributed on Pampas de la Joya, on nearly level plains. Slope gradient ranges from 0 to less than 3 percent.

They are thick soils. The internal drainage is medium, the surface runoff is medium; the permeability is moderate. There is no natural vegetation of any type.

Locations: JQ-37 Pampas de la Joya

| Horizon | Depth cms | Description |
|---|---|---|
| $A_1$ (Vw) | 0 - 7 | Loamy fine sand; grayish yellowish brown (10YR 5/4); single grain or massive structure; a characteristic in this soil is the presence of V-shaped wedges of material similar to the surface horizon; 5 to 30 cms. wide at the surface and disappearing where they reach the last horizon. These are composed of moderate yellowish brown (10YR 5/4); medium sand (including quartz grains), massive and hard when dry. This material slakes readily in water. The genesis of these wedges is unknown. Loose; neutral (pH 6.8); |

| Horizon | Depth cms | Description |
|---|---|---|
| | | 2 to 10 cms. thick; clear wavy or irregular boundary. |
| II $C_1$ (Wm) | 7 - 128 | Fine sandy loam; light grayish yellowish brown (10YR 6/2); very coarse angular blocky structure; firm; neutral (pH 6.7); 100 to 130 cms. thick; gradual smooth boundary. |
| III C2 (Uu) | 128 - 150+ | Mixture of angular and subangular gravel with unconsolidated volcanic tuff. |

b. Loma Larga Profile

The Loma Larga series are well drained Red Desert soils, formed over stratified gravel and sand of non-calcareous colluvial material. They are found on gently sloping to nearly level areas of less than 3 percent slopes. They are the most strongly developed and weathered soils in the area, due to their relatively moist microclimate, compared to other areas in the same Pampas. The moisture consists of fogs or mists during the winter season. The surface runoff is medium, the permeability is moderately rapid, the internal drainage is medium. The natural vegetation is represented by "Tillandsias spp". that grown in an environment of high relative humidity.

Location: ME-57, Pampas de Majes

Representative profile:

| Horizon | Depth cms | Description |
| --- | --- | --- |
| $A_1$ (Wm) | 0 - 30 | Loamy sand; dark yellowish brown (10YR 3/4); single grain or very weak fine granular structure; loose; neutral (pH 7.2); 18 to 45 cms. thick; abundance of small roots; gradual smooth boundary. |
| II $C_1$ (Uu1) | 30 - 65 | Gravelly loamy coarse sand; moderate brown (5YR 3/3 moist); single grain structure; gradual smooth boundary. (Internal gravel about 30% and less than 2 cms. in size). |

| Horizon | Depth cms | Description |
|---|---|---|
| III $C_2$ (Uu2) | 65 - 150 | Gravelly loamy sand; moderate brown (5YR 3/4); single grain; loose, or massive and slightly hard; in neutral (pH 7.3). (Internal gravel in less than 20% and no more than 3 cms. in size). |

c. Tesoro Profile

The Tesoro soils include well drained Alluvial soils, with inclusions of volcanic tuff distributed in thin layers in the profile below 120 cms. They are broadly distributed on the Pampas de la Joya. They are developed on plain areas with uniform slopes of less than 3 percent.

They are thick soils. The internal drainage is medium, the surface runoff is slow, the permeability is moderately rapid. There is no natural vegetation of any type.

Location: JO-30 Pampas de la Joya

Representative profile:

| Horizon | Depth cms | Description |
|---|---|---|
| $A_1$ (Wm1) | 0 - 10 | Loamy sand; moderate yellowish brown (10YR 5/4); single grain structure; loose; neutral (pH 6.9); 7 to 15 cms. thick; abrupt smooth boundary. |
| II $C_1$ (Wm2) | 10 - 30 | Loamy sand, moderate brown (7.5YR 4/4); weak fine granular structure or moderate medium platy; neutral (pH 7.2); 20 to 30 cms. thick; clear wavy boundary. |
| II $C_2$ (Wm3) | 30 - 120 | Strata or lenses of gravelly coarse sand, medium sand, fine or very fine sand; of different colors, but predominantly light grayish yellowish brown (10YR 6/2); single grain or weak very thin platy loose; contains lime and inclusions of volcanic tuff. |
| III $C_3$ (Sy) | 120 - 150+ | Mixture of alluvium with volcanic tuff of medium sand texture; light grayish yellowish brown, to light yellowish brown (10YR 6/3); massive; firm, neutral (pH 7.3). |

d. Siguas Profile

The Siguas series are well drained, relatively young Alluvial soils, formed of successive strata of coarse-textured materials, distributed on almost level areas with slopes of less than 1 percent. The surface runoff is slow, the soil permeability is moderately rapid, and internal soil drainage is medium.

Location: SU-83 Pampas de Siguas

Representative Profile:

| Horizon | Depth cms | Description |
|---|---|---|
| $A_1$ (VW) | 0 - 10 | Medium sand; moderate yellowish brown (10YR 4/3); single grain, mildly alkaline, (pH 7.7); 10 to 30 cms. thick; gradual boundary. |
| $C_1$ (Wm) | 10 - 20 | Medium and coarse sand; light grayish yellowish brown to light yellowish (10YR 6/3); single grain or very fine platy structure; soft or slightly hard; mildly alkaline (pH 7.8); 10 to 20 cms. thick; abrupt boundary. |

| Horizon | Depth cms | Description |
|---|---|---|
| II $C_2$ (Ss) | 20 - 150 | Strata of coarse and medium sand; moderate yellowish brown (10YR 5/4); single grain or weak very thin platy structure; loose; mildly alkaline (pH 7.4). |

# CHAPTER III

## LABORATORY METHODS

The bulk samples were taken from each horizon in such a way that a representative sample of the whole horizon was obtained. These samples were placed in bags for transport to the laboratory. There they were allowed to air-dry and then weighed. A wood roller and hardwood board were used to crush the soil aggregates to pass a 2 mm. sieve. The soil material less than 2 mm. in diameter was saved for physical, chemical and mineralogical analyses. Material greater than 2 mm. in diameter, consisting of gravel and concretions, was discarded after it had been weighed. Its percentage of the total sample was calculated on an air-dry basis. The samples were run in duplicate except where is indicated otherwise.

### A. Physical Analyses

#### 1. Particle-size Analyses

Forty gr. of less than 2 mm. material from each horizon was treated with dilute HCl and 30% $H_2O_2$ in order to destroy free lime and organic matter. It was then dispersed using a Calgon solution. The size distribution of the material less than 50$\mu$ in diameter was determined by a hydrometer method similar to the one described by Day, with minor modifications (16). The sands were removed using a 300 mesh sieve and then separated into different fractions by dry sieving. The results were calculated as percentages of the oven-dry weight of the samples.

2. Bulk Density

Bulk density was calculated by dividing the oven-dry weight of core samples from each horizon used for the water retention determinations by the volume of the sampling core. Three replications were used in the Peruvian Soils and six in the Michigan soils (66).

3. Water Retention

Water retention of the undisturbed Michigan soil cores and the disturbed Peruvian soils were measured at 60 and 333 cm. tension by the ceramic plate-pressure cooker method (66). Water retention at 333 cm. 5 atmospheres and 15 atmospheres were measured on disturbed Michigan and Peruvian soil samples using a 15 Bar Ceramic Plate Extractor (66). The determinations of water held were made on 5 replicates on undisturbed samples and on 3 replicates on disturbed samples. The average percentage of water retained at each tension was calculated on an oven-dry basis.

B. Chemical Analyses of Soil Samples

1. Organic Carbon

The organic carbon contents were determined following the Walkley-Black method based on the reduction of the $Cr_2O_7^{2-}$ ion by organic matter and titration of the unreduced $Cr_2O_7^{2-}$. This method was adapted from Jackson's Manual (33). A slight modification is that instead of use of 0.5N $FeSO_4$, 0.5 N $Fe(NH_4)_2(SO_4)_2$ was used for the titration.

2. Total Nitrogen

Total nitrogen was determined by the Kjeldahl method as described by Bremner (7 ), using the Macro-Kjeldahl distillation unit. The distilled ammonium-N, liberated by digestion, was collected in a 4% boric acid solution containing seven drops of a mixed indicator solution of bromocresol green and methyl red. The ammonium-N was determined in the distillate by titration with 0.0519N HCl.

3. Reaction

Soil pH was measured on a 1:1 soil-water mixture with a Beckman Zeromatic glass eletrode pH meter (66).

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4. Free Iron Oxides

The free iron oxide in the soil samples was removed by the sodium dithionite-citrate-bicarbonate method of Aguilera and Jackson, as modified by Mehra and Jackson (1956) (32). The dithionite-citrate-bicarbonate method presented herein for the removal of iron oxides employs sodium dithionite ($Na_2S_2O_4$) for the reduction, sodium bicarbonate as a buffer, and sodium citrate as a chelating or complexing agent for ferrous and ferric iron. The amounts of free iron oxides removed were determined by the orthophenanthroline method (33) using the Spectronic 20 Bausch and Lomb colorimeter with light of 490 m$\mu$ wavelenth.

5. Available Phosphorus

The available phosphorus was extracted from 2.5 grams of soil with 20 ml. of a solution of 0.03N in $NH_4F$ and 0.025 N in HCl (Bray and Kurtz No. 1 solution) (33). The suspension was shaken for one minute and then filtered. The phosphorus in solution was determined colorimetrically using the ammonium molybdate-hydrochloric acid solution of Dickman and Bray (17) and the 1-amino, 2-naphtol, 4-sulphonic acid reducing agent developed by Fiske and Subbarrow (33).

The method removes, in the words of Bray and Kurtz, "proportional parts of (or)... the more readily soluble portion of each form of available soil phosphorus."

6. Cation Exchange Capacity

The cation exchange capacities were determined by the procedure outlined in Diagnosis and Improvement of Saline and Alkali Soils. Agriculture Handbook No. 60 U.S.D.A. (66). Briefly the exchange complex was saturated with sodium ions (1N NaAc), these were then replaced with ammonium ions (1N $NH_4A_c$). Na in dilute solution was then determined with a Coleman flame emission spectrophotometer, and expressed as m.e./100 gms cation exchange capacity (66).

7. Exchangeable Cations

The exchangeable cations were extracted by adding 20 ml. of neutral 1N $NH_4Ac$ to 2.5 grams of soil sample. The exchangeable potassium and sodium were determined on the filtered solution with a Coleman flame emission spectrophotometer. Calcium was determined on a Beckman Model DU flame emission spectrophotometer. Magnesium was determined on a Perking Elmer Model 290 Atomic Absorption Unit.

The percentage transmittance in each case was compared to a standard curve to determine the amount of each cation.

8. Exchangeable Hydrogen

Exchangeable hydrogen was estimated by the Shoemaker, McLean and Pratt buffer method (56).

9. Total Zinc

To 5 grams of soil, 50 ml. of 12N HCl were added and heated until about 5 mls. were left in the beaker. It was then filtered and made up to 200 ml. with distilled water (47). The zinc was determined on a Perkin Elmer Model 290 Atomic Absorption unit. Percentage of transmittance was compared to a standard curve to determine the zinc content.

C. Clay Analyses

1. Dispersion and Fractionation

Enough of each sample was taken to yield about 3 grams of clay. The soil samples were treated with $H_2O_2$ and several drops of glacial acetic acid to remove organic matter. If carbonates were present 1N HCl was then added until acid to litmus. The excess acid was washed out with distilled water and 0.1 N NaOH was used to saturate the sample with sodium (32). The soil samples were then soaked for more than 24 hours, stirred for 15 minutes with the milk shake machine, sieved through a 300 mesh sieve and transfered to the sedimentation cylinder. The first sample of the clay sus

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suspension was taken between 18 and 24 hours, at the depth determined by Stokes Law for $< 2\mu$ clay. The sample from above the desired depth was removed with a siphon. The cylinder was refilled with distilled water and the shaking and decanting was continued until the clay yield became small.

2. Qualitative Identification of Clay Minerals

Oriented-aggregates of soil clays for X-ray diffraction analyses were prepared essentially according to the Kinter and Diamond method. This technique orients the plate shaped clay particles, so that the 001 planes of most of the clay minerals are in a condition to diffract X-rays more intensely than an ordinary powder pattern (42). About 25 mg. of clay in a dispersed sodium saturated condition was deposited on a porous ceramic plate, by drawing the water from the Na-clay suspension through the plate, using a vacuum pump. This leaves a film of clay on the surface of the plate.

In order to vary the exchangeable cation, the film thus deposited was leached with three increments of 0.1N $MgCl_2$ in 10% glycerol by volume. The excess salt was washed out with 10% glycerol solution, the plate was then air dried, and then drying was completed in a dessicator over $CaCl_2$. An X-ray diffraction pattern was obtained from these Mg-saturated glycerol-solvated, oriented aggregates. The spacing and intensities of 2:1 clay minerals tend to be increased by Mg. saturation. After the initial X-raying, the plate was again placed in the sample holder, vacuum was applied, and the clay film was saturated with several increments of 1N KCl, the excess of KCl was washed out with distilled water and the sample was air-dried at room temperature and X-rayed. The spacings and intensities of 2:1 clay minerals tend to be decreased by potassium saturation.

The plate was then heated at 300°C for two hours and X-rayed again. Finally, the plate was heated to 550°, for more than four hours, cooled, and again X-rayed. These heat treatments of the specimen are required in preparation of layer silicate clays for diffraction analysis. The former collapses vermiculite and the latter destroys the lattice structure of the kaolinite family. These four X-ray tracings were used for the qualitative identification of the clay minerals present.

Instrumental conditions used were: CuK radiation; 35 kv; 20 ma; 1° divergence and scatter slits; 0.006" receiving slit (Ni filter); time constant, 4 seconds; scanning rate, $1^{o}$ $2\theta$ per minute; scale factor 4 or 8.

3. Cation Exchange Capacity of Clays

The cation exchange capacity of the clays was determined as follows: an aliquot containing 500 mg. of clay sample was placed in a 50 ml. centrifuge tube. Ca saturation was obtained by washing five times with 1N $CaCl_2$. The excess of Ca $Cl_2$ was washed out with alcohol (ethyl 80%) until no chloride appeared according to the $AgNO_3$ test. The Ca was exchanged with Mg by 4 washings of 20 ml. each of 0.5N MgCl. The exchangeable Ca was determined on the extract diluted to 100 ml. with distilled water by means of a Beckman Model DU flame emission spectrophotometer. The determined Ca was expressed as m.e. per 100 g. of the oven-dry clay sample and is designated as CEC (Ca/Mg) (32).

4. Total Potassium in Clays

After being dried in the oven at $110^{o}$ C 0.5 g. of clay for the total potassium analysis following the Pratt, method (53) with slight modifications. Instead of $HClO_4$, $H_2SO4$ was used, in the digestion.

5. Differential Dissolution Analysis to Determine Amorphous Content

Amorphous aluminosilicates of high specific surface, often designated as allophane are rapidly soluble by the Hashimoto and Jackson method (26). The Si was determined colorimetrically following the Jackson's specifications (33) page 296, 11-83, and the Al was determined colorimetrically using Jackson's specifications (33) page 300, 11-99, under "Development of Color with Aluminon".

6. Total Specific Surface

An estimate of the total specific surface of the clay was obtained from a measure of the cation exchange capacity of the clay. "It is relaized that the cation exchange capacity is modified by a number of factors besides the internal specific surface. However, for the broad general conclusions drawn in the discussions of the specific surface of the materials, this procedure was considered to be adequate."*

D. Sand Mineralogy

The fine sand fraction (0.25 to 0.10 mm) which was saved in the mechanical analyses of the soil, was used for magnetic

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*Raman, K.V. personal communication.

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separations by the Isodynamic Magnetic Separator. The method is based on separating mineral grains according to their magnetic and electrical properties ( 8 ).

The Isodynamic Magnetic Separator is a very versatile instrument. It consists essentially of an automatic feed to a vibrator table which lies between two elongated poles of a powerful electromagnet. A wide range of mineral species can be separated according to their strength by adjusting the slope (on the long axis of the instrument), the tilt (on the short axis at right angles to the slope) of the instrument, and the strength of the magnetic field (by adjusting the current in the coils). These three can be considered as inherent variables. An independent variable is the rate of feed.

A magnetic strength was fixed by passing 1.4 amps. through the coils and a tilt of $15^{\circ}$ chosen for and maintained throughout the investigation.

Three grams of fine sand were analyzed for each horizon. Strongly magnetic minerals such as magnetite, were separated first using a small permanent magnet. Then the remainder was passed through the isodynamic separator. This gave moderately magnetic, slightly magnetic and non-magnetic fractions. The non-magnetic minerals are those that are not deflected at a value of 1.4 amps., the maximum field strength of the separator. The slightly magnetic group were deflected by the separator. The moderately magnetic group of particles was held by the separator at a value of 1.4 amps.

After the magnetic separation, the fractions were examined under the petrographic microscope in permanent mounts, after fixing the grains to a glass slide with Lakeside 70 that has a R.I. = 1.54. Minerals grains were qualitatively identified by standard optical mineralogical procedures comparing the unknown mineral with sketches and descriptions of standard minerals in reference books (27, 40, 49, 52).

# CHAPTER IV

# RESULTS AND DISCUSSION

## Depth Functions of Soil Properties

Physical and chemical data for the Michigan and Peruvian profiles under study are given in Table 2 through 5. Some of this data will be presented here in graphic form plotting soil properties horizontally as a function of depth in order to establish the vertical sequence of the properties in the profile and to show similarities or differences in depth functions among the pedons of Michigan and Peruvian soils.

### Mechanical Analyses

Particle size distribution data are presented in Table 2. In the Michigan profiles fine sand is the predominant size fraction in all horizons except on the surface horizons where very fine sand is dominant in the Spinks loamy fine sand profile and in the Lapeer coarse sandy loam profile. While the fine sand fraction is increasing with depth in Spinks, in Lapeer the maximum percentage is found in the II $A_2$ horizon and in the lower horizons decreasing.

Table 2. Physical characteristics of $\leq$ 2 mm. fraction

Particle-size distribution of $\leq$ 2 mm. fraction

Table 2. Physical characteristics of $<2$ mm. fraction

| Horizon | Sand: V.coarse 2.0-1.0 | Sand: Coarse 1.0-0.5 | Sand: Medium .05-0.25 | Sand: Fine 0.25-0.10 | Sand: V.Fine 0.10-0.05 | Sand: Total 2.0-0.05 | Silt: Coarse 0.05-0.02 | Silt: Fine 0.02-0.002 | Silt: Total 0.05-0.002 | Clay $<0.002$ | Texture class |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Spinks loamy fine sand** | | | | | | | | | | | |
| $A_p$ | 1.70 | 2.70 | 5.89 | 32.02 | 38.69 | 81.00 | 11.00 | 6.49 | 16.49 | 2.51 | l.f.s. |
| II $A_2$ | 0.90 | 1.15 | 5.25 | 57.75 | 26.45 | 91.50 | 6.40 | 3.10 | 9.50 | 0.00 | f.s. |
| III $A_2Bt$ | 0.44 | 0.44 | 8.50 | 74.37 | 14.15 | 97.90 | 0.30 | 1.80 | 2.10 | 0.00 | f.s. |
| III $A_2Bt$ | 0.00 | 0.00 | 5.10 | 84.10 | 8.60 | 97.80 | 0.40 | 1.80 | 2.20 | 1.65 | f.s. |
| III Bt | 0.00 | 0.00 | 4.10 | 82.45 | 7.45 | 94.00 | 1.60 | 1.90 | 3.50 | 2.50 | f.s. |
| **Lapeer coarse sandy loam** | | | | | | | | | | | |
| $A_p$ | 32.52 | 24.99 | 6.73 | 4.71 | 2.05 | 71.00 | 7.70 | 16.29 | 23.97 | 5.01 | c.s.l. |
| II $A_2$ | 2.90 | 5.90 | 10.10 | 49.12 | 8.88 | 76.90 | 6.10 | 11.99 | 18.09 | 5.01 | l.s. |
| III Bt | 1.81 | 6.59 | 10.97 | 27.14 | 11.49 | 58.00 | 11.30 | 18.08 | 29.38 | 16.62 | f.s.l |
| III C | 2.95 | 8.63 | 10.84 | 21.38 | 10.80 | 54.60 | 12.30 | 23.04 | 35.34 | 10.06 | f.s.l |
| **San Jose loamy sand** | | | | | | | | | | | |
| $A_1$ | 7.87 | 13.28 | 18.83 | 33.21 | 7.41 | 80.60 | 5.90 | 8.46 | 14.36 | 5.04 | l.s. |
| II C | 5.32 | 11.90 | 14.56 | 24.47 | 5.75 | 62.00 | 5.80 | 19.61 | 25.41 | 12.59 | s.l. |
| **Loma Larga loamy coarse sand** | | | | | | | | | | | |
| $A_{11}$ | 33.02 | 22.47 | 7.18 | 10.33 | 6.30 | 79.30 | 4.90 | 8.22 | 13.12 | 5.78 | l.c.s. |
| II $A_{12}$ | 14.30 | 24.63 | 11.87 | 18.45 | 8.55 | 77.80 | 4.30 | 10.38 | 14.68 | 7.52 | l.c.s. |
| III $C_{11}$ | 12.53 | 9.51 | 9.26 | 39.75 | 15.15 | 86.20 | 1.80 | 4.47 | 6.27 | 7.53 | l.s. |
| IV $C_{12}$ | 13.33 | 16.40 | 9.34 | 25.75 | 8.68 | 73.50 | 6.50 | 14.91 | 21.41 | 5.09 | c.s.l. |
| V $C_{21}$ | 23.33 | 16.35 | 16.68 | 14.22 | 13.12 | 83.70 | 3.50 | 7.71 | 11.21 | 5.09 | c.l.s. |
| VI $C_{22}$ | 33.20 | 30.87 | 10.29 | 11.74 | 4.39 | 90.49 | 1.80 | 5.20 | 7.00 | 2.51 | c.s. |

Table 2. Physical Characteristics of < 2 mm. fraction, Cont.

| Horizon | | Particle-size distribution of<2 mm. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sand | | | | | | Silt | | | Clay | |
| | | V.coarse 2.0-1.0 | Coarse 1.0-0.5 | Medium .05-0.25 | Fine 0.25-0.10 | V.Fine 0.10-0.05 | Total 2.0-0.05 | Coarse 0.05-0.02 | Fine 0.02-0.002 | Total 0.05-0.002 | <0.002 | Texture Class |
| | | | | | Tesoro sandy loam | | | | | | | |
| | $A_1$ | 9.66 | 15.33 | 14.08 | 26.46 | 10.87 | 76.40 | 4.60 | 3.86 | 8.46 | 15.14 | s.l. |
| II | $C_1$ | 26.30 | 32.31 | 14.43 | 14.55 | 2.87 | 90.40 | 1.50 | 5.59 | 7.09 | 2.51 | c.s. |
| II | $C_2$ | 16.57 | 39.67 | 17.73 | 16.70 | 3.03 | 93.70 | 1.30 | 2.43 | 3.73 | 2.57 | c.s. |
| III | $C_3$ | 11.43 | 15.91 | 12.74 | 22.08 | 11.54 | 73.70 | 5.30 | 10.94 | 16.24 | 10.06 | c.s.l. |
| | | | | | Siguas coarse sand | | | | | | | |
| | $A_1$ | 20.53 | 22.20 | 15.25 | 27.25 | 5.87 | 91.10 | 1.80 | 4.60 | 6.40 | 2.50 | c.s. |
| | $C_1$ | 34.38 | 21.96 | 14.29 | 16.11 | 4.26 | 91.00 | 2.70 | 1.27 | 3.97 | 5.03 | c.s. |
| II | $C_2$ | 25.45 | 37.25 | 15.33 | 15.35 | 3.62 | 97.00 | 0.50 | 0.00 | 0.50 | 2.50 | c.s. |

In the Peruvian profiles sand is the dominant fraction (over 75%). Only in the San Jose profile the fine sand dominant in all horizons, and this percentage decreases with depth as silt and clay increase. In Loma Larga there is irregular sand size distribution; and in the III $C_{11}$ and IV $C_{12}$ horizons there are maximum percentages of fine sand. In the Tesoro profile fine sand is the dominant sand fraction; in the $A_1$ and III $C_3$ horizons and in the II $C_1$ and II $C_2$ horizons the coarse sand predominates. In the Siguas profile the coarse sand sizes predominate in all horizons.

The silt size separate is higher in the Michigan and Peruvian profiles than the clay fraction except in the III $C_{11}$ horizon of Loma Larga, and $A_1$ of the Tesoro, and II $C_2$ of the Siguas profiles. In the Spinks and Siguas profiles much larger silt amounts are found in the upper horizons. The amount of silt is greater in the Lapeer profile than in the other profiles. In the Spinks, Tesoro and Siguas profiles its ditribution seems to follow the pattern of intensity of physical weathering, that is, increasing with proximity to the soil surface. This was expected in the Peruvian soils since disintegration is the dominant process on the arid Peruvian coast.

In the Spinks profile the clay bulge in the III $B_t$ horizon (bands) can be explained as being due to the movement of clay out of the II $A_2$. horizon; since the clay content of the latter is zero. Therefore the clay accumulation within the III $B_t$ horizon is associated with a decrease in clay in the II $A_2$ horizon. The clay content in the surface horizon of Spinks profile is probably due to depositional differences or weathering in place. If the clay had been formed in place there would probably have been decrease in the silt rather than in the sand fraction and so it seems more likely this is a depositional difference as indicated by the roman numeral designations on the horizons.

The clay bulge in the III $B_t$ horizon of the Lapeer profile is associated with movement of clay from the $A_p$ and $A_2$ horizons, indicating its illuvial nature too.

That the lower horizon of the San Jose profile contains more clay than the upper horizon is probably due to the layers coming from different parent materials, that is depositional differences, as indicated by the roman numerals on the horizons.

The Loma Larga and Tesoro profiles also show despositional differences as indicated by the roman numeral designations of the soil horizons and the variations in proportions of size separates.

The clay bulge in the second horizon of the Siguas profile probably cannot be explained as being due to the movement of clay out of the $A_1$ horizon, since the clay content of the latter is very similar to that of the II $C_2$ horizon unless more clay has formed there. However this profile may not have developed from material exactly like that underlying it.

A comparison of these six profiles indicate that there are textural similarity between Lapeer and San Jose; Loma Larga, Tesoro and Spinks, and the Siguas is coarser than the others.

There is evidence that the additional clay in the bands of Spinks and particularly the argillic horizon of Lapeer is from two sources. When clay contents of the Lapeer $A_p$ and III $B_t$ horizons of the Michigan profiles are compared with the clay content in the parent material Table 1, it is found that the increased clay content in the bands of Spink cannot be attributed entirely to illuviation; because in this profile the $A_p$ horizon is thin and the sumation of the bans are thick. In the Spinks it is also apparent that mineral weathering is occuring throughout the solum, and the clay in the bands result from both illuviation and mineral weathering in situ with the latter being of considerable magnitude in the profile. In Lapeer the increase in clay content in the illuviation horizon is approximately balanced by the theoretical loss of clay from overlying horizons.

In the Peruvian profiles such as the Siguas due to the actual arid condition where these soils are located the movement of clay could be interpreted as possibly due to illuviation when the weather was more moist than the present; or entirely by weathering in situ in the actual arid condition.

## Differences in Parent Material

From the mechanical analysis, is observed the heterogenity of the parent material. The ratio of very fine sand to coarse sand in the sampled soils, show changes in ratio with changes in parent materials, shown in Table 2.

The ratio of very fine sand to coarse sand is very heterogeneous for Spinks and is increasing with depth. In Lapeer the high ratio 1.7 is found in $B_t$ horizon indicating that it is an horizon of fine sand accumulation too.

In San Jose there is slight variation in ratio from 0.6 to 0.5, however the maximum difference is in the content of silt and clay.

In Loma Larga the abrupt changes in the distribution with depth of the different sizes of sands and silt indicate the heterogeneity of the parent material.

In Tesoro profile the distribution of the soil separates show heterogeneity of the parent material too.

In Siguas profile, the distribution of the different soil separate indicate at least two different parent materials.

Bulk Density

From the Table 3, bulk density values presented indicate in the Spinks profile an influence of the organic matter and clay content; in the $A_p$ horizon there is slightly more organic matter the bulk density is less, in the others horizons there is slight variation in the content of organic matter and clay and the changes in volume weight, are slight too, with depth. It seems that the bulk density varies directly with the fine sand content, and inversely with the very fine sand. In Lapeer profile $A_p$ and II $A_2$ has the same clay content, and the difference in bulk density value

Table 3. Soil moisture characteristics, bulk density, and specific gravity of the Michigan and the Peruvian profiles

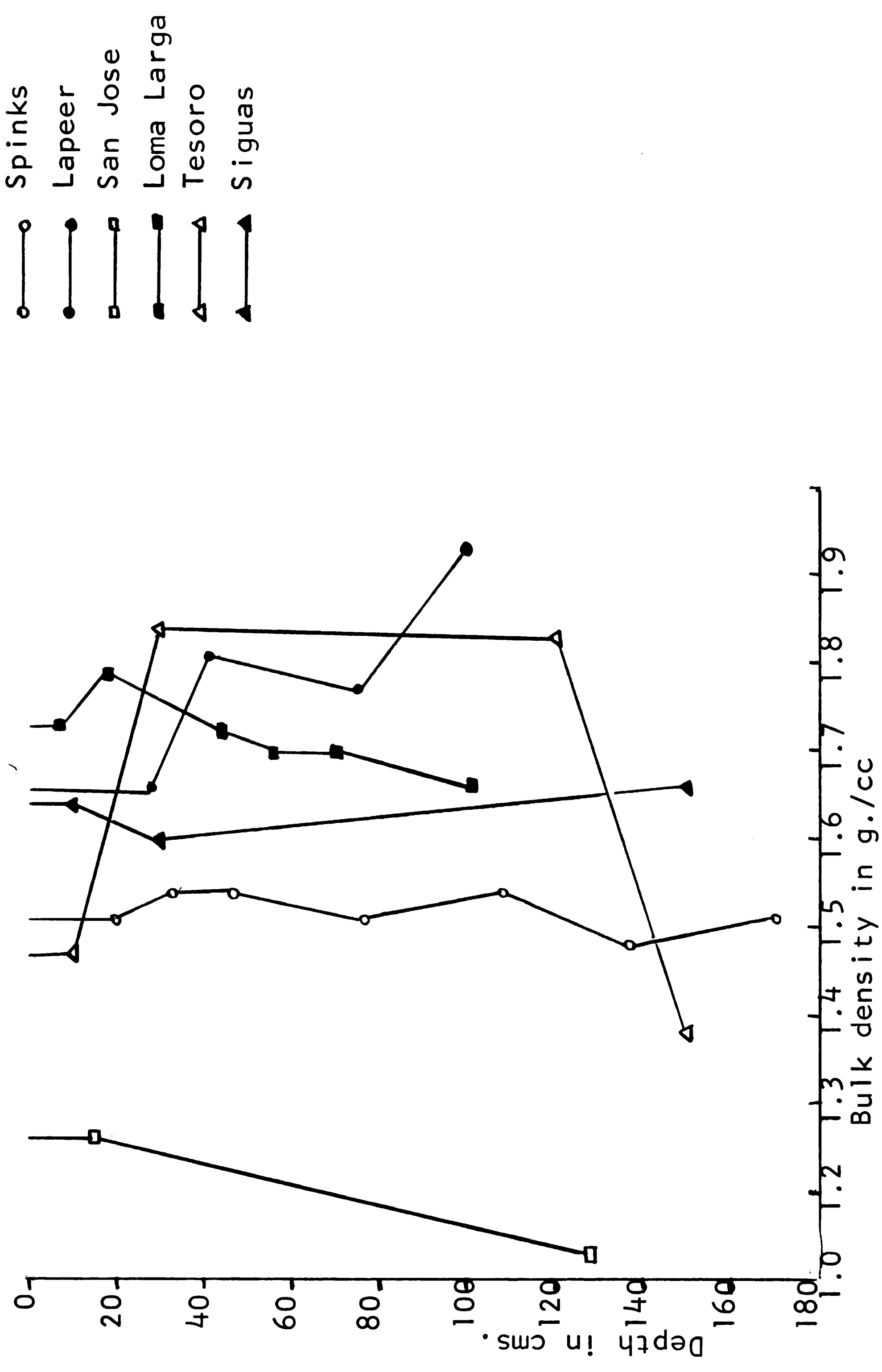
| Horizon | Undisturbed: Saturated % | Undisturbed: 0.06 Atm | Undisturbed: 1/3 Atm | Disturbed: 0.60 Atm | Disturbed: 1/3 Atm | Disturbed: 5 Atm | Disturbed: 15 atm | Available wtr. % | Bulk Density g/cc | Sp gr. | Total pore sp. (vol) % | Capil. pore sp. vol.% | Non-cap. (vol) % | Non-cap. calculated % | Total Solids % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Spinks** | | | | | | | | | | | | | | | |
| $A_p$ | 26.1 | 22.4 | 17.8 | 32.7 | 5.7 | 4.1 | 2.8 | 2.9 | 1.51 | 2.65 | 39.3 | 33.7 | 5.6 | 9.2 | 56.9 |
| II $A_2$ | 26.7 | 19.6 | 6.4 | 17.9 | 2.0 | 1.1 | 0.9 | 1.1 | 1.54 | 2.65 | 41.1 | 30.2 | 10.9 | 11.6 | 58.1 |
| III $A_2B_t$ | 26.7 | 12.3 | 3.2 | 11.0 | 1.3 | 0.7 | 0.6 | 0.8 | 1.54 | 2.65 | 41.0 | 18.8 | 22.1 | 23.0 | 58.1 |
| III $A_2B_t$ | 25.8 | 14.9 | 3.9 | 10.6 | 1.5 | 0.6 | 1.3 | 0.3 | 1.52 | 2.65 | 39.2 | 22.6 | 16.6 | 20.0 | 53.7 |
| **Lapeer** | | | | | | | | | | | | | | | |
| A | 21.2 | 17.3 | 12.9 | 25.2 | 8.0 | 4.1 | 2.8 | 5.2 | 1.66 | 2.65 | 35.1 | 28.7 | 6.4 | 8.5 | 62.6 |
| II $A_2$ | 19.1 | 14.3 | 11.0 | 18.3 | 4.6 | 1.9 | 1.4 | 3.2 | 1.81 | 2.65 | 34.5 | 23.9 | 10.6 | 7.8 | 68.3 |
| III $B_t$ | 22.0 | 18.2 | 15.8 | 24.2 | 11.9 | 5.9 | 6.5 | 5.4 | 1.78 | 2.65 | 38.9 | 32.3 | 6.6 | 0.9 | 66.7 |
| III C | 14.4 | 13.5 | 11.7 | 26.3 | 8.5 | 6.8 | 5.1 | 3.4 | 1.93 | 2.65 | 27.7 | 25.9 | 1.7 | 1.2 | 72.8 |
| **San Jose** | | | | | | | | | | | | | | | |
| $A_1$ | - | - | - | 14.5 | 5.4 | 2.8 | 2.2 | 3.2 | 1.26 | 2.35 | 46.4 | 18.2 | - | 28.2 | 53.6 |
| II C | - | - | - | 38.0 | 13.8 | 7.0 | 5.6 | 8.2 | 1.13 | 2.35 | 51.9 | 43.0 | - | 8.9 | 48.1 |
| **Loma Larga** | | | | | | | | | | | | | | | |
| $A_{11}$ | - | - | - | 15.1 | 3.6 | 2.8 | 1.4 | 2.2 | 1.73 | 2.78 | 37.8 | 26.0 | - | 11.7 | 62.2 |
| II $A_{12}$ | - | - | - | 13.4 | 2.9 | 2.0 | 1.6 | 1.4 | 1.78 | 2.65 | 32.8 | 23.9 | - | 8.9 | 67.1 |
| III $C_{11}$ | - | - | - | 8.3 | 2.2 | 1.4 | 1.2 | 1.0 | 1.72 | 2.75 | 37.4 | 14.3 | - | 23.1 | 62.5 |
| IV $C_{12}$ | - | - | - | 12.0 | 1.9 | 1.7 | 1.9 | 0.0 | 1.70 | 2.62 | 35.1 | 20.2 | - | 14.9 | 64.8 |
| V $C_{21}$ | - | - | - | 12.4 | 1.7 | 1.4 | 1.4 | 0.3 | 1.70 | 2.62 | 35.1 | 21.0 | - | 14.1 | 64.8 |
| VI $C_{22}$ | - | - | - | 8.5 | 1.3 | 0.7 | 0.5 | 0.8 | 1.66 | 2.62 | 36.6 | 14.0 | - | 22.6 | 63.3 |
| **Tesoro** | | | | | | | | | | | | | | | |
| A | - | - | - | 15.8 | 7.8 | 5.0 | 3.5 | 4.3 | 1.47 | 2.65 | 44.5 | 23.2 | - | 21.3 | 55.4 |
| II $C_1$ | - | - | - | 7.3 | 1.5 | 0.7 | 0.6 | 0.9 | 1.84 | 2.71 | 32.1 | 13.4 | - | 18.7 | 67.9 |
| II $C_2$ | - | - | - | 8.5 | 2.0 | 1.8 | 0.7 | 1.3 | 1.83 | 2.71 | 32.5 | 15.5 | - | 17.0 | 67.5 |
| III $C_3$ | - | - | - | 21.7 | 6.2 | 3.5 | 1.5 | 4.7 | 1.38 | 2.69 | 48.7 | 30.0 | - | 18.7 | 51.3 |
| **Siguas** | | | | | | | | | | | | | | | |
| A | - | - | - | 12.5 | 2.7 | 1.7 | 1.0 | 1.7 | 1.64 | 2.73 | 39.9 | 20.5 | - | 19.4 | 60.0 |
| $C_1$ | - | - | - | 11.8 | 4.5 | 2.7 | 1.6 | 2.9 | 1.60 | 2.74 | 41.6 | 19.4 | - | 22.2 | 58.3 |
| II $C_2$ | - | - | - | 4.7 | 1.2 | 0.4 | 0.2 | 1.0 | 1.66 | 2.71 | 38.7 | 7.8 | - | 30.9 | 61.2 |

Percent (vol.) total pore space = percent $H_2O$ (saturated) x B.D.
Percent (vol.) capillary pore space = percent $H_2O$ (0.06) x B.D.

is then due to difference in organic matter content, and associated structural differences. The upper horizons except parent material follows a parallelism in depth with the distribution of fine sand. The high value in the III C horizon may be due to content of gravel observed in the field and the presence of carbonates minerals with higher specific gravities.

The Peruvian profiles are representative of desert areas and the content of organic matter is small. Any change in bulk density is due to other factors than organic matter content and the variations in the profiles are erratic. (Fig. 1) The San Jose profile, from volcanic material is lower in bulk density than the other profiles.

Figure 1. Bulk Density in Relation to Depth



Spinks
Lapeer
San Jose
Loma Larga
Tesoro
Siguas
Depth in cms.
0
20
40
60
80
100
120
140
160
180
1.0
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
Bulk density in g./cc

Capillarity and Aeration Porosity

Relative volume of capillary pores, non-capillary pores and solid particles were measured from water retention and bulk density (BD) (Table 3) data as follows:

Percent (vol) total pore space = percent water (saturated) x BD

Percent (vol) capillary pore space = percent water (0.06 atm) x BD

The choice of 0.06 atm. tension in measuring the percent pore space drained, is used to conform to the minimum depth of tile placement in soil drainage work. This tension was used as a means of differentiating capillary and non-capillary pore space or aeration porosity. Total solids were also calculated by considering:

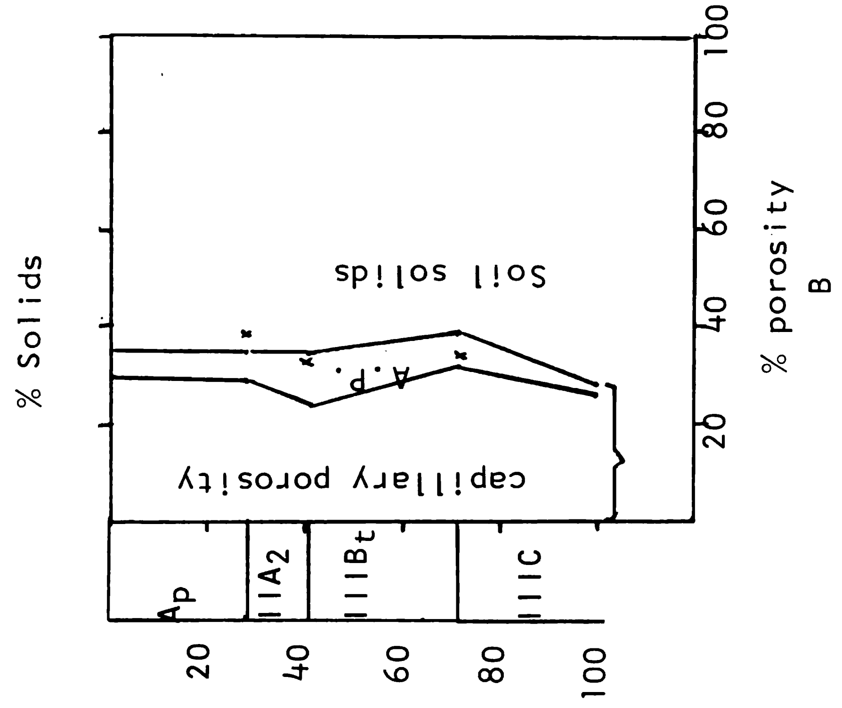
$$\text{Total solids (vol)} = \left(\frac{\text{BD}}{\text{particle density}}\right) \times 100$$

The values of total pore space measured and calculated (by subtracting total solids from 100), are very closely related. Only in the surface of the Spinks and the III $B_t$ horizon of the Lapeer profile there is a maximum difference of about 4%. The calculated total porosity figures are therefore not shown. These differences are shown in Figure 2 by the location of the soil solid contents (x) compared to the total porosities.

Figures 2 and 3 show the pore-size distribution. The Spinks is a sandy soil with slight profile differentiation. The aeration porosity (AP) is quite high in the soil between 107 and 137 cms. In the Lapeer sandy loam with a well differentiated texture profile at 41 cms. there is a maximum aeration porosity and with a minimum aeration porosity in the parent material. It has been found that soils with non-capillary or aeration porosity as low as 2% of the entire soil volume are almost complete impervious to water ( 4). Both profiles show slight variations in total porosity in their profiles with a trend toward greater capillary with proximity to the soil surface. This could be caused by a loss of finer soil materials by eluviation or by a "fluffing-up" process in which material was not lost but the average distance between grains became greater with the cultivating action of plant roots, burrowing of soil animals, or freezing and thawing of soil water.

The Peruvian profiles are not well differentiated, but Siguas and Loma Larga profiles tend to have distribution of total and capillary porosities similar to Spinks and Lapeer profiles, respectively. San Jose profile present an inverse distribution of capillary porosity and aeration porosity

Figure 2. The Capillary porosity, aeration porosity and Soil Solids in Two Michigan Profiles A. Spinks and B. Lapeer as Functions of Depth and Horizons


% Solids
Soil solids
A.P.
capillary porosity
$A_p$
$IIA_2$
$IIIB_t$
IIIC
20
40
60
80
100
% porosity
B

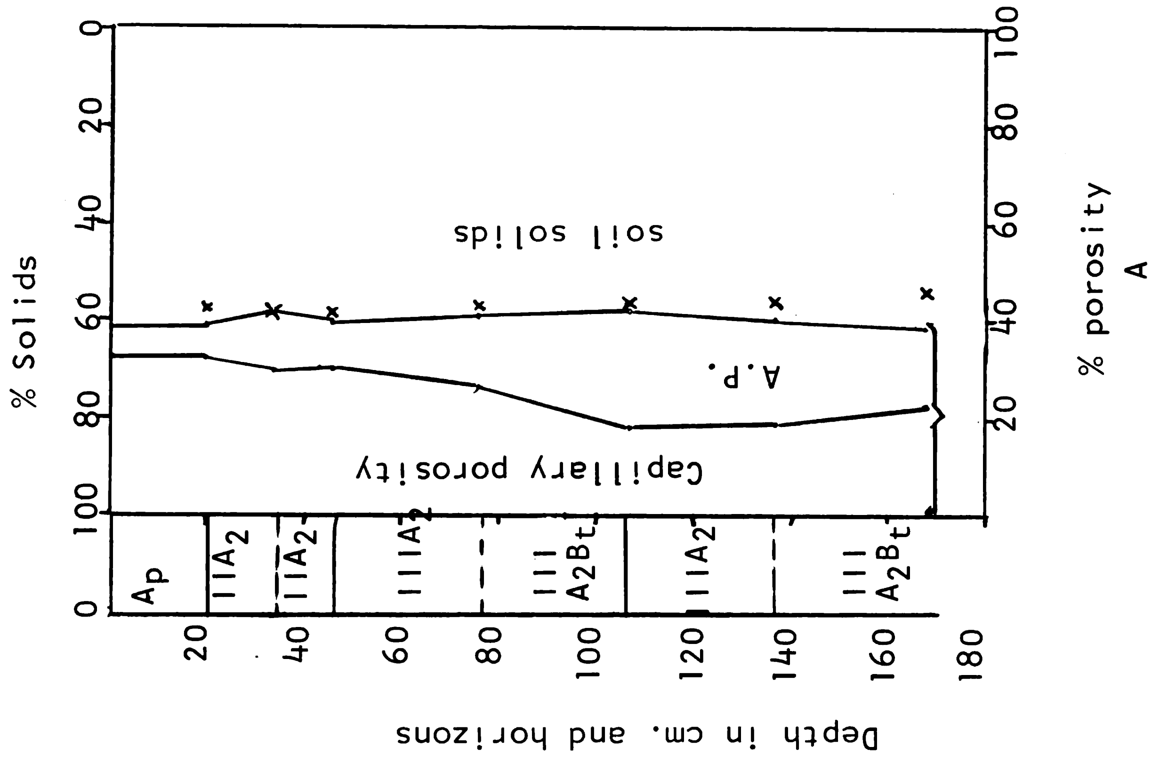
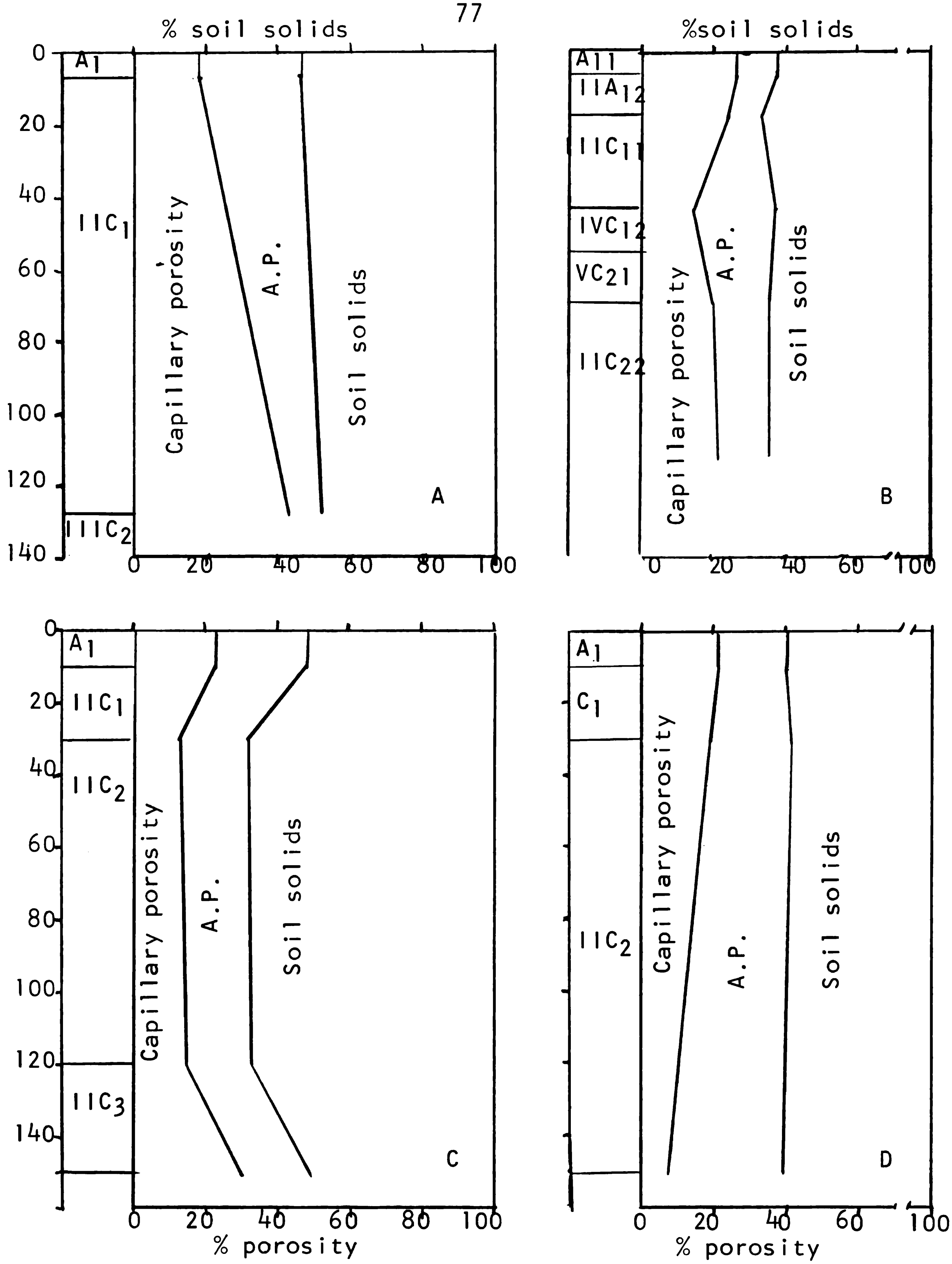

% Solids
0
20
40
60
80
100
soil solids
A.P.
capillary porosity
$A_p$
$IIA_2$
$IIA_2$
$IIIA_2$
III $A_2B_t$
$IIA_2$
III $A_2B_t$
20
40
60
80
100
120
140
160
180
Depth in cm. and horizons
% porosity
A

Figure 3. The Capillary porosity, aeration porosity and percent soil solids in four Peruvian profiles:

A. San Jose
B. Loma Larga
C. Tesoro
D. Siguas


% soil solids
A1
IIC1
IIIC2
Capillary porosity
A.P.
Soil solids
A
%soil solids
A11
IIA12
IIC11
IVC12
VC21
IIC22
B
A1
IIC1
IIC2
IIC3
C
A1
C1
IIC2
D
% porosity
0
20
40
60
80
100
120
140

compared to the Siguas profile; the differences in the type of porosity could be due to the different nature of the material that form the two layers in the San Jose profile. The Tesoro profile shows a parallelism in the distribution of total capillary and aeration porosity with depth, that follows the particle size distribution in the profile, particularly the fine sand clay contents. This indicates that the grains that have more influence in this particular size distribution of porosity are clay and fine sand.

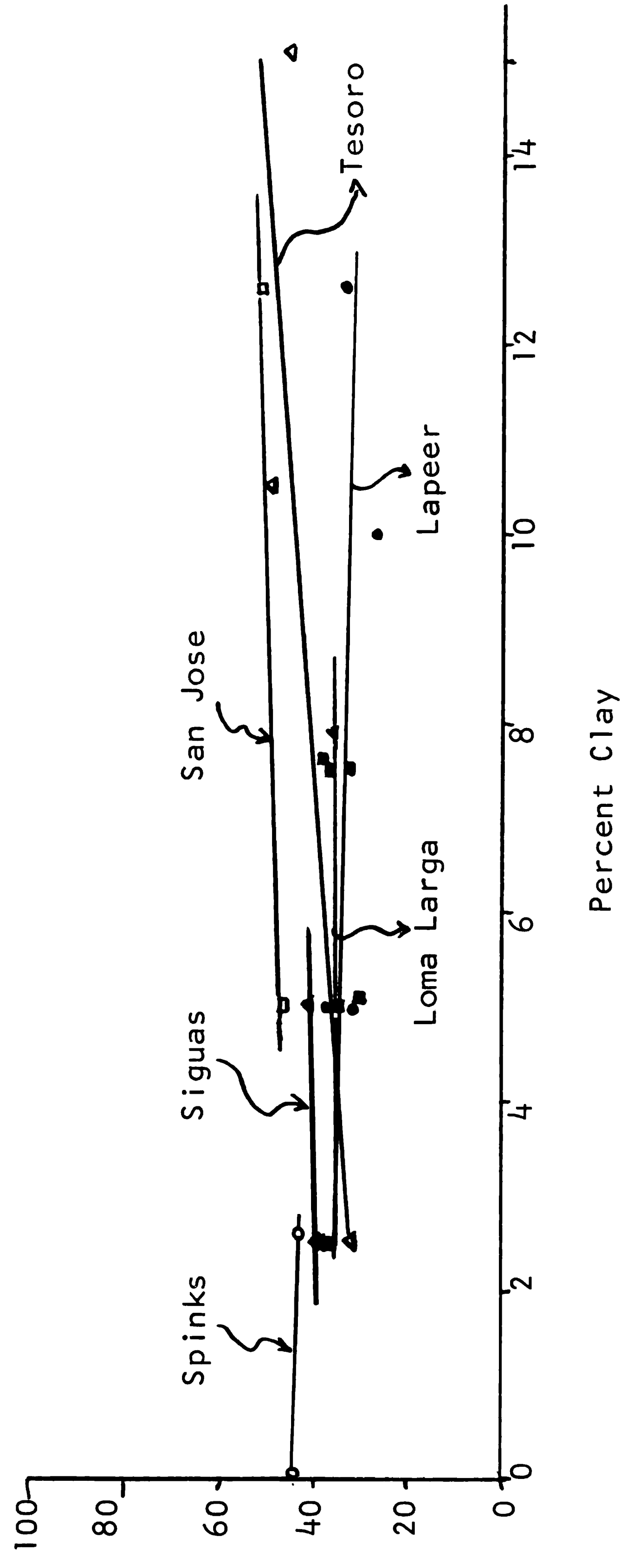
From Figure 4 it is concluded that the percent of clay has little influence on the total porosity.

Soil Moisture Characteristics

The saturated, 0.06, 1/3, 5, 15 atmosphere, and available water percentages are shown in Table 3. In general they increase or decrease with corresponding changes in the amount of fine textural material, organic matter, or capillary porosity. The magnitude of change with depth was not as great for the 15-atm. as for the 1/3 -atm. moisture percentage, although the decreases were proportionate.

Thus, in Lapeer all moisture values start relatively high in the surface horizon, decreases in II $A_2$, increases again in the III $B_t$, and then decreases in the III C horizon.

Figure 4. Percent of total porosity as related to clay content


Spinks
Siguas
San Jose
Loma Larga
Lapeer
Tesoro
Percent Clay
0
2
4
6
8
10
12
14
0
20
40
60
80
100

In Spinks all moisture percentages decrease with depth except in the last horizon where there is an increase due to the presence of more clay in bands.

In San Jose it is important to notice that the last horizon has the highest moisture percentages in that profile. It is also highest in relation to the other horizons of other soils with similar amounts of clay. This is due to its volcanic nature. This horizon it should be recalled, has the highest capillary porosity of all those under study. By other hand, moisture characteristics follow the same pattern of distribution with depth as the capillary porosity in Tesoro profile.

In the Peruvian profiles the moisture contents may be associated with greater salt content, and thicker oriented water layers, that are bound to the sodium-clay in saline soils. Since water is held at higher energy levels in the solonetzic soils, and since their profiles appear to be at field capacity for shorter periods than those of Michigan profiles, it is evident that plants growing on such soils must usually operate against a higher soil moisture stress (18) at given moisture content.

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Cation Exchange Capacity

The exchange capacity of all soils are low, ranging from 1.2 to 14.62 m.e. 100 g. (Table 4). In the Michigan profiles, Figure 5, shows the relative values of C.E.C. as function of depth; they are high at the surface, decrease in the II $A_2$ horizon, increase in the III $B_t$ horizon and decrease in the III C or III $A_2B_t$ horizon. Lapeer has a higher exchange capacity in the III $B_t$ horizon than the III $B_t$ (bands) in Spinks, which is related to the finer parent material.

The Peruvian profiles have somewhat lower cation exchange capacity than Spinks and Lapeer; where clay content is similar this reflects the influence of the organic content and the better development of the Michigan profiles.

In San Jose due to the volcanic nature of the underlying horizon, a higher cation exchange capacity was expected, but shows low. This may be due to the limitations of the method of analyses used.

The dominant cation in all the profiles is calcium. In the Michigan profiles extractable calcium ranges from 1.30 to 15.84 m.e./100 gr. and occupies between 67% and 90% of the exchange capacity.

In Spinks there is almost a normal distribution of cation exchange capacity with depth. It is high in the $A_p$

Table 4. Chemical data for Peruvian and Michigan soil profiles

| Horizon | Depth | C.E.C. | Extractable cations* | Base |
|---|---|---|---|---|

Table 4. Chemical data for Peruvian and Michigan soil profiles

| Horizon | Depth cm. | C.E.C. m.e./100 g. | Extractable cations* m.e./100 g. soil Ca | Mg | K | Na | H | Base Saturated % | pH 1:1 | Extractable Ca/Ng |
|---|---|---|---|---|---|---|---|---|---|---|
| Spinks | | | | | | | | | | |
| $A_p$ | 0-20 | 7.5 | 3.17 | 0.33 | 0.10 | 0.00 | 1.50 | 48.00 | 5.9 | 9.6 |
| II $A_2$ | 20-46 | 2.5 | 1.65 | 0.15 | 0.05 | 0.00 | 0.27 | 82.95 | 6.8 | 10.7 |
| III $A_2B_t$ | 46-107 | 1.2 | 1.52 | 0.13 | 0.04 | 0.13 | 0.10 | 100.00 | 6.9 | 11.7 |
| III $A_2B_t$ | 107-168 | 1.6 | 1.30 | 0.10 | 0.03 | 0.13 | 0.00 | 97.50 | 7.1 | 13.0 |
| III $B_t$ | 148-153 | 7.5 | 4.38 | 0.35 | 0.12 | 0.15 | 0.20 | 66.66 | 6.9 | 12.5 |
| Lapeer | | | | | | | | | | |
| $A_p$ | 0-28 | 6.4 | 2.79 | 1.12 | 0.08 | 0.16 | 0.00 | 64.84 | 7.8 | 2.5 |
| II $A_2$ | 28-41 | 3.7 | 0.55 | 0.04 | 0.04 | 0.17 | 0.00 | 72.16 | 6.6 | 3.5 |
| III $B_t$ | 41-72 | 14.6 | 6.44 | 2.04 | 0.12 | 0.22 | 0.40 | 60.32 | 6.7 | 3.1 |
| III C | 72-100 | 12.3 | 15.84 | 2.30 | 0.09 | 0.27 | 0.25 | 100.00 | 6.9 | 6.9 |
| San Jose | | | | | | | | | | |
| $A_1$ | 0-7 | 6.2 | 17.28 | 0.90 | 0.89 | 1.03 | 0.10 | 100.00 | 6.8 | 19.2 |
| II C | 7-128+ | 5.0 | 115.80 | 1.23 | 1.07 | 2.61 | 0.10 | 100.00 | 6.7 | 94.1 |
| Loma Larga | | | | | | | | | | |
| $A_{11}$ | 0-7 | 5.0 | 35.67 | 3.88 | 1.19 | 9.56 | 0.00 | 100.00 | 7.2 | 9.2 |
| II $A_{12}$ | 7-18 | 3.5 | 14.76 | 7.50 | 2.42 | 14.60 | 0.00 | 100.00 | 7.2 | 2.0 |
| III $C_{11}$ | 18-44 | 5.0 | 16.64 | 7.15 | 1.88 | 6.27 | 0.00 | 100.00 | 7.3 | 2.3 |
| IV $C_{12}$ | 44-56 | 6.2 | 23.73 | 10.22 | 3.02 | 3.96 | 0.00 | 100.00 | 7.2 | 2.3 |
| V $C_{21}$ | 56-70 | 3.7 | 56.94 | 4.42 | 1.25 | 9.73 | 0.00 | 100.00 | 7.3 | 12.9 |
| VI $C_{22}$ | 70-114 | 3.7 | 10.93 | 3.98 | 1.11 | 8.34 | 0.00 | 100.00 | 7.0 | 2.7 |
| Tesoro | | | | | | | | | | |
| $A_1$ | 0-10 | 7.5 | 47.34 | 10.80 | 2.38 | 3.96 | 0.10 | 100.00 | 6.9 | 4.4 |
| II $C_1$ | 10-30 | 3.7 | 43.78 | 3.63 | 0.80 | 9.22 | 0.00 | 100.00 | 7.2 | 12.1 |
| II $C_2$ | 30-120 | 3.7 | 17.06 | 4.16 | 1.25 | 11.30 | 0.00 | 100.00 | 7.2 | 4.1 |
| III $C_3$ | 120-150+ | 7.5 | 85.26 | 7.87 | 2.70 | 9.58 | 0.00 | 100.00 | 7.3 | 10.8 |
| Siguas | | | | | | | | | | |
| $A_1$ | 0-10 | 5.0 | 5.88 | 0.63 | 0.66 | 0.80 | 0.00 | 100.00 | 7.7 | 9.3 |
| $C_1$ | 10-30 | 7.5 | 7.69 | 1.31 | 2.42 | 1.91 | 0.00 | 100.00 | 7.8 | 5.9 |
| II $C_2$ | 30-150+ | 2.5 | 5.31 | 0.36 | 0.56 | 1.91 | 0.00 | 100.00 | 7.4 | 14.7 |

*Exchangeable plus water soluble cations

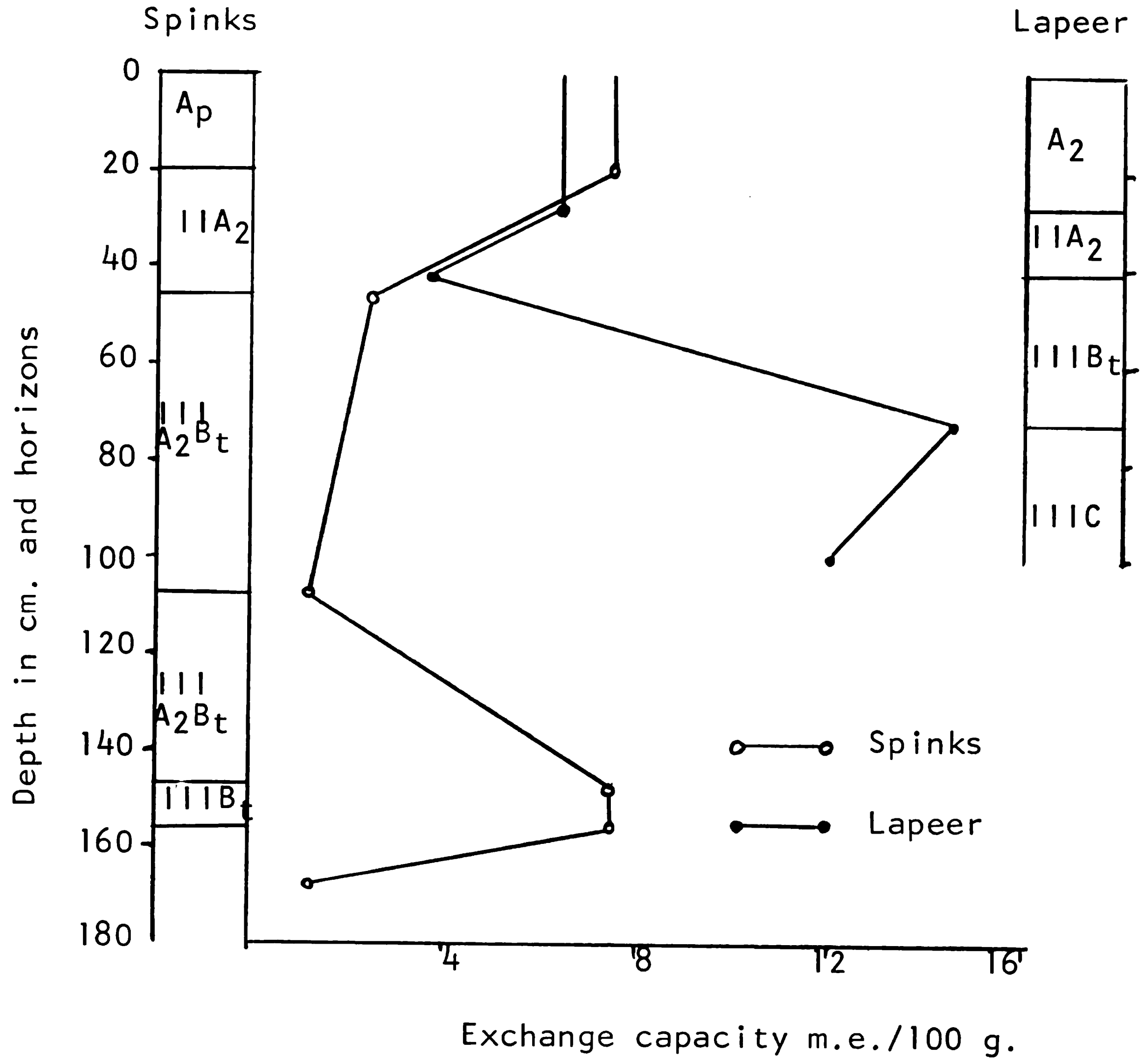
*Table 5. Chemical data for Peruvian and Michigan soil profiles, cont.*

| Available | Total | Organic | Total | Free |
|---|---|---|---|---|

Table 5. Chemical data for Peruvian and Michigan soil profiles, cont.

| Horizon | Depth cm. | Available P ppm | Available P/Zn ppm | Total Zn ppm | Organic Carbon % | Total N % | C/N | Free $F_2O_3$ % |
|---|---|---|---|---|---|---|---|---|
| Spinks | | | | | | | | |
| $A_p$ | 0-20 | 53.25 | 1.3 | 42.00 | 0.918 | 0.093 | 9.88 | 0.41 |
| II $A_2$ | 20-46 | 27.50 | 0.9 | 30.80 | 0.016 | 0.015 | 1.07 | 0.27 |
| III $A_2B_t$ | 46-107 | 14.75 | 0.6 | 24.00 | 0.040 | 0.009 | 4.44 | 0.06 |
| III $A_2B_t$ | 107-168 | 9.25 | 0.3 | 26.80 | 0.048 | 0.008 | 6.00 | 0.10 |
| III $B_t$ | 148-153 | 20.25 | 0.3 | 68.00 | 0.087 | 0.017 | 5.12 | 1.07 |
| Lapeer | | | | | | | | |
| $A_p$ | 0-28 | 14.75 | 0.4 | 30.80 | 0.630 | 0.051 | 12.35 | 0.50 |
| II $A_2$ | 28-41 | 4.00 | 0.2 | 20.00 | 0.135 | 0.018 | 7.50 | 0.20 |
| III $B_t$ | 41-72 | 4.25 | 0.1 | 46.00 | 0.190 | 0.029 | 6.55 | 0.47 |
| III C | 72-100 | 1.50 | 0.0 | 42.00 | 0.167 | 0.024 | 6.95 | 0.50 |
| San Jose | | | | | | | | |
| $A_1$ | 0-7 | 10.75 | 0.2 | 54.80 | 0.008 | 0.008 | 1.00 | 0.8 |
| II C | 7-128+ | 7.25 | 0.4 | 16.00 | 0.024 | 0.004 | 6.00 | 0.0 |
| Loma Larga | | | | | | | | |
| $A_{11}$ | 0-7 | 48.75 | 1.3 | 38.00 | 0.191 | 0.024 | 7.95 | 0.23 |
| II $A_{12}$ | 7-18 | 76.50 | 1.8 | 42.80 | 0.182 | 0.023 | 7.91 | 0.47 |
| III $C_{11}$ | 18-44 | 41.50 | 0.8 | 50.00 | 0.167 | 0.009 | 18.55 | 0.04 |
| IV $C_{12}$ | 44-56 | 90.00 | 1.8 | 50.40 | 0.167 | 0.014 | 11.92 | 0.14 |
| V $C_{21}$ | 56-70 | 58.00 | 1.5 | 39.20 | 0.171 | 0.008 | 8.87 | 0.26 |
| VI $C_{22}$ | 70-114 | 39.50 | 1.2 | 32.00 | 0.048 | 0.006 | 8.00 | 0.29 |
| Tesoro | | | | | | | | |
| $A_1$ | 0-10 | 19.75 | 0.3 | 70.80 | 0.079 | 0.008 | 9.87 | 0.43 |
| II $C_1$ | 10-30 | 17.50 | 0.3 | 50.40 | 0.008 | 0.005 | 1.60 | 0.14 |
| II $C_2$ | 30-120 | 15.25 | 0.3 | 57.20 | 0.040 | 0.004 | 10.00 | 0.26 |
| III $C_3$ | 120-150+ | 13.25 | 0.3 | 38.80 | 0.191 | 0.003 | 63.66 | 0.14 |
| Siguas | | | | | | | | |
| $A_1$ | 0-10 | 11.50 | 0.3 | 48.40 | 0.000 | 0.005 | | 0.06 |
| $C_1$ | 10-30 | 15.75 | 0.7 | 21.20 | 0.000 | 0.006 | | 0.37 |
| II $C_2$ | 30-150+ | 3.25 | 0.1 | 38.00 | 0.000 | 0.005 | | 0.04 |

Figure 5. Comparison of cation exchange capacity m.e./100 g. in the Michigan profiles as functions of depth and horizons


Spinks
Lapeer
0
20
40
60
80
100
120
140
160
180
$A_p$
$IIA_2$
III $A_2B_t$
III $A_2B_t$
$IIIB_t$
$A_2$
$IIA_2$
$IIIB_t$
IIIC
Spinks
Lapeer
4
8
12
16
Depth in cm. and horizons
Exchange capacity m.e./100 g.

horizon decrease in the underlying horizons and then increases in the III $B_t$ horizon. In Lapeer it is high at the surface decreases slightly in the II $A_2$, increases considerably in the III $B_t$ and then decreases slightly again in the III C horizon.

In the Peruvian profiles there are generally more extractable bases than in the Michigan profiles. Former studies (75) have shown there is a high percentage of soluble salts and especially gypsum in those soils. Thus the high values for extractable bases are expression of exchangeable cations and soluble salts. The arid condition do not permit removal of bases and occasional exchangeable hydrogen was found.

In the Michigan profiles magnesium is the second most important extractable cation. It generally has a vertical distribution in the profile similar to calcium. This suggests that the parent material are relatively high in magnesium-bearing minerals.

In the Peruvian profiles Na is the second most important extractable cation. They also contain more extractable K than the Michigan profiles. In San Jose, Loma Larga and Tesoro profiles magnesium is the third most abundant extractable cation and in Siguas the fourth; and it does not follow the same distribution pattern as calcium.

The ratio of exchangeable calcium to magnesium has been used as an index of weathering differences. A lower Ca/Mg ratio it has been suggested is an indication of greater weathering (67). The generally lower Ca/Mg ratios as the surface is approached in the Michigan profiles agrees with this suggestion. Lapeer present narrow ratios than Spinks, therefore, the former is more weathered. The higher ratio of exchangeable calcium to exchangeable magnesium of the $A_p$ horizon of the Spinks soils in comparison to that of the associated Lapeer can be attributed to the biotic factor of soil formation. More calcium is returned to the soil surface by the annual leaf fall, proportionately more calcium than magnesium is found in the leaf tissue of the trees of the Spinks natural vegetation as compared to the natural vegetation of the Lapeer soils. The vertical distribution Ca/Mg ratio in both Michigan profiles show evidence of calcium movement from the upper horizons. The relative high Ca/Mg ratio in the lower horizon of Lapeer profile shows the calcareous nature of the parent material.

In the Peruvian profiles the San Jose has higher Ca/Mg ratios than the other soils under study. This is probably due principally to inheritance from materials where Ca is present as an important component of gypsum or other salt and Mg is present in low amounts in the same sources. In these unleached soils the Ca/Mg ratios could not be used as an index of weathering. Therefore the Ca/Mg ratios is an expression of calcium and magnesium content of the parent materials that form these profiles. In Loma Larga the Ca/Mg ratio in general is lower than in the other Peruvian profiles.

The low extractable Na contents of the Michigan till as compared to the extractable Na content in the upper horizons are evidence that the source of sodium is the till underlying these soils. In the Peruvian profiles there is not uniform Na distribution with depth. Apparently the presence of Na is due to variable content in the parent material of difference layers of these arid profiles.

Reaction

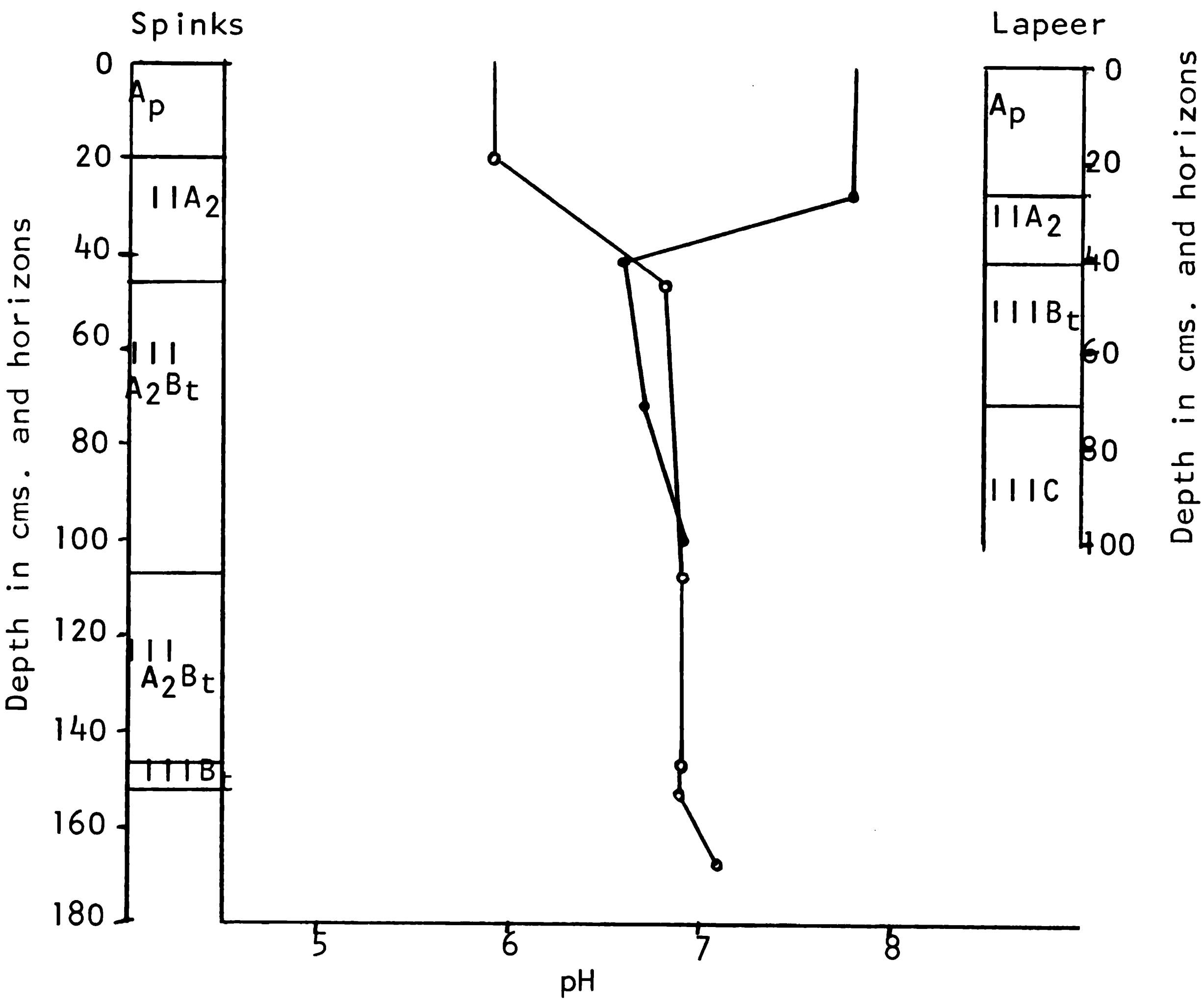
In the Michigan and Peruvian profiles the pH and extractable Na are not closely correlated. The extractable H is closely correlated with pH below neutrality in Michigan and Peruvian profiles.

The lowest pH is in the $A_p$ horizon of Spinks and in this profile the pH increases with depth. The pH profile of Lapeer is characteristic of Gray-Brown Podzolic soils. It decreases from the surface to a minimum in the upper B horizon and then increases with depth. A consideration of the chemistry of both soils show that the weathering processes by which they developed have operated in a medium acid to neutral or mildly alkaline medium. In the reaction of the entire profile of Lapeer, the calcareous parent material has had an influence. The Peruvian profiles are neutral to mildly alkaline throughout. Figure 6 shows pH as a function of depth and horizons for Michigan profiles.

Percent Base Saturation

pH values have been used 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 cation. Percent base saturation in Spinks began at very low level in the surface increases to a high point in III $A_2B_t$ horizon and decreases to a low point in the III Bt bands. In Lapeer profile, percent base saturation began at a low level in the surface, increases in the II $A_2$, decreases to a low

Figure 6. pH as a function of depth and horizons for Michigan profiles


Spinks
Lapeer
Depth in cms. and horizons
Ap
IIA2
III A2Bt
III A2Bt
IIIB
IIIBt
IIIC
0
20
40
60
80
100
120
140
160
180
5
6
7
8
pH

point in the III $B_t$ and finally increases to a complete saturation as free carbonates are reached in the calcareous till. This indicates that the III $B_t$ horizons in these profiles are not zones of accumulation of bases. The Peruvian profiles are one hundred percent base saturated. This is due to the high content of cations, mainly calcium in arid regions.

Organic Carbon, Nitrogen and C/N Ratio

The distribution and amounts of organic carbon and nitrogen are shown in Table 5. Organic carbon depth functions, show relatively high values for the surface horizons of Spinks and Lapeer and these decrease sharply into the II $A_2$ and then increase slowly down the profile. Only very slight increases in organic carbon are noted in the III $B_t$ horizons. These increases indicate a slight accumulation in III $B_t$ horizons relative to the horizons immediately above them. Such differences are not significant, but a definite trend is indicated.

Total nitrogen depth functions have almost the same shape as the organic carbon functions.

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In these forested regions it is generally assumed that most of the organic matter added to the soil is deposited on the surface; upon decomposition by microorganisms certain intermediate products become mobile and are carried down into the profile. The organic matter in the profile is thus composed of two components, the recently-living root material which was not removed when the samples were prepared for laboratory analyses, and the amorphous material capable of being moved down the profile. It is possible that depth functions of the latter components show weak minimum-maximum relations but they are masked by the relatively greater amounts of the former component in the youngest soils.

In the Peruvian profiles the maximum percentage of organic carbon is similar to the lowest percentage found in the lower horizons of both Michigan profiles. The small amount found in the arid region is normal because there are only remnants of some former scanty vegetation present. There is no uniform distribution with depth.

The low nitrogen content of these soils are not generally closely related to organic carbon distribution or as a function of depths.

The ratio of carbon to nitrogen in the Michigan profiles are highest near the surface and could probably be attributed

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to the presence of a well balanced lignin-derived material. The C to N ratio in the subsoils are below 8 to 1; this is true in general because the subsoil organic matter contains a lower percentage of lignin and a higher percentage of microbially derived material (63).

In the Peruvian profiles the C/N ratio is very variable. For example, in the San Jose profile at the surface there are only traces of organic carbon and nitrogen and the ratio is narrow. These soils are being developed under conditions of permanent wind erosion. The Loma Larga and Tesoro profiles have better balanced C/N ratio than the former. The Loma Larga soil is influenced by some intermittent vegetation.

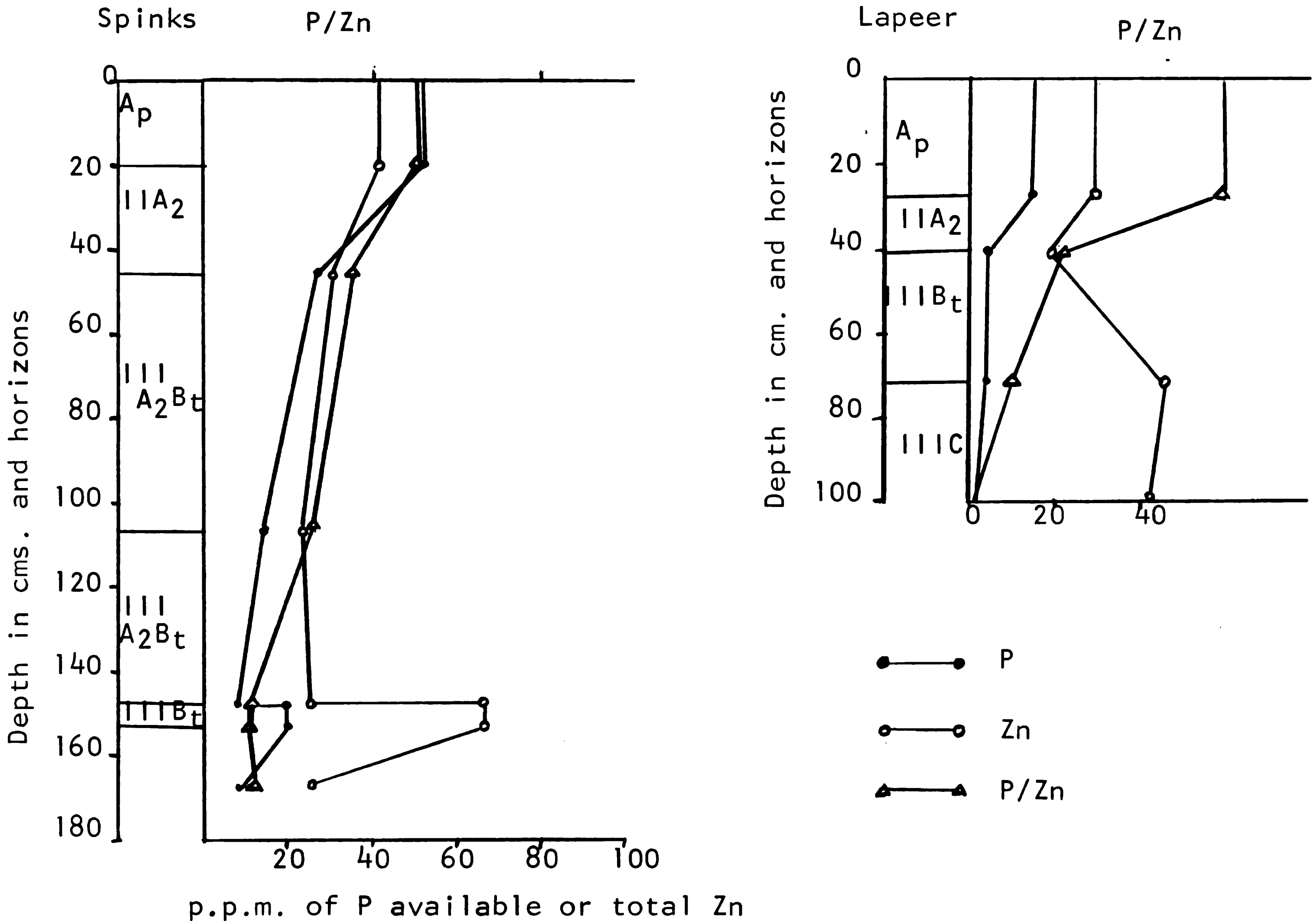
Available Phosphorus, Total Zinc and P/Zn Ratio

Available P contents of the six profiles are shown in Table 5 and their distributions as function of depth are presented in Figures 7 and 8.

Available phosphorus profile distribution are similar except for the Loma Larga profile. The values are usually highest in the surface and decrease with depth. The Spinks profile shows a minimum content at 147 cms. and increases in

Figure 7. Available P, total Zn and P/Zn ratios as functions of depth and horizons for the Michigan profiles

Spinks P/Zn Lapesr



Spinks
P/Zn
Ap
IIA2
III A2Bt
III A2Bt
IIIBt
Depth in cms. and horizons
p.p.m. of P available or total Zn
Lapeer
P/Zn
Ap
IIA2
IIBt
IIIC
Depth in cm. and horizons
P
Zn
P/Zn

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the III $B_t$ bands below. The Siguas profile has a relative maximum value at $C_1$ horizon. The Loma Larga profile has an irregular profile distribution, with increases in the II $A_{12}$ and IV $C_{12}$ horizons then decreases with depth. This profile has the highest available phosphorus contents of the profiles studied.

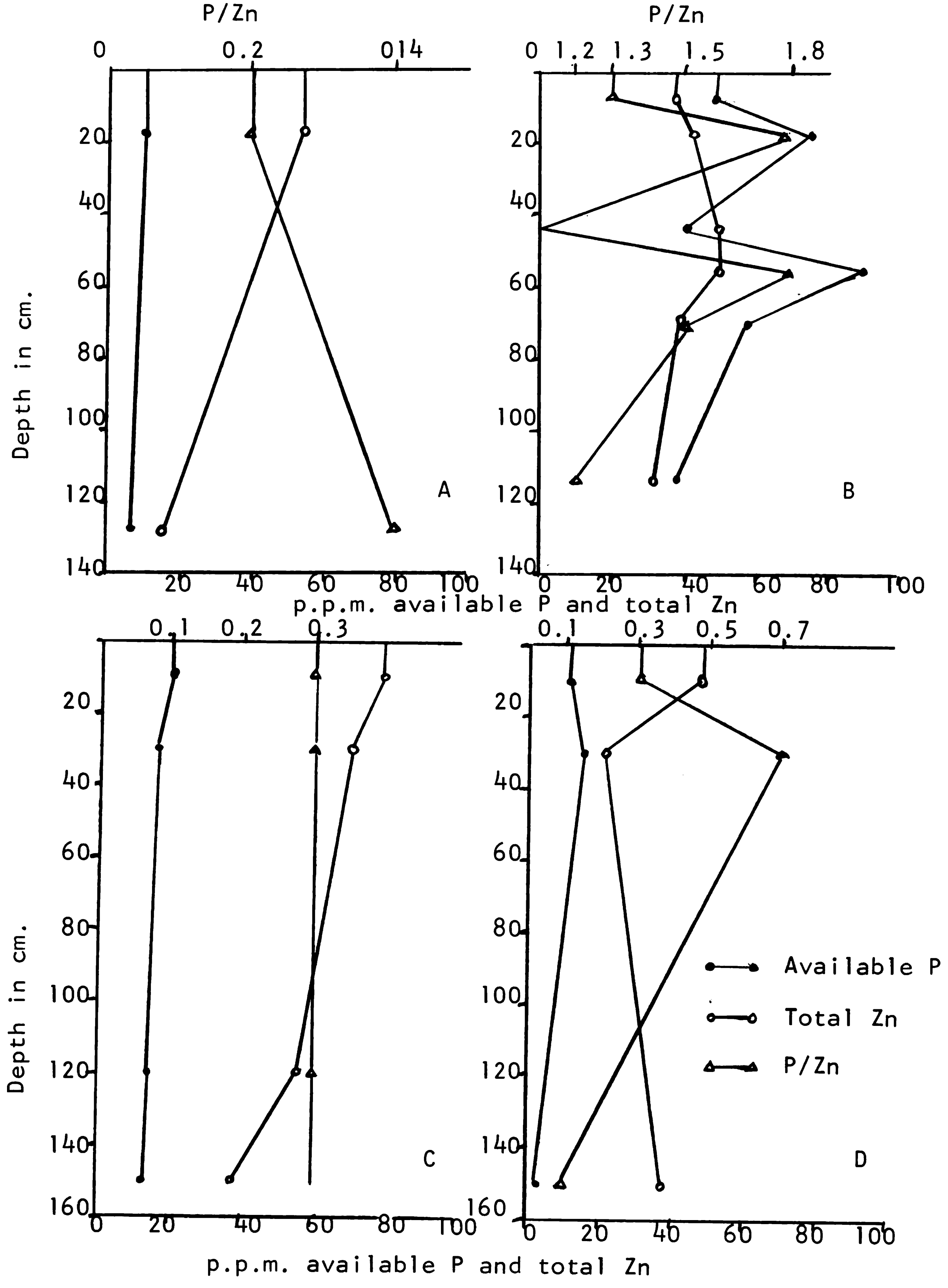
The available P values are high in the surface horizons of Spinks and Lapeer due to either P fertilization or to inorganic phosphorus and easily mineralized organic phosphorus compounds from plant residues. Decreasing available phosphorus values start immediately lower $A_p$, due primarily to the constant removal of soil phosphorus solution by plant roots and by eluviation. Accumulation of available phosphorus in the III $B_t$ bands seems due primarily to weathering of phosphate bearing minerals and illuviation. The lowest values of available P observed were in Lapeer at 100 cms., the calcareous parent material.

In the Peruvian profiles the San Jose profile is formed in materials of volcanic nature and inherits a characteristic low available phosphorus. The Tesoro and Siguas profiles are without much evident evolution or any natural vegetation. Their relatively low available phosphorus came only from a poor source of phosphorus.

Figure 8. Available P, total Zn and P/Zn ratios as functions of depth for the Peruvian profiles:
A. San Jose
B. Loma Larga
C. Tesoro
D. Siguas

Depth in cm.

Depth in cm.


P/Zn
0
0.2
0.4
P/Zn
0
1.2
1.3
1.5
1.8
Depth in cm.
20
40
60
80
100
120
140
A
B
0
20
40
60
80
100
p.p.m. available P and total Zn
0.1
0.2
0.3
0.1
0.3
0.5
0.7
160
C
D
Available P
Total Zn
P/Zn
p.p.m. available P and total Zn

A better understanding of a relatively high available phosphorus in the Loma Larga profile may be obtained from solubility product principles. Lindsay and Moreno (43) give about equal solubility for Al, Fe and di-or octo-calcium phosphates at near neutral pH values. The pH of this profile is about neutral, at neutral pH values phosphorus in the soil solution could be supplied from any or all of these sources provided they exist in the soil. They may contribute about equally if they are present in the same quantity and have the same surface area. There is more available phosphorus in this profile largely because of a higher content in the initial materials and lack of leaching. Only the seasonal mists have permitted, through the ages, some movement of available phosphorus from the surface soil and without replenishment of phosphorus removed from the soil solution. The pH must decline to about 7 before primary apatite minerals can be weathered and form appreciable amounts of secondary phosphorus compounds. According to theory (29, 43) after the pH declines to near neutrality secondary phosphorus compounds of iron, aluminum, and calcium should form with about equal ease provided the cations are present in similar quantities. The results of the present studies support the above theoretical considerations concerning relatively high available phosphorus in this profile.

Total Zinc and P/Zn Ratio

The total Zn in soils is poorly correlated with available Zn although some investigators have found areas where soils of low total Zn have more Zn deficiencies than areas of higher Zn content (64).

In the Spinks profile, Table 5, and Fig. 7, Zn is highest in the surface and decreases in content with depth, showing accumulation in the III $B_t$ bands. In Lapeer Zn decreases in the II $A_2$ horizon, increases in III $B_t$ horizon and decreases again in the III C horizon.

The reason of relatively high concentration of total zinc in the surface soil, lies in the uptake of zinc from the subsoil by plant and its translocation to the leaves. When the leaves fall and decay, zinc is released from the plant tissues and it is fixed in the surface soil (64).

Lapeer shows an accumulation of zinc in the III $B_t$ horizon, but less than in the Spinks profile. This indicates less movement of zinc in the Lapeer. Its calcareous parent material and its reaction will decrease the zinc availability. It is commonly thought that zinc availability is at a minimum in the soil pH range of about 5.5 to 7.0. As the reaction rises above pH 7, the situation becomes more complex (64). The Spinks and Lapeer profiles are both in these pH ranges, therefore Zn deficiencies may be noticed in plants growing on these soils.

In the Peruvian profiles, Table 5 and Fig. 8, the Zn contents generally vary in the same way as the available P contents. In San Jose the content of zinc decreases with depth and the P/Zn ratio increases. In Loma Larga Zn increases from $A_{11}$ through IV $C_{12}$, and decreases in the last horizon; the P/Zn ratios are higher than 1 except in the third horizon. Tesoro shows the higher total zinc values at the surface soil and third horizon, and in whole profile the zinc content is higher than available phosphorus and the P/Zn ratios are uniform at 0.3 in all horizons. In Siguas there is a relatively high value of zinc at the surface, it decreases in the second horizon and then increases in the third horizon; the P/Zn ratios vary inversely to the zinc distribution and follow more the relative values of available P.

Judging from the irregular Zn distribution in these undifferenciated profiles, and the difference in content from one horizon to the other, it seems that it is associated in this arid environment with the nature of the parent materials.

In these soils the reaction is higher than in the Michigan profiles, and it is likely that the available zinc present in these soils is near the critical level. Zinc deficiencies may, therefore, be expected to appear on crops in these areas.

Free Iron Oxides

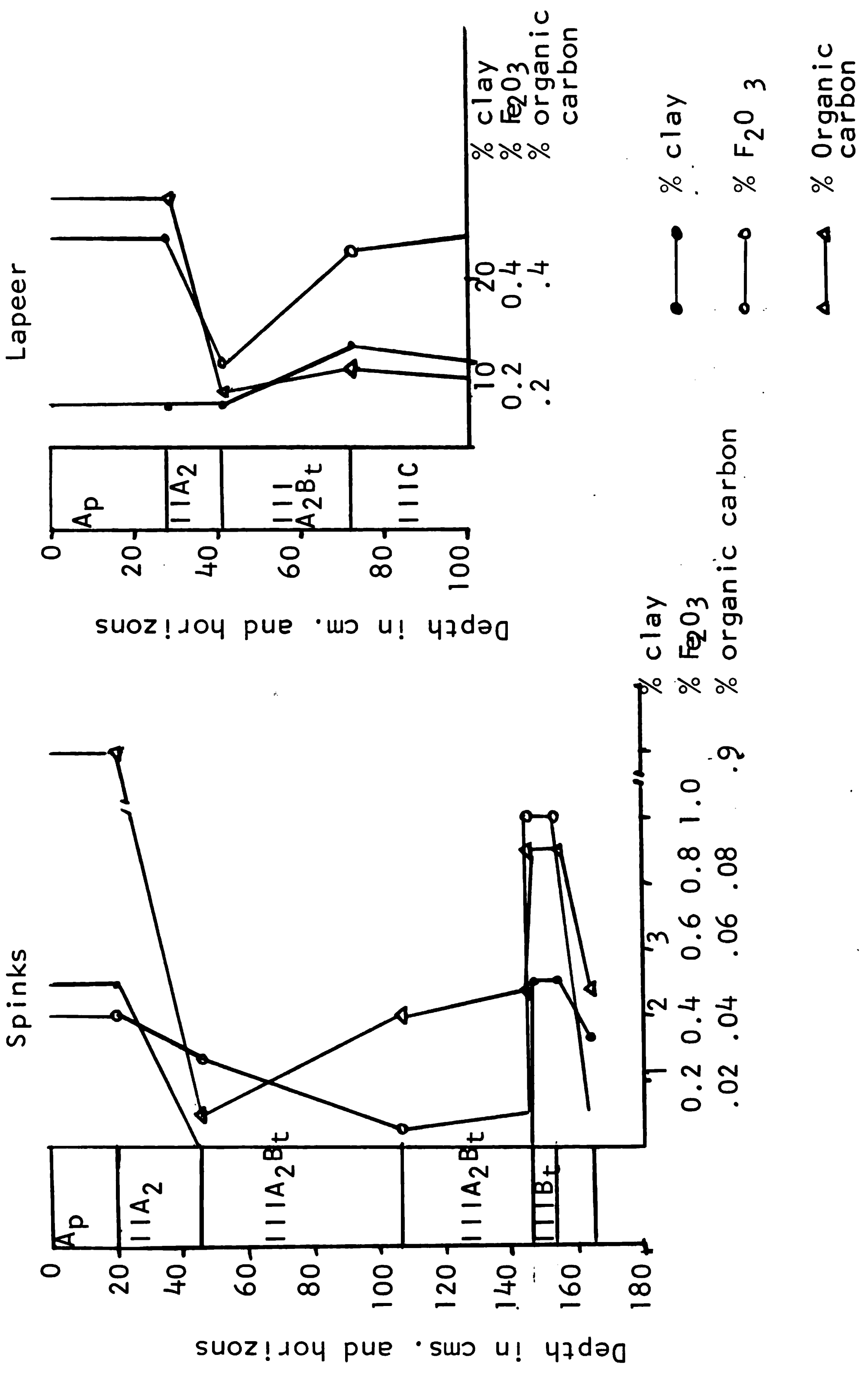
Free Iron oxides are a measure of iron that is present in the form of immobile iron oxides in the soil and not in iron silicates.

From the data reported in Table 5 and Fig. 9, it is evident that the free iron is affected by the content of clay and organic matter in the Michigan profiles; while their presence in the Peruvian profiles are completely independent of those factors.

Supporting evidence for the importance of organic matter and clay as factors in free iron oxide distribution comes from the two Michigan soils. Both have low free iron values in the II $A_2$ horizons, which are low in organic matter and clay. The $A_p$ horizons are almost similar in free iron content in both soils. The Spinks $A_p$ is higher in organic matter than Lapeer however but the latter contains more clay.

The highest amount of free iron in the Spinks is found in the bands or III $B_t$ horizons while the value highest free iron content in the Lapeer is not in the III $B_t$ horizon, the iron oxide contents of the $A_p$, III $B_t$ and III C horizons are nearly equal. In general, within either profile the highest free iron oxide distribution corresponded to the highest organic matter and/or clay contents. Increases of iron with proximity to the surface is due, in part, to the greater chemical weathering there and oxidation of the iron releases. The organic decomposition compounds may be favoring leaching of the free iron into the III $B_t$ horizons from the II $A_2$ horizons. The pH of those soils are not such as to favor iron mobility without organic matter. In comparing free iron oxide contents in the $B_t$ horizons of both profiles, there does not seem to be any clear-cut relationship between clay content and free iron content. Spinks has $B_t$ horizon with a clay content of 2.50% and a free iron content of 1.07%. Lapeer has a free iron content of 0.50% and a clay content 10%. The reasons for this lack of direct relationship is not well understood, but may be due to more additions than losses of iron oxides in the bands independent of the silicite clays. If it is true that

Figure 9. Distribution of free iron, clay, and organic carbon in Spinks and Lapeer profiles


Lapeer
Depth in cm. and horizons
0
20
40
60
80
100
Ap
IIA2
III A2Bt
IIIC
10 0.2 .2
20 0.4 .4
% clay
% Fe2O3
% organic carbon
% clay
% F2O 3
% Organic carbon
Spinks
Depth in cms. and horizons
0
20
40
60
80
100
120
140
160
180
Ap
IIA2
IIIA2Bt
IIIA2Bt
IIIBt
1 0.2 .02
2 0.4 .04
3 0.6 .06
0.8 .08
1.0 .9
% clay
% Fe2O3
% organic carbon

there is no direct relationship in the movement of the clay and free iron, periodic dessications and dehydration of iron oxides may enhance their inmobility in the bands.

In the Peruvian profiles there is not any relationship between the content and distribution of free iron with organic matter and clay content. This may be due to the weak processes of soil formation in desert areas that are very different to those in Michigan. It seems, therefore, that the presence of free iron is more in relation with the nature of parent material in those arid soils.

Mineralogy of the Clay Fraction

As indicated under Laboratory Methods, the clay fractions ($< 2\mu$) were studied by X-ray diffraction to obtain information on clay mineralogy. Orientated specimens were prepared by depositing soil clay on porous ceramic plates and X-ray tracings obtained after four treatments:

1. Mg-saturated glycerol solvated, oriented aggregate, air dried
2. K-saturated, air dried
3. K-saturated and heated to 300°C and
4. K-saturated and heated to 550°C.

Figures 10 through 15 show the X-ray diffraction patterns for two Michigan and four Peruvian profiles. The information has served to establish the mineralogical composition of the clay fractions and to assess changes which have resulted due to pedogenesis.

A summary of the estimations of the various clay minerals are presented in Table 5. The amounts of minerals present are estimated from the diffraction peak areas and their relative amounts are indicated as follows:

| | | | |
|---|---|---|---|
| x | small | xxx | large |
| xx | moderate | xxxx | predominant |

Table 6. Clay Mineral Identification and Estimation in the $< 2\mu$ Clay Fraction of Major Horizons of Michigan and Peruvian Profiles

| Horizon | Depth | Mt | Mi | Vm | Chl | Ka | Interstratified Vm-Chl | Mi-Chl | Chl-Mi-Vm | Mt-Vm | Mi-Vm | Feld |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | <u>Spinks</u> | | | | | | | | | | |
| $A_p$ | 0-20 | | xx | xx | xx | x | | | xx | | | |
| II $A_2$ | 20-46 | | xx | xx | xxx | x | | | xx | | | |
| III $A_2B_t$ | 46-107 | | x | x | x | x | xx | | | | | |
| III $A_2B_t$ | 107-168 | | xx | x | x | x | | | | | | |
| III $B_t$ | 148-153 | | x | x | | x | | | | | | |
| | | <u>Lapeer</u> | | | | | | | | | | |
| $A_p$ | | | x | | | xxx | xx | | | | | |
| II $A_2$ | | | x | | | xxx | xx | | | | | |
| III $B_t$ | | | xx | x | | x | xx | | | | | |
| III C | | x | x | xxx | | xxx | x | | | | | |
| | | <u>San Jose</u> | | | | | | | | | | |
| $A_1$ | | | xx | xx | | | | | | | xx | xx |
| | | Loma Larga | | | | | | | | | | |
| $A_{11}$ | | | xx | | x | x | | x | | | | xx |
| II $A_{12}$ | | | xx | | xx | xx | | x | | | | xx |
| III $C_{11}$ | | | xx | | x | xxx | x | | | | | xx |
| IV $C_{12}$ | | | xx | | xx | x | | | | | | xx |
| V $C_{21}$ | | x | xxx | x | xx | | | | | | | xx |
| VI $C_{22}$ | | | xx | | x | xx | | | | | | xx |
| | | Tesoro | | | | | | | | | | |
| $A_1$ | | | x | | x | | | | | xx | | xx |
| II $C_1$ | | | xx | xx | x | x | | | | | | xx |
| II $C_2$ | | x | xx | x | | x | | | | | x | xx |
| III $C_3$ | | | xx | x | | x | | | | | x | xx |
| | | Siguas | | | | | | | | | | |
| A | | x | xx | | | x | | | | | | xx |
| $C_1$ | | xx | xx | | | x | | | | | | xx |
| II $C_2$ | | xxx | xx | | | xx | | | | | | xx |

Estimates are consistent among profiles so far as possible, but small deviations were made to indicate relationships among horizons of individual profiles.

1. Michigan Profiles

   a. Spinks

From the x-ray diffraction patterns, Fig. 10, the following observations on the clay composition of the profile are made.

$A_p$ Horizon

The sample shows the presence of vermiculite, mica, and kaolinite as discrete mineral species, vermiculite is evident by peaks at 14.3°A, on Mg-saturation and glycerol solvation which collapse to 10°A with K-saturation and heating. The 10°A peak of mica is present even before the K-saturation and heating.

Evidence for the presence of kaolinite comes from the reduction in intensity of the 7°A peak on heating at 550°C. The sample contains also chlorite interstratified with mica and vermiculite. This random interstratification is shown by the broad shoulder that appears on the low side of the 10°A peak on K-saturation and heating, with no discrete peak at 14°A.

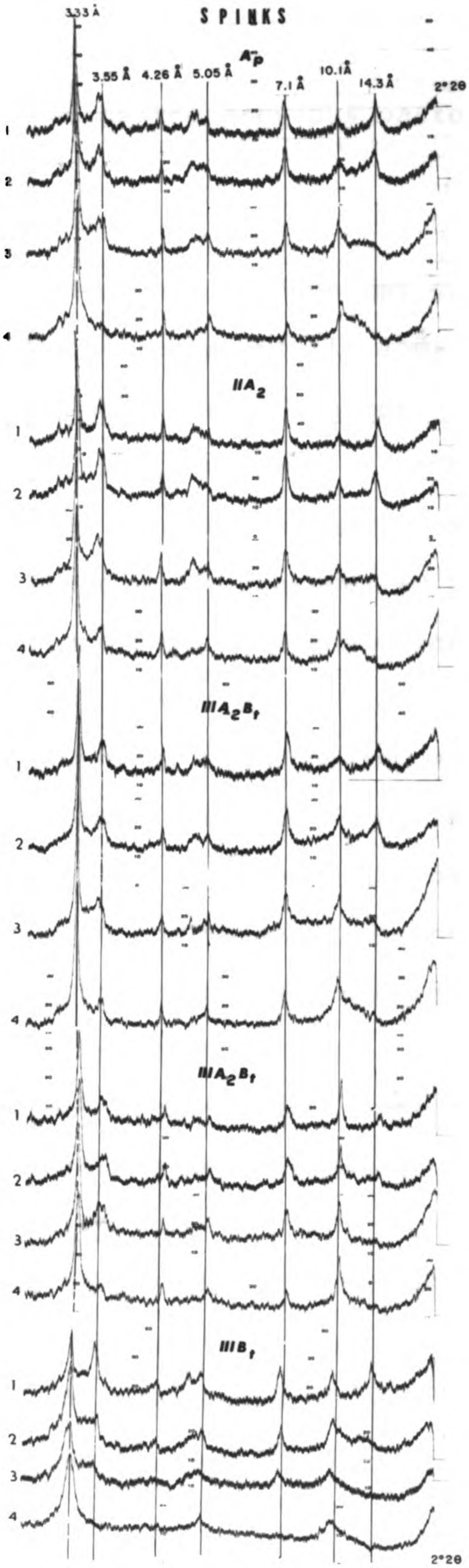

SPINKS
3.33 Å
$A_p$
3.55 Å
4.26 Å
5.05 Å
7.1 Å
10.1 Å
14.3 Å
2°2θ
$IIA_2$
$IIIA_2B_t$
$IIIA_2B_t$
$IIIB_t$
1
2
3
4
2°2θ

Figure 10

II $A_2$ horizon

Essentially the same as the previous pattern, only more chlorite present.

III $A_2B_t$ horizon

For practical purposes this horizon was sampled to different depths; the upper represent III $A_2B_t$ mostly without bands and the lower one mostly bands. In the upper III $A_2B_t$, the X-ray pattern shows it to be very similar to the previous II $A_2$ horizon and to be very crystalline. Most of the clay is represented by vermiculite and chlorite interlayer and some mica and chlorite.

In the lower III $A_2B_t$ the X-ray diffraction patterns indicate a very small amount of vermiculite, a moderate amount of mica and very small amounts of kaolinite and chlorite. The 7.1Å peak that represents the basal spacing of kaolinite coincides with the second order of chlorite is resolved into two in the reflections occurring in the 3.5 Å region, 3.55 Å is the second order of kaolinite and at 3.53 Å is the 4th order of chlorite. Thus the presence of both kaolinite and chlorite are indicated.

III $B_t$ (bands) Horizon

The X-ray patterns of this horizon showed discrete peaks of vermiculite, mica and kaolinite. The peak at 10.1 Å indicates mica. Disappearance of the 14.3 Å peak with K-saturation and heating to 300°C identifies vermiculite.

The 7.1 Å peak disappears after heating to 500°C. indicating the presence of kaolinite.

It is important to notice that the chlorite is found in all horizons except the III $B_t$ horizon from near the base of the profile sampled. This suggests the pedogenetic origin of this clay with vermiculite being changed to chlorite.

The cation exchange capacity in general agrees with the proportions of clay in each horizon; and the proportion of total potash agrees with the mica distribution, Table 7.

b. Lapeer

X-ray diffraction patterns of the Lapeer profile are shown in Fig. 11.

$A_p$ Horizon

The X-ray diffraction patterns of the Mg-saturated, glycerol-solvated and K-saturated clay gives a peak at 14.3 Å, small peak at 10.1 Å and a relatively strong peak at 7.1 Å. Upon heating at 300°C. the 14.3 Å peak shifts to a broad 10.1 Å peak, revealing an interstratified chlorite vermiculite system. The 7.1 Å heated at 550°C disappears indicating large amounts of kaolinite. The amount of mica present is very small.

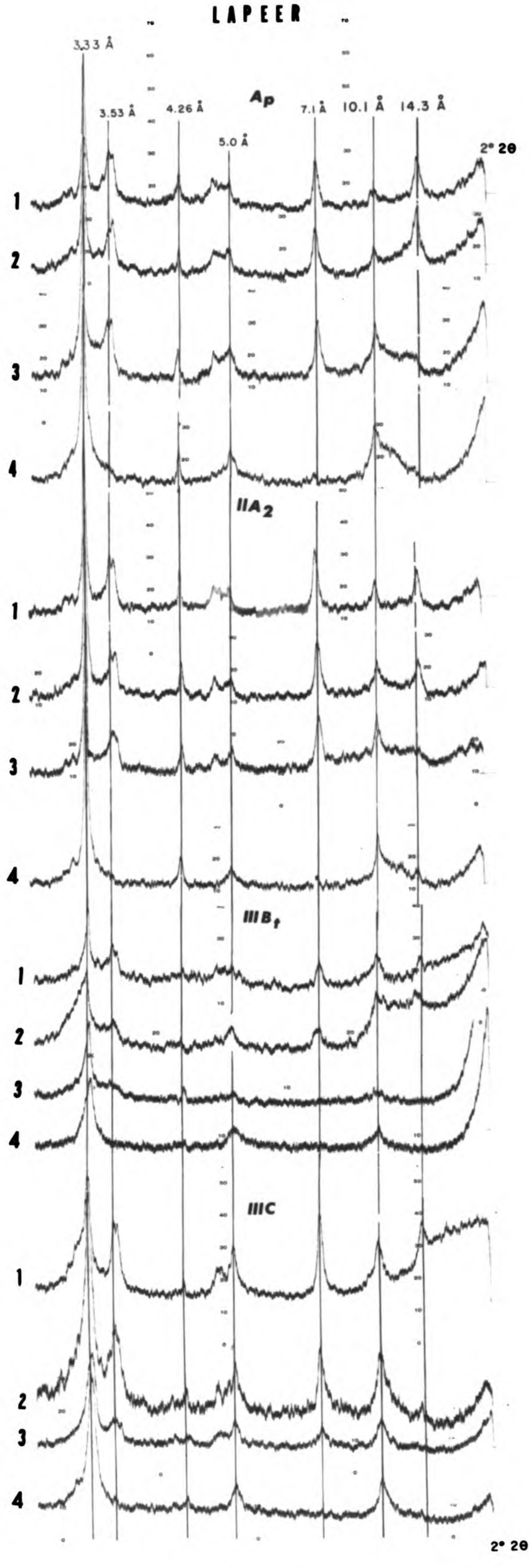

LAPEER
3.33 Å
3.53 Å
4.26 Å
5.0 Å
7.1 Å
10.1 Å
14.3 Å
2° 2θ
Ap
IIA2
IIIBt
IIIC
1
2
3
4
1
2
3
4
1
2
3
4
1
2
3
4
2° 2θ

Figure 11

II $A_2$ Horizon

Essentially the same as the previous horizon.

III $B_t$ Horizon

The type of peaks in the X-ray patterns shows that the clay is less crystalline than in II $A_2$ and III C horizons. They also reveal the presence of vermiculite, interstratified vermiculite-chlorite, mica and a small amount of kaolinite.

III C Horizon

The X-ray pattern shows vermiculite mica and kaolinite as the predominant minerals. Small amounts of montmorillonite and interstratified vermiculite-chlorite are also present.

The pattern of clay mineral distribution in the profile indicates that kaolinite is coming from the parent material and that its presence in all horizons is not pedogenic. This confirms other studies in Michigan that there is no kaolinite formation or syntehsis because there is not enough intensity of weathering.

From the Table 7 it is observed that there is more soluble $SiO_2$ and $Al_2O_3$ in the $A_p$ than in II $A_2$. This might be explained as the result of weathering but since the materials are originally different, that might also account for the difference.

In the $IIIB_t$ it is shown that there is more soluble $SiO_2$ and $Al_2O_3$ than in any of the overlying layers. This might be expected if those two components are formed in situ, and both are leached from the overlying horizons. Lower amounts of chlorite-vermiculite and large amounts of vermiculite indicate the former is pedogenetic in the overlying horizon. The high cation exchange capacity in the III C horizon is due to the predominance of vermiculite. Going up in the profile the cation exchange capacity decreases because vermiculite gets interlayered with Al to form chlorite, a product of pedogenesis. The progressive formation of pedogenic chlorite in the upper horizons which are subject to more intensive weathering is also confirmed by the presence of increasing proportions of interstratified chlorite-vermiculite in the upper horizons of the profile. The total potassium percentage distribution agrees with the distribution of the mica in the profile.

2. Peruvian Profiles

a. San Jose

The X-ray diffraction patterns of the profile are shown in Fig. 12. They show a marked difference in the nature of the clay in the two horizons. The $A_1$ horizon shows moderate amounts of mica and vermiculite and randomly

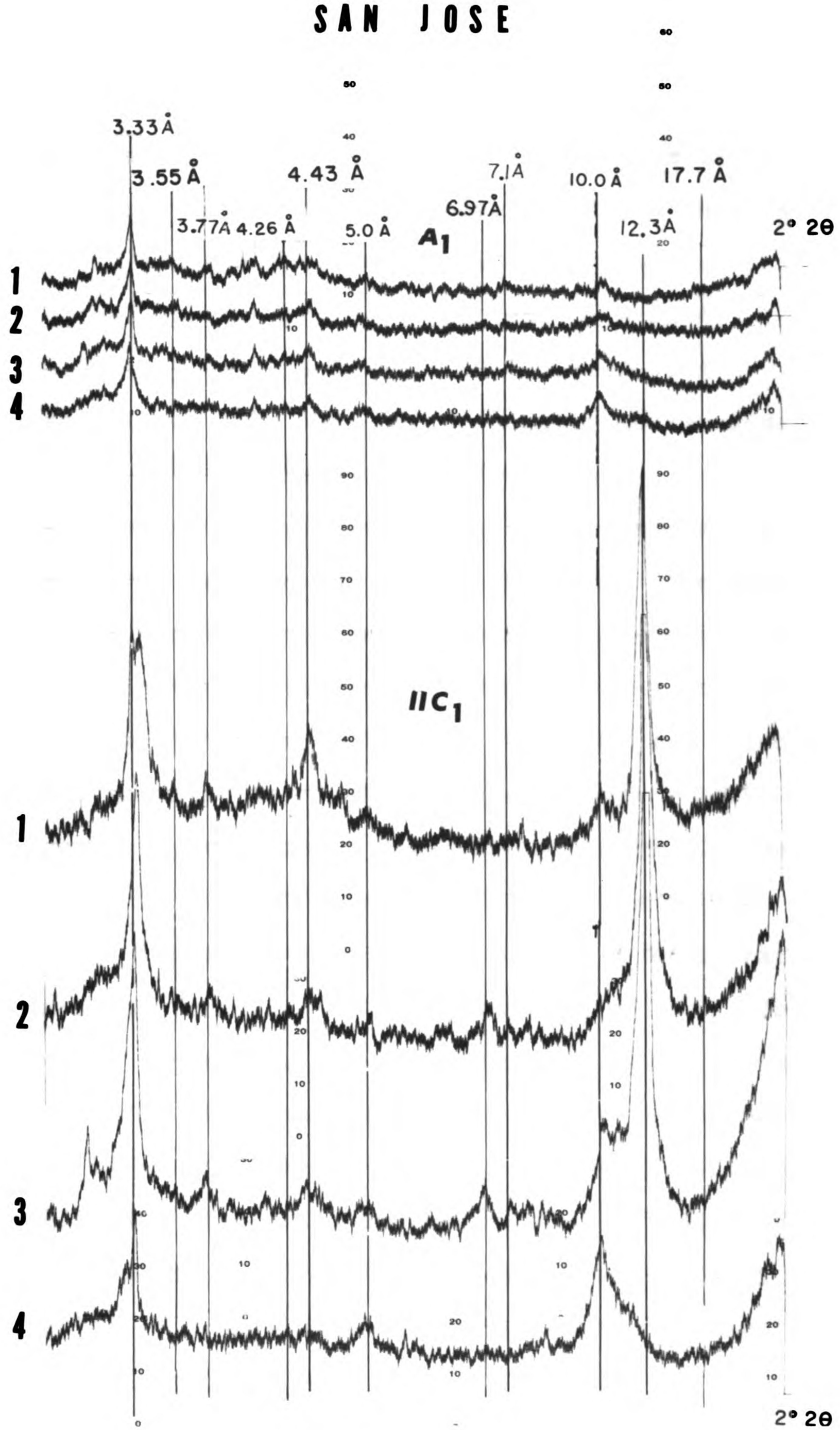

SAN JOSE
3.33 Å
3.55 Å
3.77 Å
4.26 Å
4.43 Å
5.0 Å
6.97 Å
7.1 Å
10.0 Å
12.3 Å
17.7 Å
2° 2θ
$A_1$
1
2
3
4
$IIC_1$
1
2
3
4
2° 2θ

Figure 12

interstratified mica-vermiculite together with feldspar. The Mg-saturated, glycerol solvated clay of the II $C_1$ horizon gives a definite strong peak at 12.3 Å that is completely different from any known clay. Smaller peaks in that horizon indicate spacings of 9.82 Å, 7.4 Å, 4.98 Å, 4.44 Å, 3.77 Å, 3.57 Å, and 3.37 Å 3.33 Å and others (the last one for quartz corresponds to the plate used in the X-ray diffraction).

When the II $C_1$ clay sample was K-saturated and air dried the X-ray pattern was almost the same. The main peak at 12.3 Å maintains the same basal spacing and only increases slightly in intensity. Upon heating to 300°C. the 12.3 Å basal spacing maintains its value and intensity and starts to shift to 10 Å the other secondary peaks remain generally the same. Upon heating to 550°C. the main peak at 12.3 Å collapses and shifts toward 10 Å, and the weak 7.1 Å peak, that appears when it is K-saturated, disappears completely. The other analyses of this clay are reported together with the others in Table 7. Chemical analysis of the II $C_1$ horizon sample by Dr. Raman indicates that this is mainly calcium sulfate, and contains very little silicate minerals. The observed X-ray peaks could also be assigned to different hydrated forms of $CaSO_4$, and the material is probably an evaporite mixed with negligibly small amounts of silicates. A complete characterization of this material was, however, not undertaken.

b. Loma Larga

X-ray diffraction patterns of the clay fractions are shown in the Fig. 13. In general they reveal that the clay that is found in the profile is very crystalline.

$\underline{A_{11}}$ Horizon

In this horizon are observed moderate amounts of very crystalline mica; small amounts of kaolinite, chlorite, and interstratified mica-chlorite together with feldspars.

II $A_{12}$ Horizon

Similar to the previous horizon with the difference that there is a little more chlorite and kaolinite.

III $C_{11}$ Horizon

Essentially the same X-ray patterns as in the II $A_{12}$ horizon but a little less chlorite and more kaolinite. Chlorite and mica interstratified in small amounts, and feldspar are present as in the overlying horizons.

IV $C_{21}$ Horizon

There is very crystalline mica present, chlorite in moderate amounts, traces of kaolinite, and moderate amounts of feldspar.

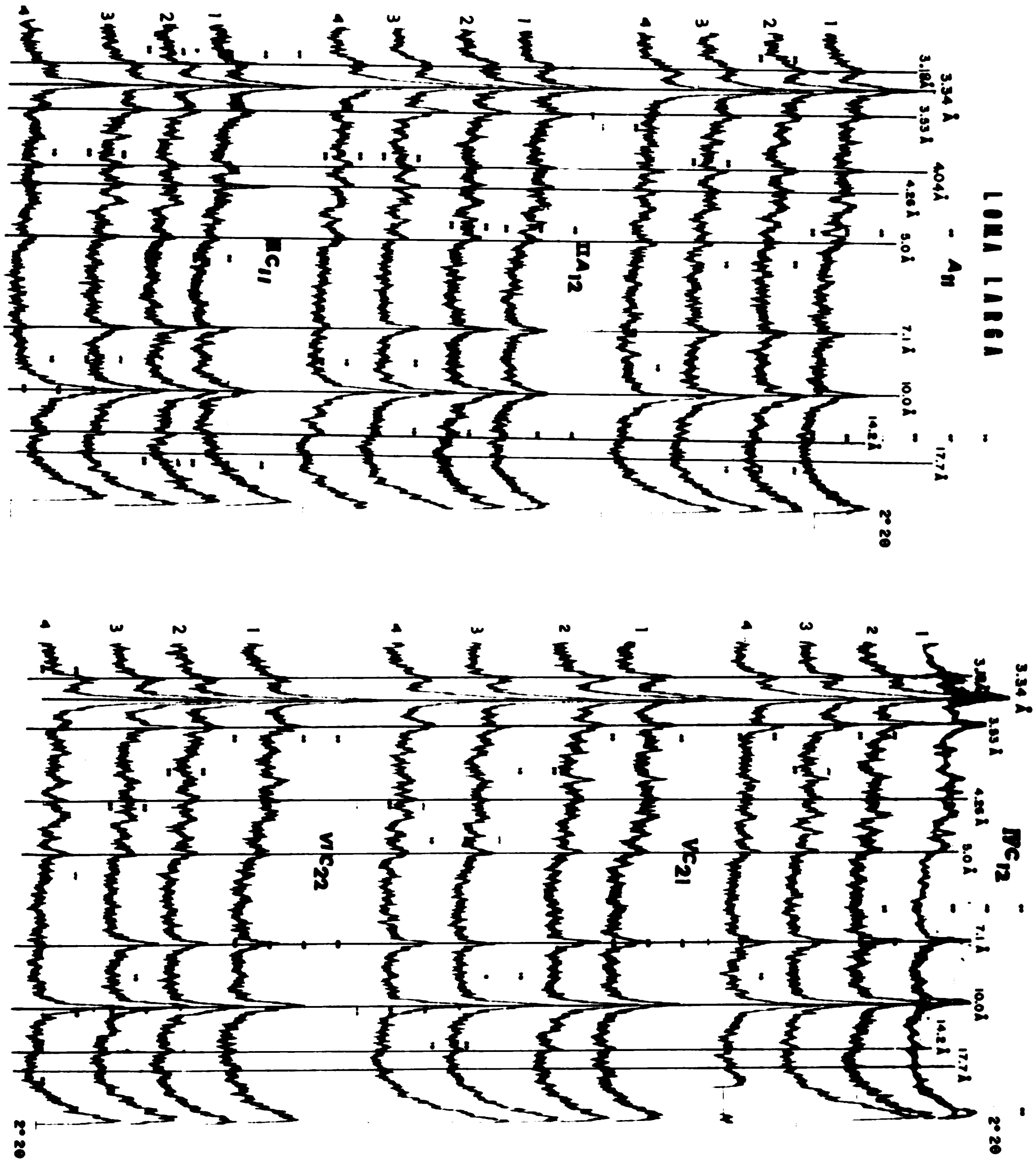



Figure 13

V $C_{21}$ Horizon

This horizon in relation to those overlying it shows differences in the X-ray patterns of the clay. In addition to large amounts of mica and moderate amounts of chlorite and feldspar, some montmorillonite and vermiculite are also present. Kaolinite is absent.

VI $C_{22}$ Horizon

This horizon contains moderate amounts of kaolinite and mica, traces of chlorite and some feldspar.

The percentages of total potassium generally agree with types of clay identified; except for the $VC_{21}$ horizon where it may be due to feldspar. The cation exchange capacity agrees well with different clays. For example the low C.E.C. of the $VIC_{22}$ horizon could be due to the fact that the predominant clays in this horizon are kaolinite and mica, both having low C.E.C.

c. Tesoro

X-ray diffraction tracings for the different horizons are as shown in the Fig. 14.

$A_1$ Horizon

The X-ray patterns of the Mg-saturated glycerol solvated clay of the $A_1$ horizon reveals the presence of montmorillonite, vermiculite interstratified with mica and

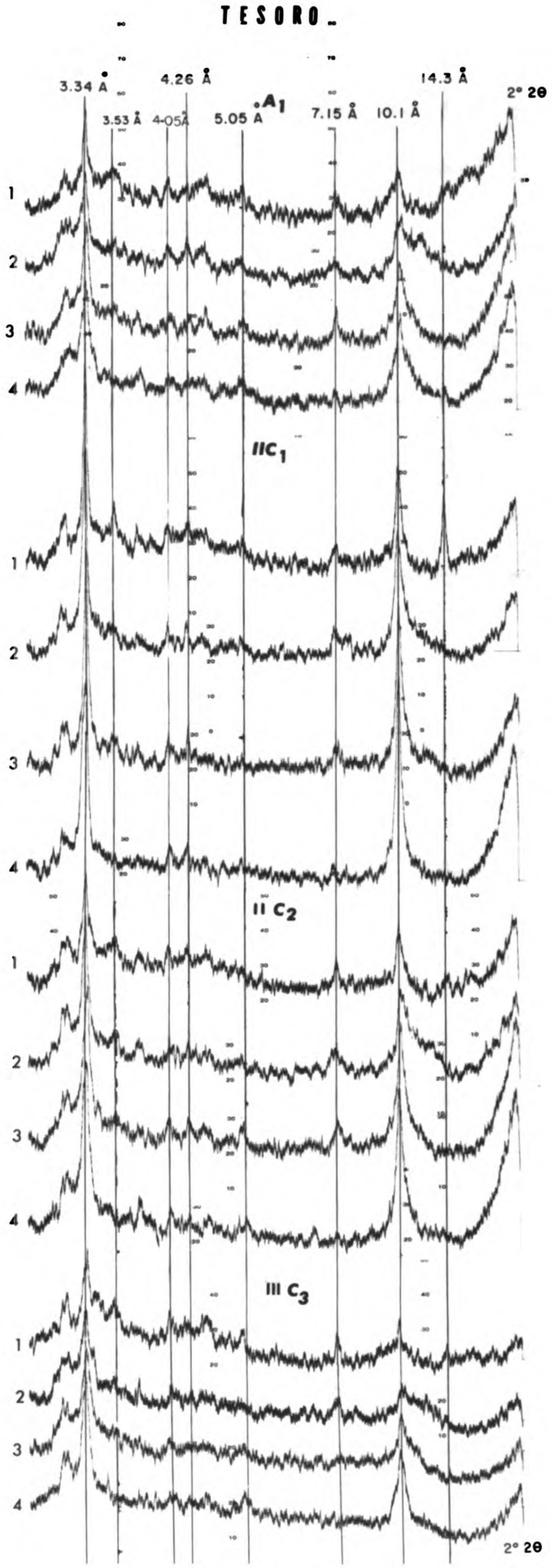

TESORO
3.34 Å
4.26 Å
14.3 Å
2° 2θ
3.53 Å
4.05Å
5.05 Å
A1
7.15 Å
10.1 Å
IIC1
II C2
III C3
1
2
3
4
2° 2θ

Figure 14

feldspar. When it is K-saturated the 14.3 Å peak collapses, indicating vermiculite. At 550°C. the small 7.15 Å peak remains, indicating some chlorite.

II $C_1$ Horizon

With Mg-saturated glycerol solvated clay treatment the X-ray shows moderate vermiculite content by presence of a relatively strong peak at 14.3 Å that disappears on K-saturation. Mica is shown by the 10.1Å peak. A very small amount of chlorite, and possibly some kaolinite are also indicated.

II $C_2$ Horizon

This horizon contains some montmorillonite, vermiculite and a moderate amount of mica, besides some interstratified mica-vermiculite, and a small amount of kaolinite.

III C Horizon

The X-ray diffraction tracing for this profile show as identifiable clay minerals some vermiculite, mica, kaolinite and some interstratified mica vermiculite.

The cation exchange capacity of the clay generally agrees with the nature of the clay in the first 3 horizons. The high value for the last horizon can be explained only by the inadequate type of analysis used in this partially volcanic soil material. Potassium percentage generally agrees with the mica content. However, the last horizon shows too low a content of mica. The presence of a relatively strong peak at 10 Å indicated at least three or four times more mica than the actual K content indicates. The irregular and inconsistent distribution of soluble $SiO_2$ and $Al_2O_3$ in the profile, particularly in the first of these, reflects variations in their content in the parent materials.

d. Siguas

The X-ray diffraction tracing for the clay in this profile are shown in Fig. 15. The $A_1$ and $C_1$ horizons show the same patterns and include montmorillonite, mica, feldspar and some kaolinite. $C_1$ shows more aluminum interlayer as observed by the very broad peak of the montmorillonite, which upon heating shows mica with a broad peak possibly due to the partially stable montmorillonite aluminum interlayer. Kaolinite disappears at 550° C.

The II $C_2$ horizon, in the Mg-saturated glycerol solvated state, shows a good peak of montmorillonite and montmorillonite with aluminum interlayers. On K-saturation this did not collapse completely but on heating it disappeared and there was an increase in the mica peak. Therefore the clay minerals are believed to be represented by montmorillonite, mica and kaolinite. The peaks at 3.18 Å and 3.20 Å are good evidence of moderate amounts of feldspar.

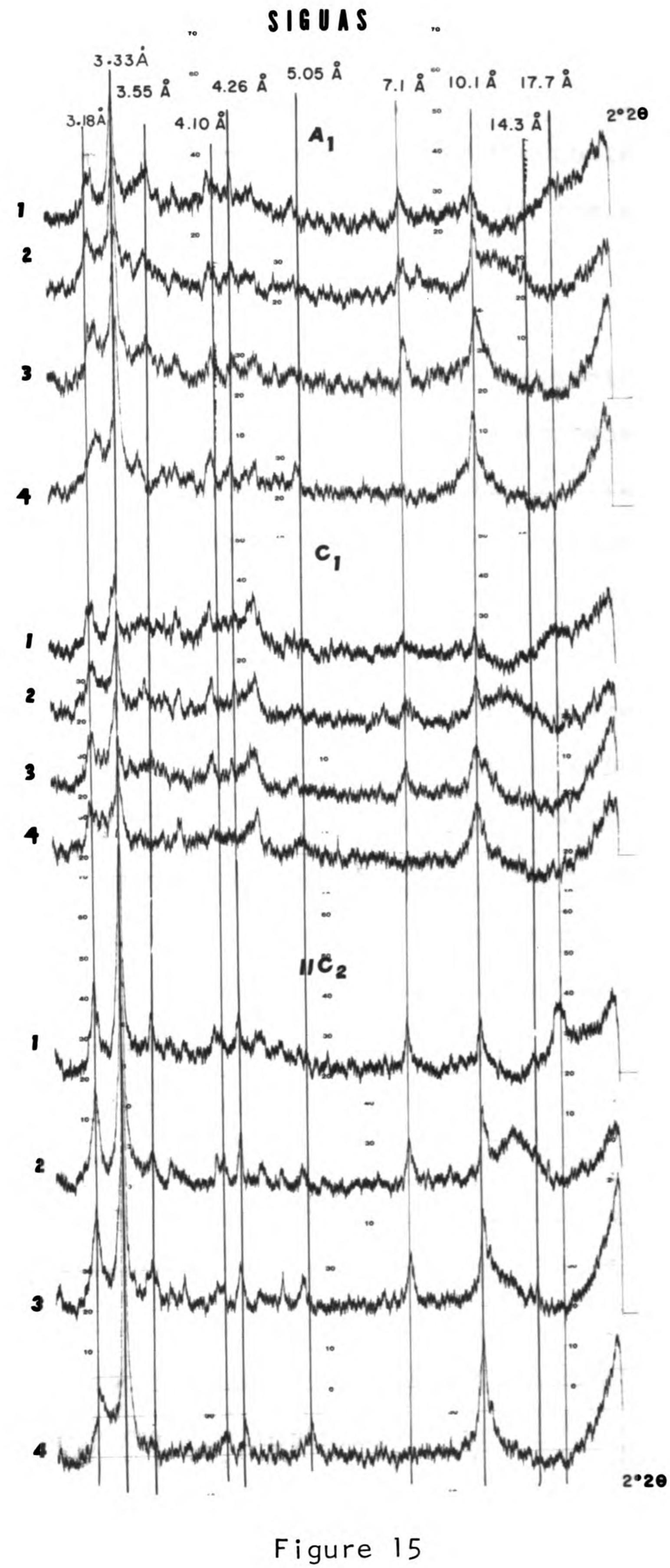

SIGUAS
3.33Å
3.55 Å
4.26 Å
5.05 Å
7.1 Å
10.1 Å
17.7 Å
3.18Å
4.10 Å
14.3 Å
2°2θ
A1
1
2
3
4
C1
1
2
3
4
IIC2
1
2
3
4
2°2θ

Figure 15

The cation exchange capacity and the content of total potassium percent in this soil agree with the clay minerals present.

Allophane

Differential dissolution data are presented in Table 7. This information was used to estimate allophane. The $SiO_2$ and $Al_2O_3$ extracted after the 110° C. treatment with 0.5N NaOH was considered to be from allophane. Allophane contents were calculated using the formula 2 $SiO_2.Al_2O_3.3.28H_2O$ (32).

To check whether allophane was present the clay fraction of all the horizons of the six profiles were analyzed by the differential dissolution procedure of Hasimoto and Jackson (32). The results given in Table 7, show that moderate amounts of silica and alumina were dissolved by rapid boiling in 0.5N NaOH, and almost at the same proportion in the Michigan and Peruvian profiles.

At first sight the dissolution of as much as 8.8% $SiO_2$ and 2.2% of the surface soils might seem to indicate the presence of allophane (to as much as 11% of the clay), even making allowances for some destruction of gibsite It seems, however, that apart from gibsite-derived alumina, the amounts dissolved simply represent dissolution of somewhat poorly crystalline kaoline or halloysite of small particle size, and that little, if any, allophane occurs in these soils.

The explanation for the amount of silica and alumina dissolved may well lie in the very small particle size clays ($> 0.2\mu$ or smaller) as shown by electron microscope. Hashimoto and Jackson (32) noted that the small size fractions of kaolins "may undergo a considerable amount of dissolution as particles approach the lower limit of crystallinite with increasing surface of reaction." The colloidal silica is apparently considerably greater in most of the Peruvian samples.

The cation exchange capacity in the three horizons of the Tesoro profile correspond to the average values of the kind of clays identified in the profile. The high cation exchange capacity of the last horizon could be for the same reason as given for the volcanic horizon of the San Jose profile.

The variability of the cation exchange capacity in the soil profile of Siguas indicates that the relative cation exchange capacity of the second horizon is due to presence of more montmorillonite.

<u>Total Potassium Content</u> ($K_2O$)

In the Lapeer profile the potassium content increases in III $B_t$ horizon as compared to the parent material. This higher proportion of mica clay content is also evident in the III $B_t$ of Spinks compared to the $A_2$ or $A_2B_t$ horizons.

In the Peruvian profiles, the content of potassium in clay from the different horizons is a reflection, in part, of the content of the parent materials, thus in San Jose, there is a great difference between the upper and lower horizons in content of potassium. This is due to the fact that the lower layer is of volcanic nature and has a low mica content as reflected in the much lower K content. This lower K content is also apparent in the Tesoro III $C_3$ horizon. In the other Peruvian soil horizons the calculated mica contents, based in the total K content, are similar to the mica contents of the clays in the Michigan soils. The mica content was dtermined by assigning all the potassium to mica, and assuming that mica contains 10% $K_2O$ (32). In the Peruvian profiles, since feldspars are present, the total potassium may not all be in mica.

<u>Chemical Properties of the Clay Fraction</u>

Some chemical characteristics of the clay fraction from the six profiles are given in Table 7.

Cation Exchange Capacity (C.E.C.)

Comparing the cation exchange capacities in both Michigan profiles it is observed that clays of low C.E.C. are predominanting in both profiles. The exchange capacity in Lapeer does show a decrease in A and B horizons relative to the C, suggesting that, in part, this could be attributed to more intensive weathering as the surface is approached with a resulting accumulation of more resistant clay minerals.

In the Peruvian profiles, San Jose shows in the lower horizon a very high cation exchange capacity, that does not correspond to any type of clay. It is true that in this volcanic material a high cation exchange capacity was expected, but not so high as observed. The cation exchange capacities were determined using Ca as the saturating cation and Mg as the replacing one. Apparently with this procedure into the cation exchange capacity besides the exchangeable cations comes some free calcium. The same explanation could be applied to the lower horizon of Tesoro, that apparently had an exchange capacity of 260 m.e./100 g.

Loma Large has in the surface of the profile a higher cation exchange capacity and there are only slight differences among the other horizons.

Table 7. Chemical composition of Michigan and Peruvian Clays (< 2μ) Fractions

| Horizon | Sample No. | % dissolved by 0.5N NaOH | | Colloidal $SiO_2$ (cal.) % | Allophane (cal.) % | C.E.C. m.e./100 g. clay | Total K% | Total $K_2O$ % | Mica (calc.) % |
|---|---|---|---|---|---|---|---|---|---|
| | | $SiO_2$ | $Al_2O_3$ | | | | | | |
| | | Spinks | | | | | | | |
| $A_p$ | 1 | 8.81 | 2.19 | 6.24 | 5.75 | 36.00 | 2.00 | 2.41 | 24.1 |
| II $A_2$ | 2 | 8.55 | 2.56 | 5.54 | 5.29 | 28.00 | 1.80 | 2.17 | 21.7 |
| III $A_2B_t$ | 3 | 7.70 | 2.42 | 4.85 | 6.38 | 10.00 | 1.50 | 1.81 | 18.1 |
| III $A_2B_t$ | 4 | 6.84 | 2.04 | 4.44 | 5.37 | 30.50 | 1.40 | 1.69 | 16.9 |
| IV $B_t$ | 5 | 10.95 | 2.87 | 7.60 | 6.32 | 35.00 | 2.00 | 2.41 | 24.1 |
| | | Lapeer | | | | | | | |
| $A_p$ | 6 | 6.50 | 1.73 | 4.47 | 4.55 | 25.50 | 2.00 | 2.41 | 24.1 |
| II $A_2$ | 7 | 5.48 | 1.66 | 2.53 | 4.37 | 22.00 | 2.00 | 2.41 | 24.1 |
| III $B_t$ | 8 | 9.75 | 2.95 | 6.28 | 7.77 | 29.50 | 2.9 | 3.50 | 35.0 |
| III C | 9 | 9.32 | 2.19 | 6.74 | 5.77 | 50.00 | 2.1 | 2.53 | 25.3 |
| | | San Jose | | | | | | | |
| $A_1$ | 10 | 18.00 | 2.19 | 16.16 | 5.77 | 42.00 | 1.8 | 2.17 | 21.7 |
| II $C_1$ | 11 | 4.27 | 0.00 | 4.27 | 0.00 | 470.00 | 0.4 | 0.48 | 4.8 |
| | | Loma Larga | | | | | | | |
| $A_{11}$ | 12 | 20.53 | 1.73 | 18.50 | 4.55 | 41.00 | 2.1 | 2.53 | 25.3 |
| II $A_{12}$ | 13 | 20.02 | 2.23 | 17.40 | 5.87 | 25.00 | 2.1 | 2.53 | 25.3 |
| III $C_{11}$ | 14 | 14.03 | 2.19 | 11.47 | 5.77 | 27.00 | 2.1 | 2.53 | 25.3 |
| IV $C_{12}$ | 15 | 24.29 | 1.66 | 22.34 | 4.37 | 23.50 | 2.1 | 2.53 | 25.3 |
| V $C_{21}$ | 16 | 9.41 | 2.13 | 6.91 | 5.61 | | 1.6 | 1.93 | 19.3 |
| VI $C_{22}$ | 17 | 27.12 | 1.81 | 25.00 | 4.75 | 7.55 | 2.1 | 2.53 | 25.3 |
| | | Tesoro | | | | | | | |
| $A_1$ | 18 | 19.51 | 2.04 | 17.11 | 5.37 | 39.50 | 2.0 | 2.41 | 24.1 |
| II $C_1$ | 19 | 27.12 | 1.81 | 24.99 | 4.77 | 45.00 | 1.3 | 1.57 | 15.7 |
| II $C_2$ | 20 | 30.58 | 1.54 | 28.77 | 4.05 | 45.00 | 1.7 | 2.05 | 20.5 |
| III $C_3$ | 21 | 14.80 | 1.53 | 12.77 | 4.55 | 260.00 | 0.8 | 0.96 | 9.6 |
| | | Siguas | | | | | | | |
| A | 22 | 15.65 | 2.34 | 12.90 | 6.16 | 24.00 | 1.5 | 1.81 | 18.1 |
| $C_1$ | 23 | 16.08 | 1.96 | 13.78 | 5.15 | 48.00 | 2.0 | 2.41 | 24.1 |
| II $C_2$ | 24 | 28.81 | traces | 28.81 | 0.00 | -- | -- | -- | -- |

## THE QUANTITATIVE EVALUATION OF UNIFORMITY OF MATERIALS AS INDICATED BY MAGNETIC, MODERATELY MAGNETIC, SLIGHTLY MAGNETIC, AND NON-MAGNETIC MINERALS OF THE FINE SAND FRACTION

Marshall and Haseman (45) considered in the quantitative evaluation of soil formation and development by heavy mineral studies, that it is first necessary to furnish convincing proof that strati-graphical and depositional differences are absent. When such depositional differences are present the site must be excluded for quantitative purposes. They pointed out, that depositional variation can be frequently detected by mechanical analyses alone, but the ultimate court of appeal is the resistant heavy mineral suite that should show no changes in the profile. "Assuming that these requirements are met, it remains to define the parent material, that is, to decide what horizon in the profile should be used as the basis for the calculations." These statements outline the limitations to studies of soil formation and development in profiles that have developed in sedimentary parent materials.

Barshad (3) points out that to evaluate the development of a soil it is necessary to define and evaluate the initial state of the soil material at each horizon. This initial state is referred to as the parent material.

Profiles which have developed from uniform parent material are said to contain the parent material at the bottom of the profile, but in reality this latter parent material is only the preserved parent material. In such profiles the horizons above the parent material are collectively termed the solum. Many soil profiles exist, however, which have developed from parent materials that were not uniform with depth and, as a result quantitative evaluation in such profiles is more difficult.

With this information in mind the possibilities for the quantitative evaluation of soil formation and development in the profile in this study were tested by magnetic and non-magnetic mineral studies. In a profile derived from a uniform parent material the amounts of resistant magnetic and resistant non-magnetic minerals should be constant in percentages or should bear a constant ratio to each other and the distribution of the percent of each mineral or ratio of each pair of minerals in each profile should remain constant. This method used here is based on separating mineral grains according to their magnetic and electromagnetic properties, applying only one general rule, that the minerals are separated in order of their decreasing magnetic strength.

The content of magnetic, moderately magnetic, slightly magnetic and non-magnetic minerals, in the fine sand fraction, their distribution in the profile, and some mineral fraction ratios are shown in Table 8 for the Michigan and Peruvian profiles. In order to have qualitative appreciation of the most common minerals present in each fraction, petrographic microscope observations were made on samples taken at random from the samples that had uniform or non-uniform distributions of magnetic and non-magnetic separates. The results are shown in Table 9

The presence of ferrous iron or other cations that oxidize readily during weathering could greatly reduce the structure stability, for upon oxidation some other cation must leave the structure to maintain the elctrostatic neutrality of the crystal lattice. Since such a cation may be involved in the linkage of the tetrahedrons its departure would weaken the structure. (3)

Applying the data of Table 8, to identify uniformity of a material with depth, it is observed that the separate attracted at 1.4 amps, maximum field strength, indicate stratification. Thus in the Spinks profile, there are three distribution patterns: one extends from 0 to 20 cms., another from 20 to 46 cms., and a third is presented in the lower horizons. In Lapeer there are three distinct distribution patterns, one extends from 0 to 28 cms., another from 28 to 41 cms., and a third from 41 through 100 cms.

In this moderately magnetic, very fine sand fraction of the 0-28 and 41-72 cms. layers of the Lapeer profile were identified resistant minerals such as garnet and less resistant ferromagnesium minerals amphiboles and biotite, Table 9. The use of the pattern of distribution of magnetic and non-magnetic minerals to identify uniformity of material with depth is based on the principle these minerals do not undergo any significant change during the course of soil formation and their distribution pattern would thus remain constant. Consequently, constancy of the distribution pattern of particles attracted at 1.4 amps. (maximum field strength) throughout the soil profile may indicate that the soil profile was formed from a uniform parent material, appearance of two or more patterns of distribution indicates that the parent material was stratified and the point of contact of the strata studied is assumed to be the point where changes in percentage distribution occurs.

However, since this magnetic fraction contains some non-resistant minerals it may not be useful in these soils as an indicator of uniformity in weathered horizons. It seems that the fraction separated as magnetite may be more useful for this purpose, since it presumably consists of only one fairly resistant mineral. Even this is not uniform in these profiles. This system of mineralogical analysis is generally, and particularly when checking also with the criteria of particle-size distribution of the whole nonclay (and possibly clay distributions, too), very useful in establishing uniformity of parent materials. However, both of the Michigan profiles in this study proved to be developed from non-uniform parent materials by these criteria. The similarity and dissimilarity of the horizons in each profile by each of these criteria, and finally by all combined, are shown by the roman numerals associated with each in Table 8.

The same principles were also applied to the Peruvian profiles. In the San Jose there is a tremendous difference in percentage content of magnetite and particularly attracted at 1.4 amps. among the horizons present, and we know therefore that these horizons are from different parent materials. Horizon $IIC_1$ is composed of volcanic materials. In Table 9 it is observed that in the $A_1$ there are predominantly ferromagnesian minerals amphibole or pyroxene (with small inclusions of iron), while in $IIC_1$

there are ferromagnesiam minerals, amphibole, feldspar with magnetic inclusions, volcanic glass fragments, and garnet (the presence of garnet is very rare because it is present only in metamorphic rocks).

In the other Peruvian profiles it seems that magnetite could be used as a better criteria for establishing uniformity of parent material. Table 8 shows the change of percentage distribution of magnetic, non-magnetic and ratio of non-magnetic to magnetic minerals in the soil profiles. The Peruvian profiles in this study are also formed in non-uniform parent materials.

It is concluded that the materials in the Michigan and Peruvian profiles are too diverse to use in quantitative analyses.

Table 8. Weight Percentages Separated Using Isodynamic Separator, Except for Magnetite, in Fine Sand Fractions

| Horizon | Depth | Sample No. | Attracted by hand magnet Magnetite % | Held at 1.4 amps at max. strength moderately magnetic % | Deflected at 1.4 amps slightly magnetic % | Not deflected at 1.4 amps. non-magnetic % | Non-magnetic / Slightly magnetic |
|---|---|---|---|---|---|---|---|
| | | Spinks | | | | | |
| $A_p$ | 0-20 | 1 | 1.07 I | 0.66 I | 3.94 I | 93.97 I | 23.85 I |
| II* $A_2$ | 20-46 | 2 | 0.07 II | 0.07 II | 3.66 I | 95.00 I | 25.96 I |
| III $A_2B_t$ | 46-107 | 3 | 0.07 II | 0.33 III | 3.66 I | 94.83 I | 25.91 I |
| III $A_2B_t$ | 107-168 | 4 | 0.33 III | 0.33 III | 3.93 I | 94.67 I | 24.09 I |
| III $B_t$ | 148-153 | 5 | 0.26 III | 0.33 III | 3.83 I | 95.00 I | 24.80 I |
| | | Lapeer | | | | | |
| $A_p$ | 0-28 | 6 | 14.48 I | 10.34 I | 18.10 I | 51.03 I | 2.81 I |
| II $A_2$ | 28-41 | 7 | 0.07 II | 0.60 II | 3.66 II | 94.67 II | 25.87 II |
| III $B_t$ | 41-72 | 8 | 0.07 II | 1.02 III | 3.66 II | 94.73 II | 25.88 II |
| III C | 72-100 | 9 | 0.13 II | 1.00 III | 3.93 II | 94.20 II | 23.97 II |
| | | San Jose | | | | | |
| $A_1$ | 0-17 | 10 | 21.00 I | 25.73 I | 0.52 I | 33.00 I | 1.92 I |
| II C | 17-128 | 11 | 2.33 II | 3.66 II | 0.25 II | 84.73 II | 10.13 II |
| | | Loma Larga | | | | | |
| $A_1$ | 0-7 | 12 | 7.07 I | 18.83 I | 14.67 I | 57.67 I | 3.93 I |
| II $A_{12}$ | 7-18 | 13 | 9.53 II | 16.40 I | 12.67 I | 60.33 I | 4.76 I |
| III $C_{11}$ | 18-44 | 14 | 0.03 III | 1.27 II | 2.83 II | 93.40 II | 33.00 II |
| IV $C_{12}$ | 44-56 | 15 | 4.93 IV | 13.33 III | 18.93 III | 62.06 I | 3.27 I |
| V $C_{21}$ | 56-70 | 16 | 8.60 I | 19.07 I | 14.93 I | 57.73 I | 3.99 I |
| VI $C_{22}$ | 70-144 | 17 | 6.40 I | 16.33 I | 18.73 III | 58.73 I | 3.13 I |

Table 8, cont.

| Horizon | Depth | Sample No. | Attracted by hand magnet Magnetite % | Held at 1.4 amps at max. strength moderately magnetic% | Deflected at 1.4 amps slightly magnetic % | Not de-felected at 1.4 amps non-magnetic % | Non-magnetic / Slightly magnetic |
|---|---|---|---|---|---|---|---|
| | | Tesoro | | | | | |
| $A_1$ | 0-10 | 18 | 10.40 I | 27.00 I | 19.02 I | 42.53 I | 2.23 I |
| II $C_1$ | 10-30 | 19 | 16.33 II | 24.67 I | 18.00 I | 40.73 I | 2.26 I |
| II $C_2$ | 30-120 | 20 | 16.93 II | 28.53 I | 16.73 I | 37.53 I | 2.24 I |
| III $C_3$ | 120-150+ | 21 | 4.77 III | 31.73 II | 14.17 II | 48.73 I | 2.91 I |
| | | Siguas | | | | | |
| $A_1$ | 0-10 | 22 | 9.50 I | 27.93 I | 16.26 I | 46.33 I | 2.85 I |
| $C_1$ | 10-30 | 23 | 9.80 I | 29.03 I | 17.20 I | 43.33 I | 2.52 I |
| II $C_2$ | 30-150 | 24 | 8.91 I | 21.50 II | 22.76 II | 60.42 II | 2.65 I |

*Roman numerals in each column indicate the original similarity or dissimilarities of the materials. The Roman I is omitted in the horizon designations, but is understood when no other number is present.

Table 9. Mineral Composition of Fine Sand Fractions in Moderately Magnetic, Slightly Magnetic and Non-Magnetic Separates, Listed in Order of Decreasing Abundance

| Horizon | Depth | Moderately Magnetic | Slightly Magnetic | Non-Magnetic |
|---|---|---|---|---|
| | | | Spinks | |
| III $B_t$ | 148-153 | chlorite, garnet amphibole | weathered quartz (coating with iron) some opaque, and rock fragments | Quartz, potash feldspar, some albite twin |
| | | | Lapeer | |
| $A_p$ | 0-28 | garnet, amphibole | Chlorite, biotite, amphibole, rock fragments, opaque coatings | Quartz, feldspar |
| III $B_t$ | 41-72 | Biotite, garnet, ferromagnesian minerals, amphibole | Opaque coatings, amphibole, rock fragments | Quartz, feldspar, some chert, epidote |
| | | | San Jose | |
| $A_1$ | 0-07 | ferromagnesian minerals, amphibole or pyroxene (with small inclusions of iron) | ferromagnesian minerals, amphibole, pyroxene, feldspar (with black inclusions) rock fragments of volcanic material | feldspar (with inclusions of opaque minerals like magnetite), quartz, calcic-plagioclase |

Table 9, Cont.

| Horizon | Depth | Moderately Magnetic | Slightly Magnetic | Non-Magnetic |
|---|---|---|---|---|
| | | San Jose | | |
| II $C_1$ | 17-128 | Ferromagnesian, amphibole, feldspar (with magnetic inclusions), some volcanic ash (with black inclusions), glass, volcanic fragments, garnet very rare, because is present only in metamorphic rocks) | Volcanic rock fragments, ferromagnesian (probably amphibole) feldspar (with inclusions), plagioclase, ash glass | Volcanic rock fragments, volcanic glass (with chunks of feldspar) |
| | | Loma Larga | | |
| III $C_2$ | 18-44 | Amphibole, garnet (and second generation garnet), few opaque minerals | Quartz (with magnetic inclusions), opaque minerals (coated with oxides), zircon (non-magnetic) feldspar (coated) | Reasonable amount of quartz, with feldspar |
| | | Tesoro | | |
| II $C_1$ | 10-30 | Amphibole (dominantly two or three classes) some volcanic fragments, occasionally feldspar | Opaque grains, amphibole, feldspar (with some inclusions) | Feldspar, little glass (with some inclusions) |

# CLASSIFICATION BY SEVENTH APPROXIMATION

(Soil Survey Staff, October 20, 1966)

A. Michigan Profiles

Spinks and Lapeer soils have ochric epipedons that grade with depth to argillic horizons, with high base status. Both soils are in the Alfisol order.

These soils are usually moist, and are not dry in most years for more than sixty consecutive days in all horizons. Are not saturated with water at any season; and lack a continuous albic horizon. They thus qualify as Udalfs.

At the Great Group level Spinks and Lapeer are both Hapludalfs. They have no irregular or broken upper boundary of the argillic horizon, have no fragipan or natric or agric horizons, have an argillic horizon with less than 18 percent of clay or shallower than 1.25 m. below the surface of the soil.

Lapeer is considered to be a Typic Hapludalf because it has an Ap horizon with a moist value of more than 3; and exchangeable sodium occupies less than 10 percent of the cation exchange capacity, throughout the argillic horizon. It has an argillic horizon that is continuous horizontally, that is continuous vertically for at least the upper 15 cm., has an average texture that is fine sandy loam, and has moist chromas of less than 6.

Since it lacks 35 percent clay in all horizons, is composed of a mixture of weatherable minerals and silicate clay minerals (mostly, kaolinite and vermiculite with chlorite intrastratified), and has a mean annual temperature between 47° and 59°. Lapeer should be in a coarse-loamy, mixed, mesic family of the typic Hapludalfs.

Spinks is considered to be a Psammentic Hapludalf that is characterized by an argillic horizon that is: free of mottles with chromas and values less than 4, is discontinuous horizontally and vertically, ahd has a texture coarser than sandy loam.

The textural analysis shows it to be loamy fine sand at the surface and fine sand in each one of the lower horizons. The mineralogical analyses indicate a high quartz content and chert in the fine earth (smaller than 2 mm). The mean annual temperature where this soil is formed is between 47° and 59°F. Spinks should, therefore, be in a sandy, siliceous, mesic family of the Psammentic Hapludalfs.

B. Peruvian Profiles

These Peruvian profiles are found on recent or on older geomorphic surfaces in areas that are undergoing active erosion or on fans and flood plains where the eroded materials were deposited. The weak weathering present in them as mineral soils is indicated by a lack of diagnostic horizons other than an ochric epipedon. They are thus all Entisols.

The Entisols that have below the $A_1$ horizon textures of loamy fine sand or coarser in all parts to a depth of 1 meter are Psamments. This includes the Loma Larga, Tesoro, and Siguas series from Peru.

Since they are usually dry in all parts of the soil between the $A_p$ horizon and 1 meter they are included in the Torripsamments great group.

Since they lack lamellae within 2 m. of the soil surface that meet all requirements for an argillic horizon except thickness; and lack within 1 m. of the surface any horizon that is more than 15 cm. thick, that contains either at least 20 percent durinodes in a nonbrittle matrix or is brittle and has firm consistence when moist, they are considered Typic Torripsamments. All three are in the sandy, mixed, nonacid, isothermic family of Typic Torripsamments.

San Jose soils could be fitted into the Orthents, because they have textures of loamy very fine sand or finer in some horizon below the $A_1$ horizon or 25 cm., whichever is deeper, but above a depth of 1 m. or a lithic or paralithic contact, whichever is shallower. They lack fragments of diagnostic horizons that occur more or less without discernible order in the soil below any $A_1$ horizon. Have an organic matter content that decreases regularly with depth and reaches levels of 0.35 percent (0.2 percent carbon) or less within a depth of 1.25 m.

Since they have soil temperature warmer than those of Cryorthents, are usually dry in most years in all parts of the soil between 25 cms, and 1 m. or a lithic or paralithic contract, whichever is shallower, they are Torriorthents.

Because they lack within 1 m. of the surface any horizon that is more than 15 cm. thick than contains either at least 20 percent durinodes in a nonbrittle matrix or it is brittle and has firm consistence when moist; lack a lithic contact within 50 cm. of the surface, and lack the following combination of characteristics:

> Cracks at some season in most years that are 1 cm or more wide at a depth of 50 cm and that are at least 30 cm long in some part;

> a coefficient of linear extensibility (COLE) of 0.09 or more in a horizon or horizons at least 50 cm. thick, and a potential linear extensibility of 6 cm. or more in the upper 1 m. of the soil or the whole soil if a lithic or paralithic contact is deeper than 50 cm. but shallower than 1 m; more than 35 percent clay in all horizons between 25 cm. and either 1 m. or a lithic contact less between 50 cm. and 1 m.

The San Jose series is in the coarse loamy, ashy, nonacid, isothermic family of the Typic Torriorthents. It is important to notice that this soil could be fitted into Psamments but the texture is too fine for that category.

A summary of classification by Seventh Approximation is presented in the Table 10.

Table 10. Summary of Classification by Seventh Approximation of the Michigan and Peruvian Profiles

| Soils | Order | Suborder | Great Group | Subgroup | Family |
|---|---|---|---|---|---|
| Spinks | Alfisol | Udalf | Hapludalfs | Psammentic Hapludalf | Sandy, siliceous, mesic |
| Lapeer | Alfisol | Udalf | Hapludalfs | Typic Hapludalf | Coarse loamy, mixed,mesic |
| San Jose | Entisol | Orthents | Torriorthents | Typic Torriorthents | Coarse loamy, ashy, nonacid, isothermic |
| Loma Larga | Entisol | Psamments | Torripsamments | Typic Torripsamments | Sandy, mixed, nonacid, isothermic |
| Tesoro | Entisol | Psamments | Torripsamments | Typic Torripsamments | Sandy, mixed, nonacid, isothermic |
| Siguas | Entisol | Psamments | Torripsamments | Typic Torripsamments | Sandy, mixed, nonacid, isothermic |

# CHAPTER V

# GENERAL DISCUSSION

## A. Comparison Parent Materials

The non-uniformity of the glacial till material underlying the two Michigan profiles is evident from the analyses conducted. The soils under study were first considered to be developed from only one parent material, similar to the present C horizons. But mechanical analyses of the fine sand fraction by the Isodynamic Separator indicated more stratifications in those profiles than had been expected on the basis of field observations. The amount of stratifications was such that the C horizons of these profiles could not be assumed to represent the origin materials of the sola. The heterogenity of the Peruvian profiles was checked by the same type of analyses, and the number of different strata was such that in the Loma Larga profile six different strata were verified.

The dominant separate is sand in the Spinks and fine sand in the Lapeer profiles. The original materials of Lapeer profile contained a higher percentage of silt and clay than those of the other five profiles but San Jose was more similar in texture to Lapeer than the other soils studied. These textural differences were correlated with some physical and chemical characteristics.

From qualitative mineralogical analyses of the fine sand in some horizons, it is concluded that Spinks and Lapeer contain similar kinds of minerals. The most representatives and common for both are quartz, weathered quartz, and feldspar. The magnetic components include amphibole, garnet, chlorite, magnetite and rock fragments; but combined they are less than 10% of the total.

In the Peruvian profiles, the most abundant minerals are ferromagnesian, including amphibole, pyroxens and magnetite while feldspar and quartz commonly are about 40% of the total. Only in the Loma Larga profile does quartz and feldspar predominate. In the substratum San Jose volcanic material predominates. Thus the mineralogic composition of the Peruvian soils are quite different from the Michigan soils.

The carbonate content in the C horizon of Lapeer was detected within 72 centimeters of the surface, while in Spinks it is over 169 cm. deep. In the Peruvian profiles calcium is found in other compounds rather than carbonate.

The underlying horizons of the two Michigan profiles are distinct, and may be briefly characterized as follows.

The Spinks profile is developed from till that is: light grayish yellowish brown to light yellow, fine sand, porous, calcareous or neutral. The Lapeer profile is underlain by a till that is moderate yellowish brown, fine sandy loam, moderately dense, and calcareous. It seems these differences in the original materials are due to variation in the tills deposited perhaps by different glacial advances.

In the Peruvian profiles it is more difficult to find similarities in the parent materials of those soils because of the heterogeneity that is observed in the same profile and among profiles.

B. Comparison of the Developed Profiles

Textural development of profiles

The $B_t$ horizons of Spinks and Lapeer could be considered as the result of illuviation, weathering in place and clay inherited from the original material.

Organic carbon accumulation

The organic carbon content at the surface are relatively high in Spinks and Lapeer, but it decreases rapidly with depth. The slight accumulations in $B_t$ horizons relative to the horizons immediately above them; are not significant. In the Peruvian profiles the organic carbon content is more related to the dry environment were those soils have been formed and it is low throughout the profile.

Carbonate redistribution

The depth to which carbonates are leached is inversely related to the carbonate content of the original materials, and is less in the Lapeer profile, where the original materials are more calcareous. In the Peruvian profiles because of the arid condition these process of soil formation are not active; there the distribution of carbonate is associated with the content in the parent materials.

Movement of free iron oxides

It is evident that the free iron is affected by the content of clay and the organic matter in the Michigan profiles. Their presence in the Peruvian profiles are completely independent of those factors.

C. Soil Genesis

From the six profiles studied only the two Michigan soils will be considered because in the Peruvian profiles the lack of chemical weathering have not permitted a clear evolution of those profiles.

Regardless of the different strata that were identified forming the Michigan profiles, it is assumed that the formation of soil in these materials began at time zero about 10,000 years ago and following it through to the present day. The forces which have acted shortly after the withdrawal of the glacier to transform the original glacial till into the present soil profiles are still acting and can be expected to produce further changes in the morphology of the profiles.

In both profiles it is likely that the original parent material was calcareous. Pioneer vegetation began additions of organic matter and accumulation through vegetational succession. Cultivation of these soils caused interruption of additions of organic matter and losses were produced. The acid groups of organic matter neutralized the carbonates and leached the products from the solum. The leaching is still in progress.

The solum of Spinks was developed from till with a low content of carbonates, since it was coarse and permeable leaching could be expected to proceed more rapidly and therefore leaching of carbonates was deep. The interchanges of cations with hydrogen or aluminum, establishing the different pH's, permitting the movement of bases, or phosphorus fixation. Both soils show development of $B_t$ horizons indicating some clay movement from the overlying horizons; but at the same time there are indications that the apparent accumulation of the clay and iron oxides may be due in part to differences between the original materials of this horizon and those above. The pH of the $B_t$ horizons are lower than those deeper in the profile.

The relatively absence of rock fragments indicates that any differences in mineralogical composition predated the development of the present profile (54). The relatively low amount of organic matter in the surface soil of both profiles and the small relative accumulation of organic matter in the $B_t$ horizons mark the organic accumulation phase of soil formation.

Spinks due to the fairly porous substratum always will permit the leaching of carbonates and bases and may never be observed in the future change of profile development toward other type of profile. While the original material of Lapeer contain large quantities of carbonates and possibly easily weathered rock fragments that partially explain some rapid development of the textural B horizon. As the rock fragments continue to weather, silt and clay will continue to increase and the most probably future development of this profile will be toward a Gray-Wooded soil.

In the Peruvian profiles there is not any manifestation of pedogenic development, only slow physical weathering will continue in the future without great changes; but when these soils are under irrigation the chemical process will participate actively in soil formation.

D. Needs for Further Research

1. The identification in the Peruvian volcanic soils of a rare X-patterns that do not correspond to any known clay is an invitation to the specialist in clay mineralogy to continue doing more research in order to characterize it.

2. Many authors pointed out, the first essential characteristic of the parent material for calculations relating to profile development, is that it should be uniform throughout the depth of the profile, or at least sufficient. But at the same time recognized that profiles formed on parent material with this requirement are relatively rare. Recently a number of profiles specifically selected as appearing to be formed in situ from relatively

uniform parent rocks, were found to be formed on stratified parent materials, one specific case is the Spinks and Lapeer series in this study. The use of particles considered strongly and moderately magnetic were useful in showing different strata. But, at the same time the distribution of the non-magnetic and slightly magnetic fractions, or their ratios, in the profile may show when the time of soil formation was enough to even out the differences inherited from the original parent material. This may be shown by constant ratios when the time is too short for the effects of active soil formation processes and they may become different ratios with more weathering. With this in mind it is advocated that more research on this matter be initiated in order to confirm or reject this proposed system. If confirmed, it would be a very simple and useful tool in the quantitative evaluation of uniformity of parent materials and soil formation or development studies.

## CHAPTER VI

## CONCLUSIONS

The six soils under study present marked variations in morphology, because of differences in enrivornment and the original materials from which they are derived. In some of the characteristics of the Michigan profiles the time has been enough to impress the effects of climate and vegetation and to even out the differences inherited from the original materials in such a way that no variations in parent materials in either profile was observed by the routine procedures in the field.

The differences inherited characteristics will decrease as the action of climate and vegetation continue. In the Peruvian profiles easily and at first glance the different strata are observed and in their arid situation most of the inherited characteristics will be long lasting.

Presenting a parallelism between the Michigan and Peruvian profiles the following main changes have occurred since the beginning of soil formation.

1. In the Michigan profiles moderate amounts of organic carbon have been accumulated and a little eluviated; while in the Peruvian profiles

only very small amounts of organic matter have been accumulated.

2. In the Spinks profile the carbonates have been leached to depths of over 1.68 m. and in Lapeer no more than 70 cm., while soluble salts were probably absent. In the Peruvian profiles carbonates were not detected and calcium was found as compounds of soluble salts, distributed uniformly in relation to depth.

3. The clay bulge of Spinks in the $B_t$ horizon (bands) is due to the movement of clay out of the $A_2$ horizon. This clay in the deep $B_t$ horizon analyzed contains discrete amounts of mica, vermiculite and kaolinite, but no chlorite. The clay content in the surface horizon is probably due to depositional differences and weathering in place. It is suggested that in pedogensis vermiculite is being changed to chlorite nearer the surface. The clay bulge in the $B_t$ horizon of the Lapeer profile is illuvial and is represented by mica, vermiculite, kaolinite and interstratified vermiculite-chlorite. It was confirmed that

the presence of kaolinite is not pedogenic. The vermiculite-chlorite was apparently forming from vermiculite in the parent material. In the Peruvian profiles the distribution of clay is due to depositional differences and the kind and amount of clay is variable in each soil. The kind and proportion of minerals in clay ($< 2\mu$) is indicated in order of abundance to be mica, feldspar, kaolinite, chlorite, vermiculite, montmorillonite, some interstratified vermiculite-chlorite, mica-chlorite, montmorillonite-vermiculite, and mica-vermiculite.

4. In the San Jose series an unknown mineral was found in the clay. This sample was difficult to disperse and will require additional investigation in order to be characterized.

5. It is concluded that in coarse textured soils the bulk density varies directly with the fine sand content and inversely with the very fine sand content. In desert areas, any changes in bulk density is due to other factors than organic matter content. The variations in these profiles are erratic. The percent of clay had little influence on the total porosity.

6. In the Michigan soils the moisture holding characteristics increase or decrease with corresponding changes in the amount of fine textured material. In the Peruvian profiles the moisture content may be associated with greater salt content that influences its availability to plants.
7. It was concluded that the ratio of exchangeable calcium to magnesium could be used as an index of weathering differences in the Michigan soil environment. But in the unleached Peruvian soils the Ca/Mg ratios could not be used as an index of weathering.
8. The $B_t$ horizons in the Michigan profiles are not zones of accumulation of bases.
9. The P/Zn ratios indicates that Zn defficiencies may be noticed in the Michigan and Peruvian profiles.
10. Organic matter and clay are associated with the free iron oxide distribution in the Michigan profiles but there does not seem to be any constant relationship between clay and free iron content in the $B_t$ horizon. Perhaps periodic dessication and dehydration of iron oxides may enhance their immobility in the Spinks bands.

11. Differential dissolution shows that moderate amounts of silica and some alumina were dissolved. The amounts of allophane calculated were in about same proportions in the Michigan and Peruvian profiles. The colloidal silica is apparently considerably greater in most of the Peruvian samples.
12. A system is proposed as a measure of uniformity of parent material. The strongly magnetic and moderately magnetic fractions may be most useful for this purpose. There is a possibility of using ratios of non-magnetic and slightly magnetic fractions for testing uniformity of parent materials and the amount of soil formation and development.
13. In the specific case of the two Michigan soils it seems that 10,000 years was enough time to even out the differences inherited from the original material, in part.
14. The Michigan soils fit well into Alfisols in the Seventh Approximation. The Seventh Approximation did not work as well for some of the Peruvian soils,

such as San Jose series. This soil was similar to the others that fitted into the suborder Psamments. However its texture is too fine for that category, and it had to be fitted into Typic Torriorthents instead of Typic Torri-psamments.

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