ARGILLIC AND CAMBIC HORIZONS IN SOILS DEVELOPED FROM HIGH LIME LOAM TILL IN HURON COUNTY, MICHIGAN

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ABSTRACT

ARGILLIC AND CAMBIC HORIZONS IN SOILS DEVELOPED FROM HIGH LIME LOAM TILL IN HURON COUNTY, MICHIGAN

By

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Investigations were carried out on four soil series recently mapped in Huron County to determine the extent to which argillic and cambic horizons have been developed in these soils.

The soils investigated were the following:

Katechay : Soil #18

Shebeon : Soil #3

Capac : Soil #3_a

Kilmanagh: Soil #5

Field observations supplemented by laboratory determinations have revealed that all the four soils have gone through some processes of development. These consist of soil structuration, addition of organic matter, some carbonate redistribution and, in some cases, the development of an argillic horizon.

In these soils, the presence of a cambic horizon is expressed by soil structuration and carbonate redistribution; in addition the most poorly drained series of the association, the #5 and occasionally the #18, soil has a gley (B_g) horizon.

An argillic horizon is present in the Capac #3_a and in one profile classified as 3_a?. In those soils, the evidence of clay

movement is centered on the ratio of $\frac{B}{Ap}$ and $\frac{B}{C}$ total and fine clay. This ratio is greater than the 1.2 lower limit established by the soil survey staff for the recognition of argillic horizons. In addition, observation of thin sections has revealed the presence of oriented clay skins in these two soils while this feature is clearly lacking in the #3, #5 and #18 soils.

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A soil survey recently started in Huron County has revealed that the majority of the soil series so far mapped has been developed from high lime glacial till deposited during the late Pleistocene epoch.

While some of these soils are very weakly developed, exhibiting for example few genetic features, others have undergone more advanced stages of evolution with clear evidence of illuviation of organic matter and migration of fine mineral materials. Still others have been found to occupy intermediary positions with formation of only addition of organic matter, an illuvial horizon only weakly expressed, or with a genetic stage consisting of the development of a cambic horizon characterized only by a loss of lime and structure development.

A systematic key that has been developed to identify and classify these soils has been based primarily on nature of the parent material, profile texture and natural drainage conditions; but at the same time, major emphasis has been put on presence of the cambic or the illuvial argillic horizons.

In the field, recognition of a cambic horizon has commonly been a matter of routine qualitative observation performed by addition of dilute hydrochloric acid to the soil and observing the presence or absence of effervescence or the presence of subsurface structural development. Recognition of an argillic horizon has been more difficult and even controversial.

Migration of colloidal mineral matter is usually identified in the field by the observation of an increase of percentage of finer material and the observation of clay skins on the ped faces. In many cases during the survey, both features were so strongly expressed that the question of whether an argillic horizon was present has not raised the slightest doubt.

But, in many other cases, the question could not be easily answered and while in several instances some clay increase has been noticed, clay coatings could not be identified easily, which suggests that the observed increase in fine materials could be due not to the migration of clay but to a feature inherited from the sedimentation pattern of the parent materials or this plus removal of lime.

Since recognition of the presence of an argillic horizon is a supporting feature for classifying soils at the highest category level, it was found necessary to conduct some basic research on the nature of the cambic horizons and to elucidate the question of the existence of an argillic horizon in the soils that have been mapped.

1. Objectives

The objectives of this research are to:

a. Characterize 4 representative soil series that have been mapped.

b. Conduct some basic research that will elucidate the question about existence of an argillic horizon in three of these soils.

c. Confirm or reject the original classification that has been developed for these soils or suggest some modifications on the basis of the results of laboratory analyses plus field and laboratory observations.

II. LITERATURE REVIEW

1. Diagnostic horizons

Classification of soils at the highest category level is highly dependent upon recognition and identification of diagnostic horizons. Diagnostic horizons may be defined as layers in a soil profile that have undergone specific, genetic changes or alterations such that they finally acquire new permanent features that may be used to trace the process of their formation and provide positive criteria that allow us to classify the soils in which they occur, in a systematic pedology.

Such important changes may consist of gains such as organic matter, transformation of the configuration of the original material, horizontal depletion in content of one or several minerals, chemical changes, migration of elements from one layer to another, or losses of substances from the profile.

From the early days of soil classification, specific soil features have been adopted as differentiating criteria. Marbut (in Jenny, 1941) has called attention to the carbonates and the iron enriched horizons as they represent main genetic features differentiating mature soils of low rainfall area from the well developed soils of humid regions, respectively. Dokuchaev (in Joffe, 1949) has established for the European part of Russia definite isohumus belts which correspond more or less to the distribution of the soil zones; and the morphology of iron has been the basic criteria for classifying the humid tropical soils of Africa as established by the French classification system (Duchaufour, 1965).

But, it is only recently that the concept of diagnostic horizons "per se"—and independently of the features of the remaining portion of the soil profile--has been introduced as the primary criterion in a new system of soil classification (Soil Survey Staff, 1960).

Diagnostic horizons have been described in both surface and sub-surface layers of the soil profile; and while some groups of those horizons are essentially opposed to each other and mutually exclusive (one horizon being formed as the result of one dominant process while another has been derived from the very opposite process), other groups seem to have been formed under similar genetic conditions.

Argillic and cambic horizons are typical examples of diagnostic horizons that seem to have been developed through similar genetic processes. They are often very intimately associated in a soil catena or landscape segment. Further, they exhibit similar macromorphological features and very often cannot be separated without additional laboratory tests and analyses. But the meaning of their existence in a soil profile is so important, as far as soil classification is concerned, that any supporting research that is likely to assist in their individual recognition must not be overlooked.

2. Argillic Horizon

The *concept* of argillic horizon has been formulated in soil classification (Soil Survey Staff, 1960) and later clarified and elaborated in Soil Taxonomy (Soil Survey Staff, 1970).

Basically, this concept implies an illuvial horizon in which layer lattice silicate clays have accumulated by illuviation to a significant extent.

In addition, the following features have been considered to be usually associated with the argillic horizons and consequently may provide bases for their identification.

1. Abrupt or clear textural change between the eluvial and the illuvial horizon; this textural change consists mostly in a finer texture in the illuvial horizon; more specifically the ratio of percentage of clay of the enriched horizon to that of the horizon above must be 1.2 or higher.

2. Existence of coatings of oriented clays on the surfaces of pores and peds somewhere inside the horizon or at the base of the horizon.

3. A ratio of fine clay (< .2 μ) to total clay larger in the illuvial horizon than in the overlying eluvial or the horizon that underlies the illuvial horizon.

4. Absence of rock structure in more than half of the total volume.

5. Smaller proportions of minerals resistant to weathering (e.g., quartz and zircon) in the illuvial horizin than in the eluvial horizon.

Soil scientists have long been debating about selection of suitable *criteria* to identify argillic horizons. Nevertheless, discussions have been centered around a few indices: relative percentage of clay or fine clay in the different soil horizons, presence of clay skins (argillans) on the peds faces and in pores, pattern of orientation of clay particles of the coatings, and less commonly the study of distribution of an index mineral throughout the profile.

The relative percentage of clay material has been used by many authors as a sign of clay movements in the soil. Grossman and Fehrenbacher (1971) in studying the migration of clay particles in 4 loess-derived Alfisols in Southern Illinois have based their conclusions on percentage of clay increase in the B horizon; Bartelli and Odell (1960), investigating movement of clay in some Brunizems of Illinois, have used the amount of clay and organic matter in the B horizon as evidence of migration. Clay translocation and albic tongues have been described by Richard and Beatty (1969) in Glossoboralfs of West Central Wisconsin.

Smith and Wilding (1972), although admitting that other criteria may provide more sensitive indices, suggest that the ratio of clay in the B to the C horizon is quite a valid criterion in identifying argillic horizons and point out that such data offer the advantage of being more widely available.

Nettleton, Flach and Brasher (1969), studying the properties associated with the presence of clay in some profiles (shrinking-swelling), have come to the conclusions of positive existence of argillic horizons in some soils which lack the other basic characteristics of the argillic horizon. To them, the percentage of clay in the illuvial B is a sufficiently valid criterion in the fine textured soils.

Although the percentage of clay increase in the B horizon is without doubt a primary means for tracing clay movement, many examples have been cited to show that this criterion alone is insufficient in many situations. In fact the clay fraction of a given horizon may have originated from different sources: it may have been formed *in situ* through weathering and neo-synthesis; it may have been translocated downward after being formed in the upper part of the solum; and more significantly, it may have been deposited stratigraphically as such before processes of pedogenesis were initiated.

Examples illustrating this last situation have been cited in soils developed from parent materials with a lithological discontinuity (Hanna and Bidwell, 1955; Foss and Rust, 1962). In those cases, deposition of the materials from two sources may have been done in such a way that individual soil layers inside the profile may have originated from depositional phases quite different in textural characteristics; consequently, mechanical analysis may reveal higher percentages of clay minerals in horizons where processes of illuviation have been of little significance.

Smeck, Wilding and Holowaychuck (1968), conducting studies of argillic horizons developed in Alfisols from Western Ohio, have cited related examples of the role of parent material in the mode and the magnitude of development of the B horizon. At the same time they have pointed out the effect of carbonate dilution on $\frac{Bt}{C}$ clay ratio.

Consequently, it appears that in addition to clay content of the Bt horizon, other features must be investigated in recognition of the argillic horizon.

On the basis of results from analytical studies conducted on Red Brown Earth, Oertel (1968) has rejected the idea that clay illuviation has played any role in the development of the B horizon of these soils; to him, analysis of the variation of volume weight characteristics of these soils offers enough evidence to contradict the hypothesis of formation of these horizons through movement of clay minerals.

Many others have suggested that the ratio of fine clay to total clay represents a more useful basis for tracing the development of argillic horizons. Such criteria have been used by Dumanski and St. Arnaud (1966), McKeague and St. Arnaud (1969) and Smith and Wilding (1972). It appears that due to their size and mineralogical makeup, fine clays are likely to move more readily than coarse clays. Consequently, their accumulation in the lower part of the profile could be used as a better and more sensitive index for illuviation.

Methods for sampling fine clays have been described by Steele and Bradfield (1935) and Tanner and Jackson (1947). These consist of centrifuging the clay suspension at a predetermined speed and taking the sample at an appropriate depth.

Field observations reveal that, once the clay particles have been removed from the upper part of the profile, they normally do not mix with the bulk of the material in the illuvial horizon; rather, they are deposited as skins and coatings whose presence is unmistakable evidence of translocation. Furthermore, laboratory studies show that the deposition of such skins does not take place according to a random pattern; instead, they tend to form "cutans" that are made of thin composite lamellae in which individual layers are deposited parallel to the surface of the peds, or the root channels. In addition, the micro structure is strongly oriented in such deposits.

Orientation patterns of clay skins and their interpretation as evidence of clay migration have been given extensive attention by Stephens (1960), Brewer (1959), Minashina (1958) and many others. It appears that orientation is favored by the flaky configuration of the individual clay particles, their ability to cohere when dry, and the surface tension of the water between plates when moist. Stephens (1960) further explains that due to their hexagonal and platy shapes, clay particles, when they migrate and are allowed to deposit, form thin flakes and shreds with well defined basal cleavage. Advantages have been taken of their particle shapes to prepare aggregates for X-ray analysis by allowing clay suspensions to sediment with the consequent orientation of the phases parallel to the surface of deposition.

Cady (1966) has presented a substantial review on mineralogical analysis, morphology, observation and application of laboratory observations of clay skins to soil genesis interpretation. As he points out, completely randomly arranged clays will exhibit no birefringence and will appear isotropic in crossed polarized light. But, once the mineral develops oriented bodies through pressures and/or translocation, birefringence can be observed. Also, it is believed that strong orientation takes place when the minerals are deposited slowly in a dispersed state and that no obvious orientation takes place when deposition occurs in a flocculated state.

Although orientation seems to be a feature exclusively associated with migrated clays, evidence has been provided by Cady (1966) that pressure may also develop oriented clay surfaces to some extent. However, microscopic observation reveals that pressure induced clay bodies are mostly concentrated around rigid bodies (quartz grains for example); also, they failed to yield any other substantial distinctive optical features. Translocated clay on the other side deposits around pores, on ped faces and exhibits lamination that is also characterized by birefringence and extinction.

Once formed, the clay skins of the argillic horizons are stable only to a certain degree. They may be partly or even completely destroyed by such factors as disturbance of the soil through swelling-shrinking or by destructive activities of soil animals. A classical example has been provided by Nettleton *et al.* (1969). They point out that in some fine-textured soils, cyclic shrinking and swelling destroy clay skins or even prevent their formation. Hence, such horizons without clay skins can still be considered argillic. Consequently, some conservative attitude must be adopted in studying clay skins in argillic horizons of similar fine textured soils.

The process of *formation* of argillic horizon has been explained by Buol and Hole (1959), Bray (1935) and many others.

It is generally admitted that the deposition of colloidal mineral materials in the lower part of the solum is the result of a migration process that takes place at three different stages. There is a first stage during which colloidal particles are peptized and dispersed. Then, the dispersed particles are translocated and deposited during a final stage. The nature of the factors responsible for the dispersion, translocation and deposition of the inorganic colloids has been reviewed.

Barshad (in Bear, 1955) mentions high rate of hydration, low electrolyte content, a pH far from isoelectric point and absence of oppositely charged colloids in the same system as favoring dispersion and movement. One group of constituents that may favor existence of these conditions seems to be the organic matter of the soils. They act as chelating agents that allow iron and aluminium to go into solution and to be carried away easily.

The role of silica in facilitating a state of dispersion of colloid material has long been debated. Kubiena (cited by Stephens, 1960) suggests that presence of colloidal silica acts as an efficient peptizing agent and confers on kaolinite and halloysite, swelling capacity and plasticity as well as extraordinary hardness when dry. This point of view is shared by Yu A (1961), who favors the idea that clay particles can be kept in a condition of suspension under the protective influence of organic matter and silica, the latter acting as a stabilizer on the particles as they move through the soil profile. On the other side, McKeague and St. Arnaud (1969) consider the concept of peptizing action of silica invalid since $Si(OH)_4$ and not silica sol is the common Si component of soil solutions.

The role of the major factors responsible for clay translocation and the actual nature of the processes involved in their migration and deposition has been further elucidated thanks to very valuable works in experimental pedology conducted in the laboratory by Jenny and Smith (1934), Brewer and Haldane (1957), Buol and Hole (1961), and Hallsworth (1963). Basically, the principles involved in those experiments consist of allowing a suspension of clay to filter through columns of coarser materials according to a predetermined specific flow intensity and to submit the system to alternate drying and wetting.

Smith (1934) has outlined the nature of the factors and processes as follows:

Many clay minerals possess an inherent tendency to disperse in the absence of flocculating agents. Consequently, in natural media, they would tend to remain peptized and could readily be put in suspension. This state of suspension is greatly enhanced by soluble organic compounds which shift the flocculation values of the electrolytes to a higher concentration.

As they are put into suspension the particles move and are carried downward where they filter through minute open spaces and are finally gradually deposited as the water leaves the pores. The water regime seems to play an important role also since no formation of oriented skins is observed in the laboratory when the system is not subjected to alternate wetting and drying cycles. Also, the size of the pores is believed to be of major importance. Above a certain pore size, the particles do not deposit, but they follow the water downward. Deposition takes place while the particles are still in suspension by attraction phenomena and surface tension, or through flocculation.

3. Practical Significances of Argillic Horizons

So far, most of the works conducted in recognizing and identifying the argillic horizon aim ultimately toward characterizing the soils in which they occur. Argillic horizons are major typifying features of the Alfisols and the alfic subgroups of many great groups of a wide range of suborders. Consequently, investigations dealing with their morphology and *interpretation* are of major importance in systematic pedology.

On a still very practical point of view, the presence of clay particles around the structural units of the soils and along pores and root channels may be expected to play important roles in the dynamics of water and the availability of nutrients. Argillans, being essentially zones of concentration of the most active portion of the soils, have an important role in soil fertility. Unfortunately, much work needs to be done in that direction since final conclusions are obviously lacking.

Among the few embryonic works performed in this field are those of Soileau (1964), who investigated the effects of iron kaolinite cutans enveloping the soil aggregates. He concluded that cutans tend to stabilize the aggregates and restrict the plant growth by making nutrients less available. Potassium uptake was particularly restricted while calcium and magnesium absorption was increased. Similar experiments were conducted by Khalifa and Buol (1960), who found that plants growing in soils rich in clay-skin-coated peds had lower nutrient uptake as compared to plants growing on partially coated peds. They concluded that clay skins act as a barrier for root growth and restrict ion diffusion. Furthermore, they think that nutrient fixation may also greatly increase at those sites where fine clays have been greatly concentrated.

4. Cambic Horizons

Unlike argillic horizons for which the basic concept centers around a single morpho-genetic feature (development of a clay enriched horizon by illuviation), the cambic horizons belong to a collective group of morpho-genetic horizons which share the common feature of having undergone some alterations of various kinds not included in other diagnostic horizons.

As defined in Soil Taxonomy (1970), the cambic horizon is an altered non-illuvial horizon having a texture of the fine earth fraction that is loamy very fine sand or finer and that has undergone alterations consisting of:

1) movements of the soil particles by frost and roots to such an extent as to destroy most of the original rock structure. However, illuviation if present must be slight and definitely not evident to the magnitude (or level) recognized in other horizons (argillic, spodic, calcic, etc.),

2) aggregation of the soil particles into peds,

3) chemical alteration such as one of the following:

   a) hydrolysis of some of the primary minerals to form clay and liberate sesquioxydes,

   b) solution and redistribution or removal of some carbonates,

   c) reduction and segregation or removal of free iron oxides accompanied by biologic decomposition of inherited organic matter.

As outlined here, the cambic horizon is expected to be related to soil processes leading to the genesis of a wide range of horizon types. Also, the concept could imply a transitory phase between horizons characterized by strongly expressed features and other horizons that show no more than a trace of development. In this line of thinking, it may not be entirely fallacious to talk about "the cambic stage of profile development" as an intermediary stage during which changes take place in the horizon, but not to the extent recognized in other diagnostic subsurface horizons with well expressed signs of soil genesis.

Due to the variability of morphology implied in this concept, it appears that an exhaustive discussion on the genesis of different types of cambic horizons is out of the question for the nature of the review intended here: rather for the purpose of this particular study the morphology of a certain type of cambic horizon will be discussed. More specifically, it will deal with manifestation of structuration and solubilization and redistribution of carbonates as they may be interpreted in profiles derived from recently deposited glacial drifts.

5. Soil Structuration or Structure Formation

Factors and processes involved in development and preservation of structure in soils have been fully investigated and substantially reviewed by Baver (1956), Martin *et al.* (1955), and Soil Conservation Service (1970). The process itself may be presented as follows in a synthesized simplified model.

Soil colloidal particles possess negative charges at the periphery of their crystals or their molecules. In the event that the charges are not neutralized by positively charged ions, the particles repell mutually and if placed in a liquid system, they are normally peptized, dispersed and very subject to movement. But once these charges are satisfied or neutralized by positively charged ions, the particles no longer repell each other; rather they gather into clusters and in a liquid system they flocculate rapidly. This flocculation phenomenon has long been accepted as the starting point in the process of structuration of soils.

Flocculation alone, however, is not enough to produce aggregation. In order to stay together, the particles must be held by naturally occurring cementing agents (or separated by surfaces of less attraction), the most commonly recognized being the organic matter of the soil, the clay particles, the oxides of iron and aluminium and to some extent the calcium carbonate.

Direct binding has been found to occur between clay particles and certain polar organic matter (Chester, 1957). It is also possible that some clay mineral (e.g., montmorillonite) may adsorb within their lattice crystals, certain amounts of protein that are shielded to some extent from action of bacterial enzymes. The bulk of organic substances involved in soil aggregation is made of polysaccharides possibly combined with other soils constituents, including clays, which render them more resistant to microbial attack (Martin, 1945). In addition, certain modified lignins, proteins, oils, fats and waxes which are related in chemical composition to microbial decomposition products or synthesized compounds have been found to increase the stability of soil aggregates.

The free iron of the soil may act two ways in promoting soil structuration: the iron in solution may function as a flocculating agent while the fraction precipitated as a gel may act as a cementing agent whose binding power increases greatly upon dehydration (Lutz, 1936).

The processes involved in structuration are believed to be closely related to the orientation phenomena that take place in a wet soil. As the soil dries out, cohesive forces between oriented clay particles increase. Since dehydration itself is a slowly reversible process, subsequent oriented layers may be laid down and coat the original aggregate before they dry out completely, adding to their sizes and stability (Peterson, 1946).

Morphology of the binding network has been substantially elucidated thanks to observation performed with the electron microscope (Kroth and Page, 1946). Polar organic compounds form physico-chemical bounds with surface active clays, thereby generating aggregates which resist destruction on wetting. Further, the aggregating agents have been found to be distributed continuously throughout the aggregates and in contact with each particle. No visible signs of capsules or coatings which could act in a protective capacity have been found.

Concurrently, with the flocculation of the soil colloids and the incorporation of binding materials, a few dynamic processes take place in soil which enhance further formation of aggregates and consolidate the composite units already generated. The most commonly recognized are: freezing and thawing, swelling and shrinking, and wetting and drying.

The specific individual effects of the above processes and their importance in genesis of structure in soils have been thoroughly reviewed by Baver (1956). The whole process includes changes in volume provoked by adsorption and desorption of water, differential contractibility and extensibility with the consequent development of tremendously unequal strains and stresses that both break the clods and compress them one against the other, allowing them to consolidate accordingly and shaping them into individual units whose morphology may be later on utilized to identify the main processes responsible for their formation and the extent to which processes of soil development have been carried out.

6. Redistribution of the Carbonates

One of the most important indexes that has been recognized as evidence of profile development of certain soils is the redistribution of carbonates inside the profile.

Young soils developed from parent materials originally rich in carbonates are expected to contain a certain amount of this substance. Measurements of percentage of carbonates left in the profile may be used as a valuable index to determine the intensity of leaching and profile development. The leaching of carbonates in the soil is a process essentially dependent upon their solubilization by soil water. Normally the calcium and magnesium carbonates predominating in calcareous soils are insoluble in pure water. However, when enough carbon dioxide is dissolved in water, carbonic acid is formed which acts efficiently in dissolving and carrying the carbonates away as bicarbonates.

In the most simplified way, the process may translate by the following equations:

$$CO_2 + H_2O \rightleftarrows H_2CO_3$$

$$H_2CO_3 + CaCO_3 \rightleftarrows Ca(HCO_3)_2$$

The solubility of calcite may be expressed in terms of mean activity of Ca^{++} as illustrated in the following equation.

$$pH - 1/2\ pCa = 4.91 - 1/2 \log pCO_2$$

As stated in Henry's law (Barrow, 1969), the solubility of a gas in a liquid is proportional to its partial pressure above the liquid. Consequently, the higher the pressure of carbon dioxide, the more soluble the calcium carbonate.

Calcium carbonate in calcareous soils is generally assumed to behave like pure calcite and a system in equilibrium at constant pressure with pure calcite would be expected to have a constant pH-1/2pCa relationship. But calcareous materials in soil have been found significantly different from pure calcite. Experiments have shown higher values than for calcite, indicating presence of more soluble calcium carbonate phases. There are possibilities that a saturated solution of a calcareous soil in equilibrium with carbon dioxide and containing organic matter and various foreign ions in addition to calcium and bicarbonate ions would behave in an unusual manner. Experiments conducted by Olsen and Watanalee (1956) show that calcareous materials of some soils are more soluble in water at constant pCO_2 than calcite. Study papers by Brooks *et al.* (1950) have described several forms of calcium carbonate, among these being varetite, calcite and aragonite, all being able to be present in soils because the known conditions required for their formation exist in the soil system. Consequently, the precipitation of calcium carbonate in presence of various clays may lead to formation of more soluble forms of calcium carbonate than calcite.

In the soil system, the concentration of carbon dioxide is normally higher in the upper part of the profile where respiration from roots and microorganisms is more intense. So when water (mostly from precipitation) enters the soil, it dissolves a high quantity of carbon dioxide. The CO_2 charged water effectively dissolves any carbonate available and carries them downward in the profile. As the solution goes through less and less CO_2 saturated layers, it becomes more concentrated in solutes and less concentrated in the solvent and soon a point is reached when the carbonate precipitates from the solution. As more water enters the profile, more carbonates are dissolved, carried downward and deposited.

As implied above, the depth to which the carbonates are leached downward in the profile is an index that may be used in pedogenesis to estimate the degree of profile development. Furthermore, the natural drainage system would be expected to play an active role. In poorly drained profiles where water is allowed to stay for a longer period on the surface, process of carbonates dissolution is expected to be carried to a greater intensity than in well drained profile in which water stays only for a short time on the surface. Consequently in interpretation of profile development, depth of leaching must be coupled with the system of drainage prevailing in the landscape.

III. GEOLOGY AND SOILS

1. Geology and Physiography

The soils so far mapped in Huron County have been found to have developed from glacial drifts. Those drifts were brought largely by glaciers which moved southwestward from the Highlands of Canada across the several great lake basins, carrying with them materials ground and gathered from the lands over which they were moving (Leverett, 1915). Traveling actively across the area, the ice has somehow shaped the landscape, cutting and filling irregularities, thus generating a smooth topography. But as they commenced to stagnate, the glaciers started losing their leveling power, gathering rather in front of them masses of debris, generating accordingly an uneven topography made of ridges, knolls and depressions.

These two main types of physiography have been recognized in Huron County by Lane (1900), who refers to them as "hill district" and "plain district." The "hill district" applies to the chaotic irregular topography that starts just north of Verona Mills, extending south-eastward to Parisville and southwestward to Gagetown. Locally this "hill district" may be considered as the backbone of the county, from where originate all the important streams of the area.

In contrast to that uneven topography, the "plain district" occupies the remaining portion of the land, east, north, and west of the "hill district." It is characterized by a more even topography consisting of nearly level, gently rolling plains. However, contrary to their general appearance, those plains are not completely flat and level. Besides the small localized irregularities observed here and there, and probably caused by deposition of the debris riding over the melting ice, lake shore phenomena, etc., the existence of a more generalized topographic feature has been recognized consisting of a slight but regular dip from the South Center of the county and sloping away toward the lake shores. Such a sloping planar surface appears in the generalized surface contour map prepared by Lane (1900). It has also caught the attention of soil scientists who have been working recently in the area (Lietzke, 1972). Leverett has explained the slanted planar surface as a topographic feature inherited from preglacial configuration of the solid rock. He recognized it as one of the two large areas in the Southern Peninsula where the rock has a marked relief above the bordering district, extending from Kalamazoo and Coldwater and going northeastward to the terminus of the "thumb." Consequently, as the glacier overrode the land, it deposited the drifts parallel to the rock surface and the sloping planar surface has thus resulted.

In her map of the *surface formation* of the Southern Peninsula of Michigan, Martin (1955) classifies most of the materials of the "Plain district" of Huron County as "Lake bed clays." Lake deposits are essentially characterized by a specific morphology consisting of a depositional pattern in which the sediments are laid down in layers according to their size and weight. Stratified silt and fine sand layers have been observed in several profiles in the localities recently surveyed, but they do not belong in any way to as generalized a pattern as the lake deposits would suggest. Instead they are rather localized features created by deposition of sediments in water probably in pockets on the glacier or in water ponded or flowing in front of the ice. The typical glacial tills observed in the soils mapped in the County usually fail to show any generalized stratification pattern since they have been slumped or pressed without being worked extensively by the water. So in essence, those drifts serving as the parent materials of the soils on the "plain district" differ from lake deposits.

2. The Basal Till

Profile observations have revealed that the calcareous loam till underlying the leached material is a denser, more compact layer which has a coarse platy structure. Locally, this dense layer has been recognized by well drillers and trench diggers under the name of "hard pan."

Leverett (1915) has theorized that the harder underlying drift has originated from older repeated glaciations between which there were long periods during which the glaciated districts were free from ice. During those interglacial periods, he thought induration had been induced mostly from weathering and cementation. Lietzke (1972) disagrees with this hypothesis suggesting rather that the unusual state of consolidation was created by the immense load of the glacier overriding a moist and relatively thin layer of material directly in contact with the bedrock. This later explanation seems more probable and has been suggested by Flint (1957), who has cited examples of cases where basal compact tills have been identified in Sweden and North America as early as 1877. Torrel (in Flint, 1957) has attributed the genesis of the basal till to deposition by lodgment beneath the ice while the upper till has been thought to originate from superglacial or englacial morainic debris deposited by slow wastage of the ice beneath it. The theory of weathering offered by Leverett (1915) to explain the unusual density of the basal till is unlikely to have produced any dense compaction of the drifts. Weathering in humid areas, in fact, involves dissolution and loss of material from the mass of the rock; consequently, the dissolution of material would have probably generated a lighter stratum instead of the denser mass commonly observed. Consequently, while it is quite possible that those tills have been laid down through different glaciations, the extreme toughness of the basal formation is probably due to the extreme pressure applied on it by the overriding ice mass.

3. Soils in Relation to Drainage and Topography

From the very beginning of the current soil survey, it has been recognized that drainage has been a major soil forming factor in the area. Surface drainage is closely related to the general physiography and local relief, well drained soils being developed in positions higher in the landscape and poorly drained soils in the depressions. The importance of drainage has been accentuated by the presence of the compact basal till at depths averaging less than 40 inches from the surface. The presence of this restricting layer tends to prevent water from moving deeper inside the profile, hence a perched water table will be maintained which will influence profile development in many ways such as reduction of iron and manganese as well as slowing migration and deposition of clay particles and dissolution plus redeposition of carbonates.

In the survey that was begun last year, while no strong relationship could be established between presence of basal till and the different soil features in a systematic pattern, direct associations were observed between drainage, microrelief and soil morphology as follows:

1) The well drained soils are located in positions higher in the landscape and are characterized by lighter color of the surface horizon. Furthermore, they show very little or no mottling in the B horizon. They are leached to a lesser depth than the less well drained soils. In addition, they show a tendency to have clay flows and associated features such as angular structure in the subsoil.

2) The somewhat poorly drained soils occupy intermediary positions in the landscape. They have slightly darker surface color, they show abundant to common subsoil mottles, but not the extent of formation of a gleyed Bg horizon. They may show substantial evidence of clay flows and in general are leached to depths equal to or greater than their well drained associates.

3) The most poorly drained series occupy the lowest portion of the landscape on concave slopes and in the immediate vicinity of drainage ways or depressions. The color of their surface horizon is darker; their B horizon shows abundant mottles with formation of a thick gleyed horizon in many cases. They exhibit little or no evidence of clay movements in the profile and in a very consistent way, they are leached much deeper than the well drained and the somewhat poorly drained soils.

4. Mottlings and Gleyed Bg Horizons

Probably the most important feature around which the classification of the soils of Huron County was centered is the observation of the degree or intensity of development of the gley horizon. Directly related to the dynamics of water inside the profile, the degree of expression of the gleyed horizon ranges from the development of a discontinuous pattern of gray and brown mottles to the continuous solid gray of the well expressed Bg horizon.

Commenting on development of gley horizons, Joffe (1949) points out the importance of the existence of poor drainage conditions favoring a state of water logging that brings about anaerobic conditions which induce reducing reactions. Under these conditions, iron compounds are transformed from the ferric to the ferrous state and become more soluble.

A more elaborate hypothesis links the chemistry of gleying to activity of soil bacteria and decomposition of soil organic matter (Bloomfield, 1949). Organic matter carried by rain water would provide an energy source for micro-organisms at the surface of structural elements. Gleying would then commence at these surfaces and gradually extend into the structure elements. Once the capacity of the extract to dissolve more iron has been exhausted, the ferrous iron would be immobilized to some extent by sorption on ferric oxides in the lower layer (Bloomfield, 1951).

Consequently it would seem that the presence of organic matter would be more important than existence of poor drainage conditions in promoting development of the gley horizon since gley fails to develop in water logged soils with low organic content (Duchaufour, 1965). Nevertheless a water table near the surface is believed to be of primary importance.

Furthermore, due to the naturally high oxide-reduction potential in the partially reduced horizon (Duchaufour, 1965), one may expect that a strong tendency for reversibility exists in those soils. Consequently, as soon as reducing conditions become less accentuated, as in the case of persistence of dryer climatic conditions, the reaction tends to shift back to the oxidized state with consequent development of redder, or browner, colors.

Reducing conditions were found to prevail in large proportions of the soils of Huron County. The naturally moist regime of the area and the presence of the dense layer of compact till at relatively shallow depth favor the formation of perched water tables that fluctuate up and down according to the supply of water. During the dryer months, intense evaporation or slow percoloation will cause this perched water to disappear and consequently oxidizing conditions will cause some of the ferrous compounds to revert to an oxidized state with development of brighter colors; hence the origin of the association of the gray, brown and reddish-brown colors observed on or in the peds.

During the survey the standard adopted to separate the mottled horizons from the gley horizon was the existence of a continuous layer, one inch or more thick, of materials having a value of 2 or less (Lietzke, 1972).

IV. CHARACTERISTICS OF THE SOILS INVESTIGATED

Four soil series have been selected for this study. They have been tentatively described as Shebeon (#3), Capac (#3a), Kilmanagh (#5) and Katechay (#18).

They share quite a few characteristics in common: they have been developed from loamy parent material on flat poorly drained till plains. The dominant texture is a loam, but in places the surface texture becomes finer, approaching a clay loam; and in other places there is a tendency for an increase in amount of coarser materials and exhibition of a sandy loam texture. The #18 soil is calcareous throughout the profile.

The #5 series is the most poorly drained of the group. It is essentially characterized by a strongly developed gleyed Bg horizon and a more intense degree of leaching (20-40 in). In the Huron County legend this series has been described as an Aeric Haplaquept but in some cases it was found to have a thick and dark Ap horizon which qualifies it for Typic Haplaquoll. Where the dark surface is thinner it would qualify as a Mollic Haplaquept as Parkhill is currently classified.

The #18 series, as for the #5, is poorly drained and occasionally exhibits development of a well expressed gley horizon. Furthermore, it is found to be calcareous right at the surface.

The Ap is often thick and dark, but it appears that the thickness of this horizon decreases under cultivation. Field observations have revealed that this soil has a thinner Ap horizon in the Sand Beach area where it is thought to have been under cultivation for a longer period. When the Ap is thick and dark, this series is classified as Typic Haplaquoll, but in other instances where the Ap is thinner and lighter it has been recognized as an Aeric Haplaquept.

The #3 and #3a Soils: Normally the #3 series are less poorly drained than the #5 and the #18. It occupies the slightly higher positions of the landscape and exhibits gleying to a much lesser degree.

The mapping of #3 and #3a has presented some complications due to the variability observed in texture and morphology. While the representative #3 profiles are commonly characterized by a loam texture, not significantly finer in the B horizon, other pedons, #3a, have been described with a substantial increase of finer material with depth. In cases the illuvial origin of this horizon was obvious, as suggested by presence of clay coatings on peds faces and along the pore channels. But in many other cases the presence of a finer textured horizon could not be related to any illuviation since the features usually associated with clay illuviation were absent.

Consequently, the soils in which there were no obvious signs of clay illuviation were classified as #3 Aeric Haplaquepts while the soils with clear development of a textural Bt horizon were classified as #3a Aeric Ochraqualfs.

Following are the descriptions of two soil profiles of each of these soils at sites where they were sampled in this study. Those specific soils were selected because they are extensive and represent the trend in profile development under conditions ranging from minimal leaching to conditions of intense leaching and under different natural drainage situations.

Site 1 Soil #3

Location: N.W. $\frac{1}{4}$, N.W. $\frac{1}{4}$, Section 34 T 18 N R13 E Dwight Twp.

265 feet E. & 665 feet S. of N.W. corner of the Section

Soil classification: Aeric Haplaquept, fine-loamy, mixed, mesic.

Vegetation: Beans

Drainage: Somewhat poorly drained

Slope: $\frac{1}{2}$% East

Physiography: Nearly level plain

Elevation: 708 feet

Horizon	Depth (Cm)	Description
Ap	0-23	Dark grayish yellowish brown (10 YR 3/2) moist; moderate yellowish brown (10 YR 4/3) dry; loam; weak, medium, subangular, blocky structure; friable; mildly alkaline; abrupt smooth boundary.
B2	23-32	Moderate yellowish brown (10 YR 5/4) moist, with few gray brown to strong yellowish brown (10 YR 5/6) mottles; loam; moderate, medium, subangular, blocky structure; firm; mildly alkaline; clear wavy boundary.
C_1	32-50	Moderate yellowish brown (10 YR 5/4) moist; with many grayish yellowish brown (10 YR 5/2) mottles; loam; medium, subangular blocky structure; firm; moderately alkaline; calcareous, gradual wavy boundary.

Notes: Color names are from Intersociety Color Committee, National Bureau of Standard system.

Horizon	Depth (Cm)	Description
C_2	50-108	Moderate yellowish brown (10 YR 5/4) moist, with some light brownish gray (10 YR 5/1) moist mottles; loam; moderate to strong subangular blocky (occasionally platy) structure; firm to very firm; moderately alkaline, calcareous.

Note: Firm, compact till was encountered at 50 cms.

Site 2 Soil #5

Location: N.W. $\frac{1}{4}$, N.W. $\frac{1}{4}$; N.W. $\frac{1}{4}$, Section 34; T. 18 N., R. 13 E.

Dwight Twp.

Soil classification: Aeric Haplaquept, fine-loamy, mixed, mesic.

Vegetation: Beans

Drainage: Poorly drained

Slope: 1% East

Physiography: Nearly level flat plain

Elevation: 710 feet

Horizon	Depth (Cm)	Description
Ap	0-20	Dark grayish yellowish brown (10 YR 3/1.5) moist, grayish yellowish brown (10 YR 4/2) dry; loam; moderate, medium, subangular blocky structure; friable to firm; neutral; abrupt wavy boundary.
$B_{21}g$	20-28	Light brownish gray (10 YR 5/1) moist, with many dark brown (10 YR 4/3) strong yellowish brown (10 YR 5/6) mottles; loam; moderate, medium to coarse, subangular blocky structure; firm; neutral; clear irregular boundary.
B_{22}	28-62	Yellowish brown (10 YR 5/4) moist, with many grayish yellowish brown (10 YR 5/1) and strong yellowish brown (10 YR 5/6) mottles; loam; strong, coarse, subangular blocky structure; very firm; mildly alkaline; gradual wavy boundary.

Horizon	Depth (Cm)	Description
C_1	62-88	Moderate yellowish brown (10 YR 4/3) moist; with some gray (10 YR 5/1) and strong yellowish brown (10 YR 5/6) mottles; loam; strong, coarse, subangular blocky structure; very firm; mildly alkaline, calcareous; diffuse boundary.
C_2	88-125	Moderate yellowish brown (10 YR 4/3) with some brownish gray (10 YR 4/1) mottles; loam; strong, coarse, subangular blocky structure; very firm; mildly alkaline, calcareous.

Profiles 1 and 2 were described in the same landscape. Profile 2 occupies a more poorly drained area in the field. Water was encountered in profile 2. Profile 2 was quite stony and presence of pebbles made the sampling of cores rather difficult.

Site 3 Soil #3_a

Location: S.W. $\frac{1}{4}$, S.W. $\frac{1}{4}$; S.W. $\frac{1}{4}$, Section 30, T. 16 N, R. 10 E, Winsor Twp., 60' N. and 264' E. of S.W. corner of the Section.

Classification: Aquic Argiudoll, fine-loamy, mixed, mesic.

Vegetation: Plowed field

Drainage: Somewhat poorly drained

Slope: 1-2% West

Physiography: Slightly undulating till plain

Elevation: 622 feet

Horizon	Depth (Cm)	Description
Ap	0-37	Dark grayish yellowish brown (10 YR 3/2) moist, grayish yellowish brown (10 YR 5/2) dry; gritty loam; weak to moderate, medium, subangular blocky structure; firm to friable; mildly alkaline to slightly calcareous; abrupt smooth boundary.
$B_{21}t$	37-55	Moderate yellowish brown (10 YR 5/4) moist, with many grayish yellowish brown (10 YR 5/2) mottles and some dark gray brown (10 YR 4/2) organic coatings; clay loam; moderate fine, subangular blocky structure; firm (slightly plastic, wet); mildly alkaline; gradual wavy boundary.
$B_{22}t$	55-71	Moderate yellowish brown (10 YR 5/4) moist, with many grayish yellowish brown (10 YR 5/2) mottles and some (10 YR 4/2) organic coatings; loam; visible clay skins; moderate, medium, angular blocky structure; firm to friable (slightly plastic, wet); mildly alkaline; abrupt smooth boundary.

Horizon	Depth (Cm)	Description
C_1	71-98	Moderate yellowish brown (10 YR 5/3) moist, with common gray brown and yellowish brown mottles; loam; weak, medium, subangular blocky structure; very firm; moderately alkaline; abrupt wavy boundary.
C_2	98-125	Dark brown (10 YR 4/3), with many dark gray (10 YR 3/1) mottles; loam; strong, coarse, platy structure that is occasionally moderate, medium, subangular blocky; very firm; calcareous.

Since the Ap was found to be unusually thick (37 cms) samples were taken at two different depths in this Horizon: 0-27 and 27-37 cms. The upper part had a higher porosity while the lower layer was more compact.

Site 4 Soil #18

Location: N.E. $\frac{1}{4}$, N.E. $\frac{1}{4}$, S.W. $\frac{1}{4}$, Section 17, T. 16 N, R. 10 E., Winsor Twp., 60 feet S. and 276 feet W. of N.E. corner of S.W. $\frac{1}{4}$

Classification: Typic Haplaquoll, fine-loamy, mixed, mesic.

Vegetation: Beets

Drainage: Poorly drained

Slope: 0%

Physiography: Till plain

Elevation: 610"

Horizon	Depth (Cm)	Description
Ap	0-25	Brownish black (10 YR 2.5/1) moist, light brownish gray (10 YR 5/1) dry; fine loam; weak, coarse, subangular blocky structure; firm to friable; moderately alkaline, calcareous; abrupt smooth boundary.
B_{1g}	25-33	Grayish yellowish brown (10 YR 5/2), with some grayish yellowish brown (10 YR 4/2) coatings; silt loam; weak to moderate, medium, subangular blocky structure; firm; moderately alkaline, calcareous; clear wavy boundary
B_{2g}	33-68	Grayish yellowish brown (10 YR 5/2) with many strong yellowish brown (7.5 YR 5/6) mottles; loam; moderate, medium, subangular blocky structure; firm; moderately alkaline, calcareous; clear, wavy boundary.

Horizon	Depth (Cm)	Description
C_1	68-100	Moderately yellowish brown (10 YR 4/3), with many moderate yellowish brown (10 YR 4/4) mottles and some grayish yellowish brown (10 YR 5/2) coatings; gritty loam; moderate to strong, coarse, platy structure; firm to friable; moderately alkaline, calcareous. A chunk of strong yellowish brown (7.5 YR 3/6) silty clay loam to silty clay was observed from 58-68 cms. The dark brown coatings observed around the peds, in the C horizon, were thought to be of organic origin.

Site 5 Soil #3a?

Location: S.W. $\frac{1}{4}$, S.W. $\frac{1}{4}$, N.W. $\frac{1}{4}$, Section 27, T. 18 N, R. 13 E, Dwight Twp., 362 feet E. and 180 feet S. of N.W. corner of S.W. $\frac{1}{4}$

Classification: Aeric Ochraqualf?, fine-loamy, mixed, mesic.

Vegetation: Hay field

Drainage: Somewhat poorly drained

Slope: 1%

Physiography: Nearly level plain

Elevation: 703"

Horizon	Depth (Cm)	Description
Ap	0-25	Dark grayish yellowish brown (10 YR 3/2) moist, grayish yellowish brown (10 YR 5/2) dry; loam; moderate, medium, subangular blocky structure; firm; mildly alkaline; abrupt smooth boundary.
B_{21}	25-46	Moderate yellowish brown (10 YR 4/3), with many common strong yellowish brown (10 YR 5/8) and grayish yellowish brown (10 YR 5/2) mottles; loam; weak, fine, subangular blocky structure; friable; mildly alkaline; gradual wavy boundary.
B_{22}	46-68	Moderate yellowish brown (10 YR 4/4) with many grayish yellowish brown (10 YR 5/2) and strong yellowish brown (10 YR 5/8) mottles; loam; moderate, medium, subangular blocky structure; firm; moderately alkaline; clear wavy boundary.

Horizon	Depth (Cm)	Description
C_1	68-88	Moderate yellowish brown (10 YR 4/4) with common grayish yellowish brown (10 YR 5/2) coatings; loam; moderate, medium, subangular blocky structure; firm; moderately alkaline, calcareous; clear, wavy boundary.
C_2	88-115	Moderate yellowish brown (10 YR 4/3) with many grayish yellowish brown (10 YR 5/2) coatings; loam; strong, coarse, platy structure; very firm; moderately alkaline, calcareous.

Profile particularly stony with several big boulders observed.

Site 6 Soil #5

Location: N.E. $\frac{1}{4}$, S.E. $\frac{1}{4}$, S.W. $\frac{1}{4}$, Section 6, T. 16 N, R. 15 E, Sand Beach Twp.

Classification: Aeric Haplaquept, fine-loamy, mixed, mesic.

Vegetation: Navy beans, poor stand, weedy.

Drainage: Poorly drained

Slope: 1%

Physiography: Nearly level plain

Elevation: 717'

Horizon	Depth (Cm)	Description
Ap	0-28	Brownish gray (10 YR 3/1.5) moist, to dark grayish yellowish brown (10 YR 3/2) moist, grayish yellowish brown (10 YR 4/2) dry; loam; weak, medium, subangular blocky structure; firm to friable; medium acid; abrupt, smooth boundary.
B_{21g}	28-42	Light brownish gray (10 YR 5/1) with common strong yellowish brown (10 YR 4/6) mottles; loam with some clay coatings on peds; moderate, medium, subangular blocky structure; firm; slightly acid; clear, irregular boundary.
B_{22}	42-73	Strong yellowish brown (10 YR 5/6) with common grayish yellowish brown (10 YR 5/2) mottles; loam to clay loam; few clay coatings in old root channels; weak, medium to coarse, subangular blocky structure; firm; mildly alkaline; gradual wavy boundary.

Horizon	Depth (Cm)	Description
B_{23}	73-88	Moderate yellowish brown (10 YR 4/4) with common light olive gray (5 Y 5/1) mottles; loam to clay loam; moderate, medium to coarse, subangular blocky structure; firm; mildly alkaline; clear wavy boundary.
C_1	88-105	Moderate yellowish brown (10 YR 4/4) with many light olive gray (5 Y 5/1) mottles; loam; weak, coarse, platy breaking to medium, subangular, blocky structure; firm; mildly alkaline, calcareous.

Site 7 Soil #3

Location: S.W. $\frac{1}{4}$, S.W. $\frac{1}{4}$, S.W. $\frac{1}{4}$, Section 5, T. 16 N, R. 15 E, Sand Beach Twp.

Classification: Aeric Haplaquept, fine-loamy, mixed, mesic.

Vegetation: Beans

Drainage: Somewhat poorly drained

Slope: 1%

Physiography: Nearly level plain

Elevation: 715"

Horizon	Depth (Cm)	Description
Ap	0-23	Dark grayish yellowish brown (10 YR 3/2) moist, light grayish yellowish brown (10 YR 6/2) dry, with some brownish gray (10 YR 3/1) to black (7.5 YR 2/0) mottles; loam; weak, fine, granular structure; firm to friable; mildly alkaline; abrupt smooth boundary.
A_2/B_{12}	23-25	Moderate yellowish brown (10 YR 5/4); sandy loam; weak, fine, granular to subangular blocky structure; friable; mildly alkaline; abrupt, broken boundary.
B_{21}	25-42	Moderate yellowish brown (10 YR 5/4) with common light gray brown (5 YR 6/2) mottles; gritty loam; moderate, medium, subangular blocky structure; firm; mildly alkaline; clear wavy boundary.
C_1	42-55	Moderate yellowish brown (10 YR 4/4), with common light olive gray (5 Y 5/1) mottles; silt loam to loam; subangular blocky structure; firm to friable; moderately alkaline, calcareous; abrupt smooth boundary.

Horizon	Depth (Cm)	Description
C_2	55-105	Moderate yellowish brown (10 YR 5/4) with common light brownish gray (10 YR 6/1) mottles; loam; strong, coarse, platy structure; very firm; moderately alkaline, calcareous.

Site 8 Soil #18

Location: S.W. $\frac{1}{4}$, S.W. $\frac{1}{4}$, Section 5, T. 16 N, R. 15 E, Sand Beach Twp., 470 feet E. and 300 feet N. of S.W. corner of the Section

Soil classification: Aeric Haplaquept, fine-loamy, mixed, mesic.

Drainage: Poorly drained

Slope: 1%

Physiography: Nearly level till plain

Elevation: 719 feet

Horizon	Depth (Cm)	Description
Ap	0-23	Brownish gray (10 YR 3/1) moist, grayish yellowish brown (10 YR 5/2) dry, with common medium gray (7.5 YR 5/0) mottles; loam; weak, medium, subangular blocky structure, friable; mildly alkaline; abrupt, smooth boundary.
B_{21}	23-48	Moderate yellowish brown (10 YR 5/3) with many light brownish gray (10 YR 5/1) mottles; fine loam; moderate, fine to medium, subangular blocky structure; friable; mildly alkaline; clear, wavy boundary.
C_1	48-70	Moderate yellowish brown (10 YR 4/4) with common light brownish gray (10 YR 5/1) mottles; loam; strong, coarse, platy structure; firm to very firm; mildly alkaline; clear, wavy boundary.
C_2	70-100	Moderate yellowish brown (10 YR 4/4) with common light brownish gray (10 YR 6/1) distinct coatings; loam; strong, coarse, platy structure; firm; mildly alkaline.

V. METHODS OF ANALYSIS

1. Soil Sampling and Preparation

Two separate sets of samples were taken from each soil horizon:

1) Bulk samples were collected with spade and shovel in such a way as to obtain a composite cross sectional sample of each horizon. The samples were allowed to air dry and were then crushed gently with a rolling pin and passed through a 2 mm sieve. The fraction larger than 2 mm was washed, air dried and weighed for determination of percentage gravel.

2) Undisturbed core samples were collected with a special core sampler fitted with cylinders and a hammer (Blake, 1965). As the sample is driven, the soil sample is introduced into the cylinder with a minimum of disturbance. The cylinder containing the sample is then removed and stored in special plastic coated boxes. A total of five core samples were taken from each horizon.

2. Physical Determinations

a) Total porosity

The total volume of pores was obtained by measuring the amount of water retained by the soil (on a dry weight basis), after the individual core samples were allowed to soak in water for a minimum of sixteen hours, prior to the measurement of the hydraulic conductivity. The percentage of water at saturation, computed on an oven-dry weight basis gives the total volume of pores (Vomocil, 1965).

b) Hydraulic conductivity

This property was determined by measuring the volume of water flowing through the saturated core samples under a constant head of 1 inch for a specific length of time (Klute, 1965).

c) Bulk density

This value was obtained by dividing the weight of the oven dry core (following hydraulic conductivity measurements) by the volume of the core (Blake, 1965).

d) Mechanical analysis

The pipette method was used for mechanical analysis of the <2 mm soil material (Kilmer and Alexander, 1949). Organic matter was first destroyed through successive additions of H_2O_2 in presence of glacial acetic acid. Carbonates were removed and exchangeable bases displaced by addition of a volume of 0.5 N HCl. Samples were then filtered and washed through a buchner funnel under vacuum, then titrated with 0.1 N NaOH and shaken for 24 hours on a reciprocal shaker. Sand fractions were removed by washing through a 300 mesh sieve, then oven dried. Silt and clay were transferred to a 1000 ml sedimentation cylinder and sampled by taking 25 ml aliquots at proper depths and settling times according to Stoke's law. Sand fractions were further subdivided by sieving through a set of five sieves. Fine clays <0.2 μ were further sampled using the procedure and chart developed by Tanner and Jackson (1947). The suspension was centrifuged at 3000 rpm for 35 minutes and aliquots taken at proper depths. Percentage of each size fraction and solution losses were calculated on an oven dry, acid insoluble basis.

Gravel was separated by washing the sample retained on the #10 sieve during sample preparation; the clean gravel was air dried and weighed. Its percentage was calculated as percent of the original air dried samples.

3. Chemical Determinations

a) Organic matter

One gram of finely divided sample was attacked with concentrated sulfuric acid in presence of potassium dichromate. The suspension was then titrated with ferrous ammonium sulfate in presence of phosphoric acid and NaF with diphenyl amine added as an indicator (Jackson, 1958).

b) pH

Ten grams of air dry soil were mixed with 10 ml of distilled water in a 75 ml cup. The suspension was allowed to equilibrate for one hour. Measurements were made by using a Beckman Zeromatic pH meter (Peech, 1965).

c) Calcium carbonate

Finely ground samples were attacked with 2 N HCl in a closed system. The evolved CO_2 was absorbed by a solution of 2 N NaOH which was then titrated, after 24 hours, with 1 N HCl using phenolphatlein and bromo cresol green. The CO_2 was calculated as $CaCO_3$ equivalent in the oven dry 2 mm sample (Bundy and Bremmer, 1972).

4. Mineralogical Observations

Air dried soil samples from each horizon were impregnated under vacuum with Hylol epoxy resin (refract. index 1.55). Then the block was mounted using Hillquist Thin Section Epoxy cement (refract. index 1.55). The cover glass was finally installed using Cadeax as a binding agent (Batten, 1973). The thin sections were prepared by Gary Section Service, Tulsa, Oklahoma.

VI. RESULTS AND DISCUSSION

The results of the preceding analysis are presented in Tables 1, 2 and 3. Their discussion follows.

1. Calcium Carbonate Equivalent

The percentage of calcium carbonate equivalent observed in the soil samples varies widely (Table 1). Furthermore, since these soils have been developed from materials that were initially calcareous, the values obtained may be directly related to the intensity of leaching to which these soils have been subjected.

Except for the #18 soils which were calcareous at the surface, the Ap and the B horizons of all the soils are characterized by low percentages of carbonates: most of the figures being below 1.0% except in one particular area (site 3). In this specific field, the Ap was observed to be unusually thick and made up of two distinctive layers. Consequently, those features suggest that the upper 9 inches of this horizon may have been brought in from more calcareous soils, which incidentally occupy large mapping units in the general area.

The observation of the distribution of carbonate inside the profiles fails to show any gradual increase with depth; rather the level stays relatively low until a certain depth is reached where a very sharp increase is recorded. This feature is probably directly related to the dynamics of the water movement inside the profile, since the water is the dissolving and redistributing agent responsible for the

Table 1. Physical and chemical properties of the soils sampled

	Horizon	Depth (cms)	Porosity (%)	Bulk Density (gm/cm^3)	Hydraulic Conductivity in/hour	pH	% Organic Matter	% Carbonates, as $CaCO_3$
Site #1	Ap	0-23	39.1	1.54	.158	7.61	2.21	.012
Soil #3	B_2	23-32	34.8	1.68	.15	7.67	.56	.73
(Dwight Twp.)	C_1	32-50	33.9	1.73	.074	7.89	.50	19.24
	C_2	50-108	33.8	1.76	.003	7.97	.33	27.9
Site #7	Ap	0-23	37.2	1.6	.50	7.50	2.70	.30
Soil #3	B_{12}	23-42	33.7	1.69	.10	7.63	.57	.48
(Sand Beach Twp.)	C_1	42-55	35.6	1.72	.11	7.84	.69	6.61
	C_2	55-105	31.5	1.88	.03	8.20	.49	23.01
	Ap_1	0-27	43.5	1.4	1.02	7.60	3.02	1.88
	Ap_2	27-37	36.9	1.63	.02	7.58	2.27	.66
Site #3	$B_{21}t$	37-55	38.6	1.63	.23	7.80	.80	.28
Soil #3a	$B_{22}t$	55-71	40.4	1.50	1.1-19	7.78	.43	.82
(Winsor Twp.)	C_1	71-98	35.4	1.72	.11	8.05	.40	23.97
	C_2	98-125	31.2	1.90	.008	8.15	.20	28.87
	Ap	0-25	39.9	1.55	.68	7.31	2.55	.80
Site #5	B_{21}	25-46	37.5	1.68	.22	7.57	.60	.16
Soil #3a?	B_{22}	46-68	36.3	1.69	.13	7.66	.80	.15
(Dwight Twp.)	C_1	68-88	34.4	1.75	.05	8.03	.41	20.2
	C_2	88-115	31.2	1.86	.02	8.18	.67	23.6

Table 1 (cont'd.)

	Horizon	Depth (cms)	Porosity (%)	Bulk Density (gm/cm^3)	Hydraulic Conductivity in/hour	pH	% Organic Matter	% Carbonates, as $CaCO_3$
	Ap	0-20	46.38	1.29	2.51	6.58	2.59	.27
Site #2	B_{2g}	20-28	37.3	1.60	.16	6.88	1.13	.21
Soil #5	B_{22}	28-62	36.4	1.64	.41	7.30	.53	.39
(Dwight Twp.)	C_1	62-88	35.2	1.71	.006	7.60	.60	26.16
	C_2	88-125	31.3	1.70	.03	7.71	.33	29.89
	Ap	0-28	45.0	1.40	.30	6.17	4.41	.29
Site #6	B_{2g}	28-42	40.8	1.51	.17	6.63	2.11	.14
Soil #5	B_{22}	42-73	40.2	1.64	.22	7.10	.80	.02
(Sand Beach Twp.)	C_1	73-88	38.9	1.60	.43	7.30	.80	.02
	C_2	88-105	37.2	1.61	.022	7.65	.70	6.24
	Ap	0-25	39.4	1.52	.85	7.84	4.62	7.81
Site #4	B_{1g}	25-33	32.8	1.80	.90	7.92	.87	28.38
Soil #18	B_{2g}	33-68	37.4	1.70	.14	8.13	.73	29.53
(Winsor Twp.)	C	68-100	30.7	1.91	.04	8.13	.33	29.63
	Ap	0-23	38.6	1.58	1.1	7.72	2.11	.70
Site #8	B	23-48	34.1	1.75	0.15	7.97	.61	8.1
Soil #18	C_1	48-70	33.1	1.77	.26	8.00	.73	20.31
(Sand Beach Twp.)	C_2	70-100	32.4	1.83	.004	8.00	.48	25.84

movement of carbonates in soils; as it moves slowly downward, it probably becomes saturated and dissolves no more carbonates with depth.

Inside a catena, the #5 soils are consistently leached to a greater depth than the associated better drained soils of similar texture; this may seem contradictory since a poorly drained soil is one inside which free circulation of water is restricted due to limiting layers. So if the soil is poorly drained, water movement will be impeded at a depth closer to the surface, which does not seem to be the case for the #5. This paradox may be explained by the fact that while precipitation runs off of the convex or sloping surfaces it is concentrated in the depressions and more water is available there for leaching and carbonate dissolution.

The chemistry of the dissolution of the carbonates from the upper part of the profile and their redistribution in the lower portion of the solum has already been explained in the section on "Review of Literature." The sharp increase of the values inside the profile of the soils investigated seems to be related to the level at which the percolating water becomes saturated. With increasing depth, further solution is accompanied by deposition from the saturated solution.

Since the system is in equilibrium with the CO_2 pressure of the air, one may expect any features that govern the entry of air into the soil or the supply of CO_2 to play an important role in the distribution of carbonates in the solum. Those relationships will be discussed later.

2. <u>pH</u>

The general trend is a gradual and consistent increase from the Ap to the C horizon where the highest value is observed for individual soils (Table 1). Except for the #5 soil for which values lower than 7.0 were obtained for the Ap (6.16 to 6.88), all the other horizons have values higher than neutrality, and 8.00 or higher in the lower part of the profile. The maximum values were observed for the #18, which is calcareous to the surface. The #3 and #3a occupy an intermediary position between the #5 and the #18.

One point worth noting is that during the pH determination, the figures obtained could not be reproduced exactly on duplicate readings. The maximum discrepancies were in the order of 0.15 of a pH unit.

As explained by Turner and Clark (1956), the pH of calcareous soils does not have much meaning unless the concentration of the CO_2 in the air at equilibrium with the suspension is known. Furthermore, time is believed to be an important factor; at the beginning of the reaction dissolution of $CaCO_3$ will cause the pH to increase, but once the rate of transfer of CO_2 increases, the pH decreases with time until an equilibrium is reached. Consequently, the relative unstability and lack of perfect reproduction experienced during the determination may well be explained in that manner.

3. Organic Matter

As expected, the values for individual soils are higher in the Ap (Table 1), for which they range from 2.11 to 4.62%. The organic matter level drops significantly in the B horizons and still more in the C, where the minimum of .20-.70% are observed.

The organic matter is essentially a very dynamic fraction of the soil. It can be built up fairly rapidly and destroyed as easily through specific soil management practices. Nevertheless, the distribution of organic matter through the profile may reflect in many cases the genetic evolution of the soils. Furthermore, it seems to be directly related to the topography and drainage conditions under which the profile has developed. In general, organic matter is higher in the poorly drained soils, undoubtedly on account of anaerobic conditions developed during wet periods (Jenny, 1941) that inhibit organic matter decomposition.

Relatively higher amounts of organic matter were found in the surface horizon of the #5 and the #18 which are considered to be the least well drained soils of the group sampled. Average figures are about 3.43 for those soils and 2.62 for the #3 and #3a soils.

The trend of distribution of the organic matter inside the profiles does not always follow a systematic pattern that could easily be explained. However, in about one half of the profiles, there is a sharp decrease as one progresses from the Ap to the B horizon, then a slight increase is observed at the top of the C_1 horizon before the values drop to a minimum in the C_2 horizon.

Migration of the organic matter and its combination with other elements in the soils such as clay colloids and iron has been discussed in the "Review of Literature." Perhaps this downward moving organic matter is flocculated at the top of the calcareous C horizon.

The data obtained from the analysis of the samples show a slight positive correlation between variation of clay in the profile and percentage of organic matter.

During the examination of the profiles in the field, and during the sampling, the presence of a dark gray and black coating was often observed on the subsoil ped faces; these were believed to be due to the migration of soluble organic matter. In some cases, these black coatings give an odor of H_2S on acid treatment and are apparently sulfides of manganese.

4. Bulk Density

Values of bulk density range from 1.29 to 1.9 (Table 1). The pattern is a general and consistent increase with depth in the profiles.

a) The Ap horizon

Figures for the Ap range from 1.29 to 1.58. The lower values correspond to surface layers that have been plowed or cultivated recently or to areas where some fresh organic material, e.g., straw, has been incorporated into the soil. Higher values are probably due to partial compaction of the horizon.

In one particular case (soil #3a at Site #3), where the A horizon was observed to be unusually thick (37 cms), two sets of core samples were collected, one from 7.5 to 15 cms and the other one from 22.5 to 30 cms. In fact, the values are lower (1.4) for the upper part and higher (1.63) for the lower part of the same horizon. This field had been freshly plowed and the upper part was porous as a result.

Although there is a tendency for the Ap of the #18 soils to show values higher (1.52-1.58) than those of the other soils, no effort should be made to generalize this tendency; the reason is that the plow layer is essentially subjected to seasonal overturning, compaction, and general disturbances brought about at the time of land preparation, fertilization, planting and harvesting. As a consequence, density values are very likely to change rapidly within short periods, depending on recent management and general farming practices.

b) The B horizon

Values range from 1.50 to 1.80 depending on the soils series and the particular nature of this horizon. The lowest ranges of values (1.51 and 1.60) were obtained for the #5 soils, which are poorly drained and the most intensively leached soils. On the other side, highest values (1.75 and 1.80) were obtained for the #18 soils, which are characterized by a minimum degree of leaching. The soil #18 of Site #4 was strongly calcareous right at the surface; it also shows the highest value of bulk density in the B horizon. This fact suggests that among other factors, absence of leaching may account directly for a high value of bulk density in the B horizon. Perhaps removal of calcite and/or dolomite and other minerals may lead to decrease in specific gravity of the soil materials and open up pores in the horizon leached. Another example of low value (actually the lowest one, 1.50) was obtained for a B_2t horizon of the 3_a type soil (Site #3). In this particular case, the low value is probably due to a high degree of aggregation usually observed in these well structured argillic horizons. In fact, during the sampling, the structure of the soil was found to be so well developed that special care had to be taken to avoid disturbance of the sample.

c) The C horizon

One should consider separately the upper part of the C and the underlying C_2 which in most cases corresponds to the compact basal till. Values obtained for the upper C_1 horizon range from 1.60 to 1.77. Here again, the lowest values were obtained for the intensely leached #5 soils and the highest values (1.91) for a #18 soil. This suggests again the existence of a close relationship between bulk density and the intensity of leaching. The bulk density value is definitely higher in the C_2, with figures ranging from 1.8 to 1.9, except in Soil #5. In the field, whenever present, the compact till was easily noticed by its massiveness, its firmness and its coarse platy structure.

5. Hydraulic Conductivity

The results obtained for the hydraulic conductivity (sometimes called permeability) are less consistent than those recorded in the determination of bulk density (Table 1). In fact, in averaging the values for a given horizon, figures too far apart from the central tendency had to be ignored. This decision was made after close examination of most of the cores showing this discrepancy revealed the presence of vertical pores or unusual cracks believed not to be representative of actual natural soil conditions. This is an important point that needs to be recognized whenever data obtained in laboratory determinations of hydraulic conductivity must be used to evaluate the properties of a soil to adsorb and transfer water.

In spite of the wide ranges of values obtained for individual horizons, a general tendency may be recognized. It consists of a decrease in values from the Ap to the C_2 for which a minimum of 0.004 in/hour was observed for the C_2 of Site #8, Soil #18.

a) The Ap horizons

A maximum value of 2.51 in/hour was obtained for a #5 soil (Site #2) while the minimum of 0.158 was obtained for the #3 soil (Site #1). Incidentally, both profiles were described in the same field. It seems therefore that individual values for the Ap are related to local management and cultural practices. Higher values may be due to recent plowing or cultivation, and lower values to compaction by tillage implements and lack of recent sod crop production.

b) B horizons

Except for a few cases, permeability of the B horizon was found to be lower than for the Ap horizon. Unlike the Ap, major differences are thought to be due not merely to management but to more permanent factors closely related to genesis of soils. In several cases it was observed that the upper B had a permeability value lower than that of some horizon immediately underneath (B_{22} particularly). In those cases, field observations and laboratory data have revealed the presence of slightly finer texture or more organic matter at those levels.

In another case, a very high value was obtained for a well structured (B_2t) horizon; this was certainly due to presence of large size pores and inter-ped gaps, very common in some of the argillic horizon.

c) C horizons

The compact till is definitely characterized by a very low value of permeability. In fact, in one case (one core sample from Soil #18, Site 8, Sand Beach Twp.), absolutely no flow was observed after a constant head was maintained over the sample for more than four hours.

6. Genetic Significance of Bulk Density, Porosity and Hydraulic Conductivity Values

Since changes in bulk density, porosity and hydraulic conductivity of soils are the results of physical and chemical phenomena consisting of dissolution and redeposition of minerals or increases and decreases of the volume of the mass of the soils through changes in temperature and moisture, it seems logical to relate the magnitude of their expression to degree of development of a soil profile.

In studying the evolution of soil profiles developed from glacial till in Michigan, Bailey *et al.* (1957) used, along with a mineral study, the change of volume of the soil mass as an index of profile development. Also, as mentioned in the section "Review of Literature", related to cambic horizon, evidence of structure formation, and redistribution of carbonates are among the main criteria commonly used to recognize the formation of cambic horizons.

Hydraulic conductivity is essentially a function of the soil porosity, which is itself closely and commonly inversely related to the bulk density of the soil.

Maximum values of bulk density are normally associated with horizons that have been subjected to minimal removal of materials through chemical reactions and solution. But as water is allowed to move through the profile, soluble materials are removed and translocated. As dissolution progresses, voids are created and become more and more extensive with time.

However, the increase in voids is not directly proportional to the intensity of the dissolution of the materials; as soluble substances depart from the horizon, the local bearing capacity decreases and, as a consequence, some collapsing normally occurs, making the actual porosity less than the original volume of the soluble material.

Nevertheless, the genesis of these first empty spaces triggers a chain reaction in which water after creating the original voids allows more water and air to circulate through the profile. Exchanges become more intense and soon a complete network is established. The soil then starts to have structure. This phenomenon allows other processes to take place. For example, water in entering the soil is absorbed within the layers of the colloidal materials and the fluctuation in water content leads to swelling and shrinking of the mass of the soils and the resulting pressures and tensions create intense consolidation and dislocation that further create more pores in the mass of the soil.

In addition to those processes, more stresses are created as the soil is subjected to significant changes in temperature (particularly because of the freezing and thawing of water). The minerals of the soil being subjected to differential expansion and contraction are further dislocated.

As a consequence of the repetition of all these processes inside the profile, the soil mass becomes porous, structured, occupies more volume for a given weight, and the bulk density decreases while the porosity increases. Therefore, by comparing the bulk density of the unaltered parent material to that of the developed soil profile, one may end up with a good estimate of the changes that have taken place inside the profile and the degree of evolution reached by individual horizons.

Applying this concept to the profiles described during this study, an evaluation of the degree of development of the different soils can be made.

The figure 1.75 seems to be the original value for the bulk density of the basal till. The upper C horizon has an average value of 1.67.

In comparing the value 1.67 with the bulk density of the different horizon of the soils, one comes up with some interesting conclusions.

The #18 soils (except within their surface horizon) show no values significantly higher than this average 1.67. The #5 soil on the other side shows values significantly lower than the average. This soil has been subjected to intense leaching and one may theorize that solubilization of the carbonate accounts for this decrease in the bulk density value, except that the C horizon at Site #2 still contains >25% carbonates.

The #3 and #3a soils have values somehow intermediate between those obtained for the #5 and the #18 soils. The degree of leaching of these soils has been considered to be also intermediate.

7. Mechanical Analyses

a) Non-clay

In this section we will consider first the sand-silt-clay fractions (Table 2), and later the fine clays (<.2 μ) (Table 3). An observation of the values obtained for the *silt* fraction fails to show any consistent trend either from one soil to another or within a given profile. The main feature is that the sum of coarse silt and fine silt tends to center around 32% with the fine silt (.02-.002) making up a larger fraction of the total. On the other side, the values obtained for the *sand* and *clay* are more meaningful and will be given more consideration.

With the silt fraction showing very slight fluctuation, the relationship between the percentage of clay and the percentage of the sand should lead itself to more meaningful interpretations. Since the sum of all three fractions is 100%, with the silt constant, sand and clay must vary inversely. That is, if the percentage of one increases, it corresponds to a decrease in the other fraction.

Table 2. Particle size distribution of the soils sampled (% on oven dry, carbonate free basis except >2 mm on air dry total sample)

	Depth (cms)	>2 Total Sample	2-1 %	1-.5 %	.5-.25 %	.25-.1 %	.1-.05 %	Total Sand %	.05-.02 %	.02-.002 %	<.002 %
		Particle Size in mm									
	0-23	-	.8	3.1	12.1	17.6	14.0	47.6	14.5	20.0	17.9
Site #1	23-32	2.4	.7	2.7	12.1	18.1	13.2	46.8	13.2	19.3	20.7
Soil #3	32-50	4.9	.4	2.5	10.1	20.6	17.2	50.8	10.6	18.8	19.8
	50-108	6.1	.8	3.2	11.5	17.6	12.6	45.7	11.4	20.9	22.0
	0-23	8.8	1.5	5.2	17.7	20.2	14.7	59.3	10.0	15.7	15.0
Site #7	23-42	7.0	1.8	4.1	16.9	22.7	12.5	58.0	8.5	15.6	17.9
Soil #3	42-55	4.6	1.0	2.7	9.8	15.3	16.5	45.3	10.2	24.5	20.0
	55-105	8.8	1.5	2.9	9.4	15.3	15.1	44.2	11.9	23.0	20.9
	0-27	2.9	.5	3.3	18.6	25.1	8.9	56.4	16.4	14.1	13.1
	27-37	1.4	.4	3.7	17.4	20.9	8.5	50.9	10.8	19.1	19.2
Site #3	37-55	2.4	.7	3.3	13.2	15.8	11.6	44.5	4.8	27.1	23.6
Soil #3a	55-71	2.6	.4	2.5	10.1	10.6	17.2	40.8	7.2	24.6	27.4
	71-98	6.4	.8	3.6	12.1	14.3	12.4	43.2	10.1	22.4	24.3
	98-125	9.9	1.5	4.2	14.9	3.7	27.1	51.4	8.6	18.0	22.0
	0-25	3.8	.1	3.1	11.6	12.2	20.9	48.8	12.0	23.1	16.1
Site #5	25-46	5.2	.8	2.8	11.4	17.4	12.3	44.7	13.3	17.4	24.6
Soil #3a?	46-68	6.9	.7	2.7	12.7	17.5	11.8	45.4	11.4	19.1	24.1
	68-88	4.1	1.1	3.8	14.2	11.9	23.2	54.2	10.3	16.6	18.9
	88-115	6.6	1.2	3.2	9.1	9.5	21.9	44.9	9.9	22.9	22.3
	0-20	-	.5	2.7	11.3	18.3	14.9	47.7	4.8	25.6	21.9
Site #2	20-28	1.5	.6	2.8	10.4	15.8	14.3	43.9	9.5	21.5	25.1
Soil #5	28-62	6.6	.6	3.3	11.0	7.5	21.9	44.3	10.7	19.8	25.2
	62-88	6.5	1.3	1.9	5.8	10.7	9.0	28.7	24.0	21.3	26.0
	88-125	5.2	1.5	3.5	6.9	11.3	10.1	33.3	9.8	24.1	32.8

Table 2 (cont'd.)

		Particle Size in mm									
	Depth (cms)	>2 Total Sample	2-1 %	1-.5 %	.5-.25 %	.25-.1 %	.1-.05 %	Total Sand %	.05-.02 %	.02-.002 %	<.002 %
	0-28	2.2	1.3	3.6	14.5	15.7	13.9	49.0	10.5	19.3	21.2
Site #6	28-42	2.8	1.2	3.0	10.3	15.6	12.5	42.6	11.4	19.3	26.7
Soil #5	42-73	5.9	.9	3.6	11.6	15.0	18.8	49.9	9.6	19.2	21.3
	73-88	4.2	.5	2.5	10.3	16.7	15.7	45.7	10.1	19.7	24.5
	88-105	3.7	.7	2.6	9.1	15.1	15.7	43.2	10.6	21.6	24.6
	0-25	2.1	.8	3.7	19.3	17.9	7.0	48.7	11.0	18.8	21.5
Site #4	25-33	3.5	.5	2.7	12.5	15.2	10.3	41.2	6.4	28.1	24.3
Soil #18	33-68	5.3	.7	3.1	13.0	17.7	10.1	44.6	8.5	21.3	25.6
	68-100	8.1	1.3	3.9	14.9	22.5	12.6	55.2	7.5	17.0	20.3
	0-23	3.8	1.0	4.5	16.2	22.6	17.2	61.5	9.1	14.9	14.5
Site #8	23-48	3.9	.6	2.6	11.1	14.5	22.4	51.2	10.1	18.9	19.8
Soil #18	48-70	9.6	.8	3.2	10.6	18.0	14.6	47.2	11.6	21.0	20.2
	70-100	7.3	1.0	2.7	9.6	17.2	16.2	46.7	11.1	21.4	20.8

For the majority of the profiles the percentage of sand is higher (47.6 to 61.5) in the Ap than in the other horizons. From the Ap to the B horizons, there is generally a slight decrease that is followed by an increase corresponding to the depth of the more assorted till from where the values may again increase or decrease. The larger portion of the sand materials seems to be concentrated in the fine and very fine fractions where the values range from 7.0 to 25% compared to .1 to 1.8% for the very coarse sand.

b) The clay fraction

Without one single exception, the percentage of total clay is lower in the Ap from where an increase is observed as one progresses to the B horizons. The ratio of the clay percentage found in the B horizon to the clay percentage of the Ap ranges from 1.13 to 1.52 (Table 3).

This ratio is a very important index since it has been set as a criterion that indicates the amount of illuviation of clay that has taken place in the profile (Soil Conservation Service, 1970). More precisely, the boundary of 1.2 indicates the line above which intensity of illuviation is believed to be enough to confer on the horizon the characteristics of an argillic horizon.

Although the recognition of other criteria is usually expected, the increase in the percentage of clay fraction from the A horizon to the B has been widely used (Grossman and Fehrenbacher, 1971; Richard and Beatty, 1969; Bartelli, and Odell, 1960) as a criterion for argillic horizons.

The increase of clay with depth was observed in many sites during the survey conducted in Huron County during 1972 (#3a and #3a? soils).

However, in many cases the other features associated with clay illuviation could not be recognized (#3a?). It has been shown (Smeck and Wilding, 1968) that in soils developed from parent materials characterized by lithologic discontinuities the clay index should be used in a very conservative way since the clay increase may have been due to segregation in the parent materials before any profile development has the chance to start.

To compensate for this possibility, Smith and Wilding (1972) have suggested that a ratio of $\frac{B}{C}$ total clay be used as a supporting criterion in soils characterized by original lithologic discontinuity between the A and B horizons. It seems that such an index might be quite appropriate to evaluate the clay movement in most of the soils described.

An increase in total clay content was found sufficient (>1.2) to qualify 4 of the soils with having an argillic horizon. Those soils were #3a of Site #3, #3a? of Site #5, #5 of Site #6 and #18 of Site #8. However, in one of the soils, #18, the clay index fails to drop at the level of the C horizon, suggesting that the high index is due to the intrinsic nature of the initial soil materials and not to a migration of the fine materials from the upper part deeper into the solum.

It seems therefore that in order to keep a meaningful value in the interpretation of argillic horizons, the clay index should drop significantly below the B horizon. Consequently, whenever this tendency is not observed, it is very likely that migration has not taken place to any extent. Rather what seems to be migration may be the result of a lithologic discontinuity of the parent material. Only profiles at Sites #3, #5 and #6 meet both of these criteria. These were sites believed to have argillic horizons in the field.

Further observation of the clay distribution in the profile shows that in the majority of the cases, the basal till has slight to significant higher clay percentage than the upper till. Such a distinctive feature has also been pointed out by Flint (1957), who suggests that the higher clay content of the basal till is due to the fact that little or none of the finest sediments in it had the opportunity during deposition to be flushed away by running water from the melting glacier. On the other side, the higher percentage of sand content and lower clay content of the upper part of the till may be due to the fact that it was repeatedly washed by trickles and rills of melt water during its existence as ablation moraine. Similarly, in a study conducted on particle size distribution of some Michigan soils developed from glacial till in Michigan, Mick (1949) attributed the relatively finer texture of the lower horizons to the fact that those horizons were not subjected to the wave action that has been quite effective in removing considerable portions of the fine material from the upper part of the till during the retreat of the glaciers.

c) Fine clays

The determination of fine clays (Table 3) is based on the principle that centrifugal acceleration is used to replace the force of gravity in the rate of fall of particles. This determination was carried out in a centrifuge under a speed based on nomographs developed by Tanner and Jackson (1947). Although the principle is simple, under the same acceleration, speed of fall of particles is a direct function of their sizes, as stated by the authors. The assumptions implicit in the method, such as estimation of the hydrated specific gravity of the particle, drift of centrifuge temperature, acceleration and deceleration

Table 3. Clay and fine clay analyses

	Horizon	Depth (cms)	Particle Size (mm) <.002 % <2 mm	<.002 B/A clay	<.002 B/C clay	<.0002 % <2 mm	<.0002 B/A fine clay	<.0002 B/C fine clay	% <.002
Site #1	Ap	0-23	17.89			8.4			45
Soil #3	B_2	23-32	20.74	1.15	1.04	8.7	1.03		42
(Dwight Twp.)	C_1	32-50	19.84			8.0		1.08	39
	C_2	50-108	21.97			8.1			37
Site #7	Ap	0-23	15.09			7.0			46
Soil #3	B_{12}	23-42	17.88	1.18	.89	8.4	1.2		47
(Sand Beach Twp.)	C_1	42-55	20.00			10.0		.84	35
	C_2	55-105	20.88			7.0			35
Site #3	Ap_1	0-27	13.06			2.8			39
Soil #3a	Ap_2	27-37	19.18			6.1			49
(Winsor Twp.)	$B_{21}t$	37-55	23.64	1.23	1.12	8.6	1.4		35
	$B_{22}t$	55-71	27.35			9.0			34
	C_1	71-98	24.26			4.1		2.1	17
	C_2	98-125	22.03			3.8			17
Site #5	Ap	0-25	16.06			8.5			53
Soil #3a?	B_{21}	25-46	24.57			9.7	1.4		39
(Dwight Twp.)	B_{22}	46-68	24.09	1.52	1.27	9.4			39
	C_1	68-88	18.88			6.1		1.5	33
	C_2	88-125	22.32			6.3			28
Site #2	Ap	0-20	21.94			10.0			45
Soil #5	B_{2g}	20-28	25.10			9.3	.93		37
(Dwight Twp.)	B_{22}	28-62	25.15	1.14	.96	9.0			36
	C_1	62-88	26.03			6.0		1.5	23
	C_2	88-125	32.76			6.0			18

Table 3 (cont'd.)

			Particle Size (mm)						
			<.002			<.0002			
	Horizon	Depth (cms)	% <2 mm	B/A clay	B/C clay	% <2 mm	B/A fine clay	B/C fine clay	% <.002
	Ap	0-28	21.24			8.9			42
Site #6	B_{21g}	28-42	26.65			9.8	1.1		37
Soil #5	B_{22}	42-73	21.29	1.25		8.8		1.06	38
(Sand Beach Twp.)	C_1	73-88	24.56		1.08	8.2			38
	C_2	88-105	24.57			8.9			41
Site #4	Ap	0-25	21.53			12.8			59
Soil #18	B_{1g}	25-33	24.32	1.13		7.3	.6		35
(Winsor Twp.)	B_{2g}	33-68	25.59		.96	9.1		7.8	35
	C	68-100	20.26			4.0			21
Site #8	Ap	0-23	14.53			5.9			40
Soil #18	B	23-48	19.78	1.36		6.5	1.1		33
(Winsor Twp.)	C_1	48-70	20.22		.97	6.3		1.03	31
	C_2	70-100	20.83			6.1			29

of the centrifuge create enough error that slide rule calculation of nomographs is sufficiently accurate.

Although every effort was made to minimize the instrumental errors as much as possible, the percentage of fine clays found in individual samples could not be reproduced exactly with the materials available in the laboratory. To compensate for this inconsistency, sets of samples from the same profiles were centrifuged at the same time so that the errors could remain comparable. Consequently, the relative value of the results may keep their meaning, even if some errors have been introduced in the determination.

To make the results more meaningful, the values of percentage of fine clay obtained for each sample was computed on two bases: first, the percentage of fine clay for the total less than 2 mm fraction, and second, the percent of the fine clays in the total clay. This last value was found to be relatively quite meaningful and significant. In addition, the ratio of fine clay in the B relative to the A and C horizons was calculated.

The absolute percentage of fine clays shows different trends for individual profiles. For the poorly drained soils, this value remains fairly uniform throughout the profile with a slight tendency toward a minimum at the level of the C horizon. The results for Soil #3a from Site #3 depart from this general tendency. The values, rather low in Ap 2.8% or 6.1%, increase sharply to 8.6 and 9.8% in the B_t horizons, from where they drop sharply to 4% in the C horizon. A small increase is also observed in B horizon for the soil #3a, Site #5, but the extent is not as great as for the #3a, Site #3.

The ratios of fine clay in the B horizon relative to the A and C horizons exceed the 1.2 ratio required for total clay in the B/A of argillic horizons and the ratio is somewhat greater for the B/C ratio than the B/A ratio for both of the #3a soils. In none of the other profiles do those ratios consistently exceed 1.2.

The relative percentage $\frac{\text{fine clay}}{\text{total clay of Ap}}$ is quite high for all the samples (Table 3); the lowest value is 39 and the highest 59%. This means, therefore, that the fine clays account for about one half plus or minus 10% of the total clays. From the Ap to the C horizon, there is a general decrease in the ratio of the fine to total clays until a minimum (17 to 37%) is reached in the C horizon.

The sequence of figures observed in the #3a soil, Site #3, last column, Table 3, differs from the general trend just as described above. For this profile, there is a sharp increase at the bottom of the Ap. Then at the bottom of the solum, a much sharper decrease is observed as the values drop from 34 to 17% in the C.

This trend of increase of the absolute values of fine clays in the B_2 horizon and the further drop in the percentage near the C horizon suggest that this profile (#3a, Site #3) has been the site of substantial clay migration from the upper part of the profile deeper into the solum. This feature is supported also by observation in the field of angular blocky shape of structural units showing the presence of shiny clay skins in the B horizon.

Some coatings were observed at the Site #5 (Soil #3a), but they were not as well expressed as for Site #3.

8. Thin Sections

Preliminary observation of the thin sections deal with examination of the pores distribution, the presence or absence of coatings along the pores, identification of the nature of the coating materials and the observation of particular minerals such as calcite and iron oxides.

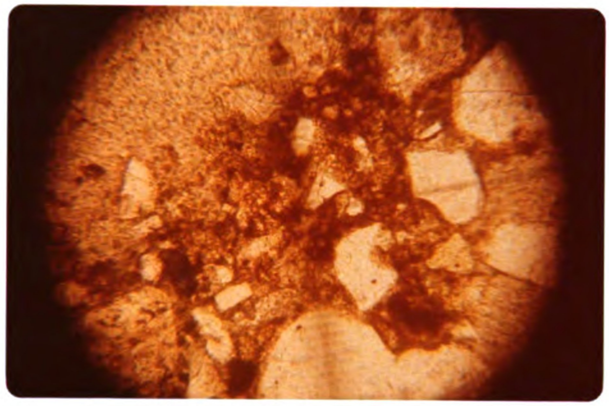
A systematic analysis of all the profiles, sample by sample, was not possible since the sections cut and mounted through a lengthy procedure could not be prepared on time for all the samples. However, some very meaningful observations have been performed on the sections available. They are summarized as follows:

The presence of *calcite* and/or dolomite crystals has been identified by the observation of highly birefringent bodies. This feature was well expressed in the C horizons of all the soils, but not very common in the B or the A horizon of the #3, #3a and #5 soils. On the other side, the observation of a thin section from the Ap of the #18 soils exhibits the presence of these highly birefringent bodies.

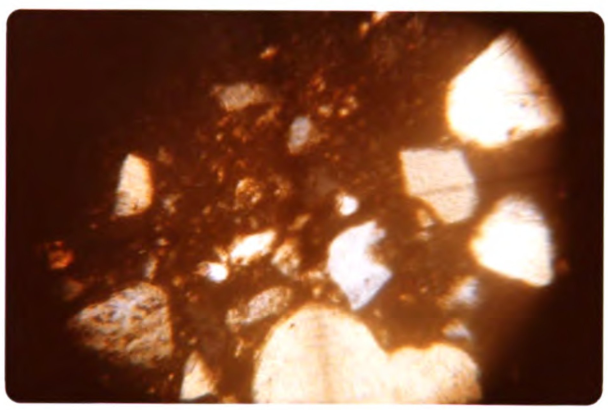
a) Argillans

The few slides that were observed show that argillans have not been formed extensively in most of the horizons except in the $B_{21}t$ and $B_{22}t$ of the #3a soils (Figures 1 and 2). In those horizons the argillans in reflected light show a smooth glazed surface or a ropy appearance with a waxy luster as described in Brewer (1964). Under high magnification the coatings show well expressed lamellae usually of golden color; upon rotation they show the classical extinction of oriented clays.

While the coatings were most easily observed on the $B_{22}t$ of the #3a soil of Site #3, the morphology is more uneven and less continuous for the $B_{22}t$ of the #3a? soil of Site #5 (Figures 3 and 4). There the more massive appearance suggests that adequate clay movement has taken place but that the development of clay skin orientation was not carried out to the extent observed for the other soil #3a. Possibly also some of the destructions cited by Nettleton *et al.* (1969) may have taken place in this #3a profile.

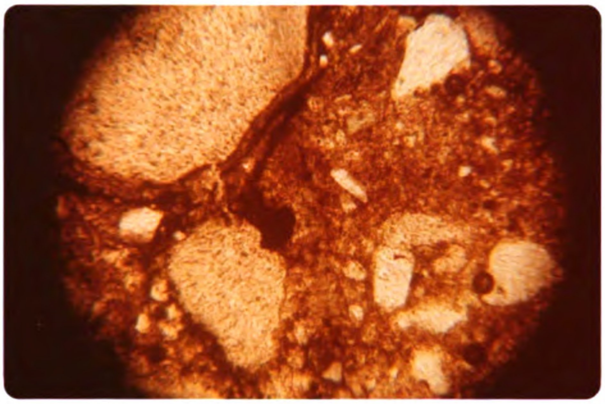


A

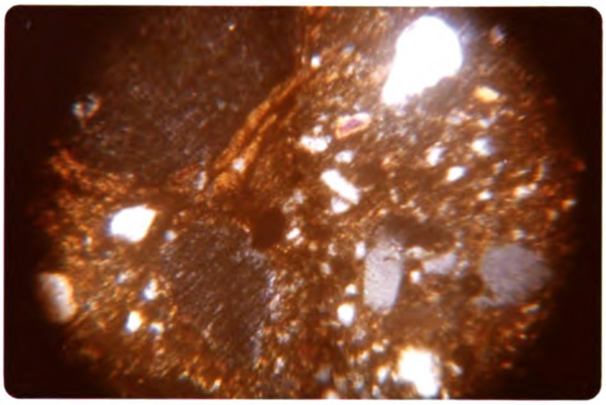


B

Figure 1. Thin section of sample from B_{21} horizon, Soil #3, Site #7: under plain light (A), under crossed nicols (B).

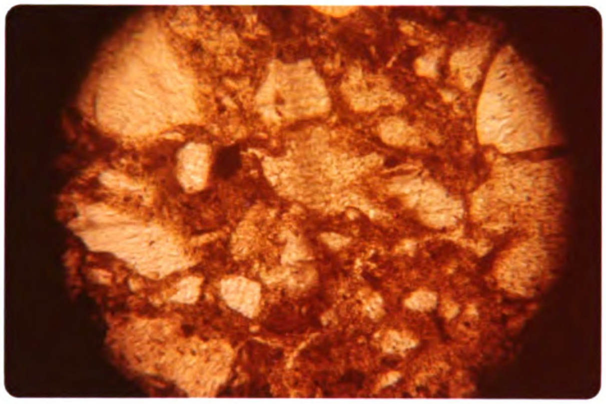


A

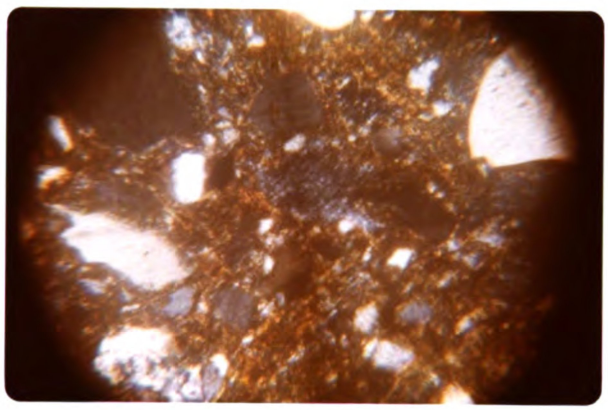


B

Figure 2. Thin section of sample from $B_{22}t$ horizon, Soil #3a, Site #3: under plain light (A), under crossed nicols (B).

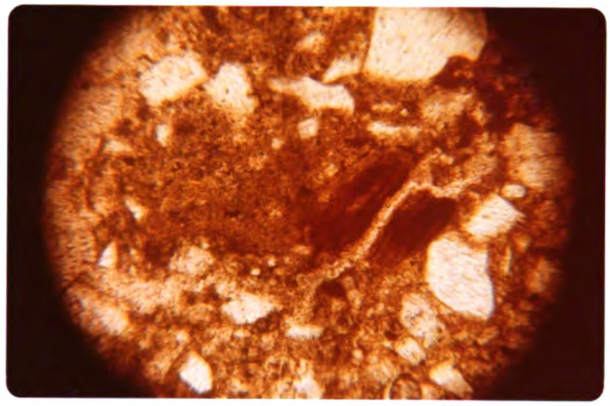


A

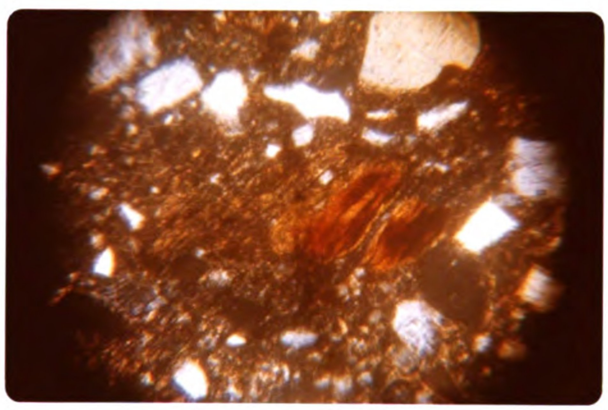


B

Figure 3. Thin section of sample from B_{21} horizon, Soil #3a?, Site #5: under plain light (A), under crossed nicols (B).



A



B

Figure 4. Thin section of sample from $B_{22}t$ horizon, Soil #3a?, Site #5: under plain light (A), under crossed nicols (B).

VII. CONCLUSIONS

Field observation along with data from laboratory analyses have provided evidence that profile development has occurred to some extent in all the soils that were studied. The evidences of this development are: some additions and migration of organic matter, structuration, the redistribution of carbonates, the existence of a gley horizon, or the development of an argillic horizon.

Organic addition and development of the structure appear to be the first processes that have taken place since they are observed in all the four soils studied, including the #18, which lacks most of the other features and which is considered to be the least developed of the soils.

Carbonate redistribution has taken place only to a small extent in the #18 soil and to a larger extent in the #3 and #3a soils. The #5 soil shows a maximum degree of leaching.

The observation of clay coatings in the field, the existence of a finer texture in the B_2 horizon as revealed by the mechanical analyses, and the evidence of optically oriented clay in the observation of the thin sections confirm that the #3a soil has experienced extensive enrichment of the B_2 horizon in clay material through the process of illuviation. This concentration of clay in the B relative to the A or C horizon is even more evident in the <0.2 μ clay fraction. For these soils, the presence of argillans is observed by continuous clay coatings exhibiting well expressed patterns of extinction.

This feature, although present in some soils originally classified and mapped as #3 soils, which were observed to have a finer textured B horizon, is not so well expressed as in the #3a soil; but the presence of some oriented clay added to the increase of clay percentage in the B horizon is a sufficient index to recognize the presence of an argillic horizon in these #3a? soils.

Thus, in many mapping units labeled #3 soils, illuviation of clay has taken place to an extent that qualifies the B horizon for being an argillic horizon. Accordingly, it is suggested that the systematic key designed at the beginning of the survey be revised. The soils classified and mapped #3 soils should rather be recognized as a complex of Aeric Haplaquepts and Aeric Ochraqualfs.

VIII. NEEDS FOR MORE RESEARCH WORK

An analysis of the survey has revealed that a large proportion of the area recently mapped is occupied by the #3 soils.

Also, transect observations have shown that in the locality of Sand Beach Twp., the #3 soil is made of 64% Aeric Haplaquepts and 36% Aeric Ochraqualfs. The "index of purity of the #3 soils" is unknown for Dwight Twp. and Winsor Twp.

Consequently, it is believed that more transect observations should be carried out to determine the extent to which soils with an argillic horizon exist in the mapping unit at those localities.

Also, since the presence of argillic horizons may have important significance in soil chemistry and soil fertility as far as availability of nutrients is concerned, it would be interesting to find out whether some of the fixation or mechanical blocking mentioned by Soileau (1964) and Khalifa (1969) are taking place actively in the Alfisols developed from the high lime, loam, till of Michigan.

In addition, a more elaborate series of observations on the thin sections will allow us to follow the progression of the genesis of the argillic horizon in these soils. Those studies could be supplemented by some clay analysis that could indicate the extent to which some of the clay mineral present has been formed *in situ*.

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