CHARACTERIZATION, GENESIS, AND MANAGEMENT OF SOILS WITH CALCIUM CARBONATE-RICH HORIZONS IN EAST-CENTRAL MICHIGAN

By

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ABSTRACT

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Soils with carbonate-rich horizons were identified in Tuscola County. Through field studies and laboratory analyses, the distribution of these soils in Tuscola, Bay, Saginaw, and Huron counties was determined. The formation of the carbonate-rich horizons was investigated and related management probelms were identified.

The carbonate-rich horizons are only found in Tuscola county. In these horizons three terrestrial and thirteen aquatic species of molluscs and one plant specie were identfied. The presence of shells and the glacial history of the area suggest the calcium carbonate rich horizons are geologic in origin. A limnic subgroup is proposed to classify mineral soils with marl layers. Based on transect observations, Tappan soils occupy 70% of the Lenawee variant-Tappan complex mapping units. Therefore, it is suggested this mapping unit be named Tappan-Lewanee variant complex. Tappan soils had very high levels of available phosphorus and relatively higher levels of extractable zinc and manganese than Thomas and Lenawee variant soils.

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CHAPTER I

INTRODUCTION

Calcic horizons usually occur at some depth in soils in the arid and semiarid regions of the world. The finding of soils with calcic horizons in the upper 50 cm of humid Saginaw Valley soils which receive an average of 762 mm/yr (30 inches) of precipitation was unexpected.

Calcic horizons had not been identified in Michigan until the Tuscola County soil survey team began investigating some mapping units as to the variability of crop yields in the northwestern part of the country. Four pedons were described and sampled in the mapping units. Two were classified as Calciaquolls and two as Haplaquolls (Mausbach, 1982). These soils are found in association with Haplaquolls on nearly level terrain or in slight depressions on the glacial lake plain of Saginaw Bay.

The dominant crops grown in these soils were corn, sugar beets, and dry beans. However, their growth is stunted and yields are low. Plant chlorosis, phosphorus and micronutrient deficiencies are common. With good management, higher yields have been produced. There are several accepted theories on the formation of calcic horizons in arid and semiarid areas; however, in humid regions, there are only a few theories.

This study was undertaken to determine the distribution of soils with carbonate-rich horizons, to characterize pedons of Calciaquolls and Haplaquolls, to investigate the formation of the carbonate-rich horizons and to identify the management problems.

CHAPTER II

LITERATURE REVIEW

Calcic Horizons and Carbonate Morphology

The accumulation of secondary calcium carbonate or of calcium and magnesium carbonate in a soil profile is defined as Calcic horizons, if they meet specific carbonate content criteria (Soil Survey Staff, 1975). Calcic horizons are found in humid, semi-arid, and arid regions of the world. Although soils with calcic horizons are common in many areas of the world, they are characteristic of arid and semiarid regions. The term caliche, croute calcaire for the hardened caliche, and calcisols are alternating terms in old literature for calcic horizon.

Soil Survey Staff (1975) points out that calcic horizons have two forms:

> In one the underlying materials have less carbonate than the calcic horizon. Ths form of calcic horizon includes horizons of secondary carbonate enrichment that are 15 cm (6 inches) or more thick, have a carbonate content equivalent to $\geq$ 15 percent $CaCo_3$, and have a Ca CO_3 equivalent at least $\overline{5}$ percent greater than C horizon. In the other form, the calcic horizon is 15 cm or more thick, has a $CaCO_3$ equivalent $\geq$ 15 percent and contains $\geq$ 5 percent, by volume, of identifiable secondary carbonates as pendants on pebbles, concretions, or soft powdery forms. If this calcic horizon rests on limestone, marl, or other very highly calcareous materials ($\geq$ 40 percent $CaCo_3$ equivalent), the percentage of carbonates need not decrease with depth.

The 15 percent requirement for $CaCO_3$ is waived if the textural class is sandy, sandy-skeletal, coarse-loamy, or loamy-skeletal with less than 18% clay. However, to be considered as a calcic horizon, the horizon must have at least 5% (by volume) more soft powdery secondary calcium carbonate than an underlying horizon, and the calcic horizon must be at least 15 cm thick.

Calcic horizons range widely in carbonate content, bulk density, consistency, texture, and manner of carbonate occurrence. Some calcic horizons are soft, others are extremely hard, and some are indurated (Gile, 1961). Roots and fluids penetrate some Ca horizons rather easily, but not other calcic horzons. Calcic horizons become hard and strongly indurated with maturity (Price, 1933). Calcium and aluminum silicates were more abundant near the upper surface, making up as much as 10 to 15% of the total, and the silicates were thought to be responsible for the hardness (Shreve and Mallory, 1933).

In New Mexico soils Gile (1961) illustrated two basic occurrences of carbonate: (1) carbonate distributed throughout a horizon, which probably encompasses the "finely disseminated" carbonate noted by Harper (1957) in other western U.S. soils; and (2) carbonate segregated within a horizon, which consists of concentrations of carbonate separated by the soil matrix. Indurated and nonindurated nodules and concretions fall in the segregated category, and have been described by many workers (Gile, 1961; Gile et al., 1966; Sehgal and Strops, 1972; Soil Survey Staff, 1975). Joffe (1949) stated that the more compact, hardened concretions in Chernozems (Mollisols) formed in worm and spider channels. Cylindrical nodules in old cicada burrows in New Mexico were noted by Gile et al. (1966). Micromorphologically, the above carbonate forms would be included in Brewer's (1976) glaebules;

glaebules commonly include part of the soil matrix, indicating an in situ origin (Soil Survey Staff, 1951; Brewer, 1976). If acid-insoluble residues of carbonate nodules approximate the same sand and silt contents as the carbonate-free soil matrix, then such assays provide further evidence of the in situ, pedogenic origin carbonates.

Other segregated carbonate forms include: (1) threads, webs, or filaments that result from carbonate deposition along soil pores; and (2) channels, seams, viens, and ped coatings of carbonate (Gillam, 1937; Joffe, 1949; Soil Survey Staff, 1951; Harper, 1957; Gile, 1961; Peterson et al., 1966). The micromorphological equivalents are Brewer's calcans and crystallaria (Brewer, 1976).

Mircomorphological analysis of carbonate morphology can be particularly useful in evaluating the conditions of carbonate precipitation. Folk (1974) indicates that fine-grained micrite is characteristic of rapid precipitation, as by dessication, while in more dilute conditions such as beneath a water table, coarse-grained (>4μm) carbonate is formed, often via recrystallization from finer-grained precursor carbonate. Sehgal and Stoops (1972) noted a distinct correlation between soils influenced by shallow fluctuating water tables, and the presence of compound carbonate-sesquioxidic nodules and associated neoferrans (segregated iron). Thus, carbonate morphology can be a particularly useful tool in evaluating the genesis of the soils in the absence of biogenic carbonate forms, such as coral or mollusk shells, and the lack of fossils of organisms.

Several studies indicate that carbonates of clay and silt size are more common in horizons of secondary accumulation (Harper, 1957;

Redmond and McClelland, 1959; Rostad and St. Arnaud, 1970; Wilding et al., 1971). Carbonate particle size depth functions are useful indicators of secondary carbonate precipitation.

A number of workers have shown that calcic horizons exhibit varying degrees of expression or stages of development (Redmond and McClelland, 1959; Gile, 1961; Arkley, 1963; Rostad and St. Arnaud, 1970; Birkeland, 1974; Soil Survey Staff, 1975). Gile (1961), in a study in New Mexico, classified Ca horizons from weak to very strong on the basis of unconfined compressive strength, carbonate content, bulk density, and infiltration rate. Bulk density and unconfined compressive strength increased with carbonate content, while infiltration rate decreased.

Gile et al. (1961) depicted two "morphogentic" sequences for these same soils, one for gravelly soils and one for nongravelly soils. The sequences ranged from minimal development on the youngest geomorphic surface (stage I) to petrocalcic horizons on the oldest surfaces (stage IV). The latter stages were termed K horizons, a term proposed by Gile et al. (1965) for carbonate enriched horizons, in which fine grained secondary carbonates separate primary skeletal grains. A similar phenomena was noted by Gouide (1972) in calcrete (caliche) deposits.

Harper (1957) rated soils with carbonate accumulations as minimal, medial, or maximal. In South Texas, along bottoms and terraces of the Rio Grande River, Hawker (1927) described five stages of carbonate accumulation in soils. The degree or amount of accumulation increased as land surfaces became older, culminating in indurating caliche (petrocalcic horizons). In the three development stages proposed by Sehgal and Stoops (1972), indurated nodules and fine-grained carbonate were characteristic of the most advanced stage of development, as was the development of a K-fabric. In general, it appears that extensive carbonate impregnation of the soil matrix and more numerous carbonate nodules are typical of advanced stages of carbonate accumulation.

The System $CaCO_3$ - CO_2 - H_2O (Soil Carbonates)

The chemical system of $CaCO_3$, CO_2, and H_2O has been studied extensively. The chemical reaction for this system is given by Miller (1952), Birkeland (1974), and Bohn et al. (1979) as follows:

$$Ca^{2+} + CO_2 + H_2O = CaCO_3 + 2H^+ \quad (1)$$

Calcium and magnesium carbonates may be used interchangeably in these equations.

Alkaline conditions favor $CaCO_3$ by consuming H^+ and driving the reaction to the right. A decrease in partial pressure of CO_2 results in carbonate precipitation while an increase favors carbonate dissolutions.

$$CaCO_3 + CO_2 + H_2O = Ca^{2+} + 2HCO_3^- \quad (2)$$

Biological oxidation of organic matter leads to an increase in CO_2 partial pressure of the soil air, which promotes carbonate dissolution in upper soil horizons (Birkeland, 1974). The solubility of $CaCO_3$ depends on temperature and CO_2 pressure in equilibrium with water. At constant temperature and increasing CO_2 pressure, the solubility of $CaCO_3$ increases; whereas with constant CO_2 pressure and increasing temperatures the solubility of $CaCO_3$ is low. For example, it has been observed that at a temperature of approximately 300°C, calcite is less soluble in pure water than is quartz (Miller, 1952). Increase in temperature results in decreased carbonate dissolution because the solubility of CO_2 in water decreases with increasing temperature. In soils, the relatively high Ca^{2+} concentrations and limited water contents tend to force reaction (1) to completion and to repress reaction (2). At a lower pH $CaCO_3$ dissolves by reversing equation (1).

Evaporation has little or no effect on the precipitation of $CaCO_3$. Van Hook (1937) concluded that the rate of evaporation, even in an atmosphere of zero relative humidity, was not rapid enough to have significant effect on precipitation.

The System $MgCO_3$ - CO_2 - H_2O

The solubility of magnesium carbonate in water is related to CO_2 pressure is qualitatively similar to calcium carbonate. At constant temperature, the solubility of $MgCO_3$ increases with an increase in CO_2 pressure, and at constant CO_2 Pressure the solubility decreases with increasing temperature (Faust, 1949).

The Relationship of Ca + Mg in Solution

It has already been stated that the solubility of calcium and magnesium carbonate is qualitatively related. They are not, however, equally soluble in a given water solution. For example, at CO_2 pressure of one atmosphere and a temperature of 19.5°C $MgCO_3 \cdot H_2O$ is soluble to the extent of 42.3 grams per liter, while only 1.08 grams of calcium carbonate per liter are soluble at a CO_2 pressure of one atmosphere and a temperature of 18°C (Faust, 1949).

The data show that a magnesium-rich solution may be derived from a solution of calcium and magnesium in equilibrium with CO_2. Data from Faust (1949) clearly showed the process. Natural waters, rich in calcium and magnesium first showed a decrease in calcium content because of the lower solubility of $CaCO_3$, compared to $MgCO_3$ (Faust, 1949; Freeze et al., 1979).

Many natural waters are supersaturated with respect to $CaCO_3$ (as calcite). This apparent high solubility of $CaCO_3$ is greater than that predicted by equilibria equations, even taking into account dissolved CO_2 levels (Krauskopf, 1967). This phenomena has also been noted with soil carbonates. Olsen and Watanabe (1959) found that solutions equilibrated with calcareous soils had a greater solubility for the soil carbonates than solutions in equilibrium with pure calcite. They postulated that an unstable phrase of $CaCO_3$ that is more soluble than calcite was present controlling solution equilibrium; Mg-substituted calcite was suggested as one possible unstable phase. Suarez (1977), in an investigation of ion activity products of Ca^{++} and CO_3^{--} in water under irrigated soils known to contain calcite, also found a greater solubility of soil carbonate than would be expected were calcite or even aragonite the controlling phase; in fact, the waters were in equilibrium with known crystalline form of $CaCO_3$. They discounted Mg-substitution in calcite as a factor, however, and of one atmosphere and a temperature of 19.5°C $MgCO_3 \cdot H_2O$ is soluble to the extent of 42.3 grams per liter, while only 1.08 grams of calcium carbonate per liter are soluble at a CO_2 pressure of one atmosphere and a temperature of 18°C (Faust, 1949).

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Carbon-dioxide in Natural Waters

There are several processes which tend either to enrich or deplete the amount of carbon dioxide in natural waters. The atmosphere contains carbon dioxide to the extent of 0.03 percent by volume or approximatley 300 ppm. Falling rain entrains and adsorbs this carbon dioxide in excess in the normal atmospheric concentration. Dissolved air may contain as much as 2.14 percent or 21,400 ppm CO_2 at 20°C (Clarke, 1924). Miller (1952) stated that ground water in the vadose zone may attain a high CO_2 content due to soil bacterial actions. The soil air frequently has a CO_2 pressure more than 100 times that of the atmosphere, due primarily to the root respiration and microbical decay of organic matter (Bohn et al., 1979).

The several phenomena which tend to deplete the CO_2 content of natural waters are photosynthesis, agitation of the water, and increasing temperature (Miller, 1952). The role of photosynthesis is an important aspect to be considered in the precipitation of calcium carbonate.

Miller (1952) estimated that rain water in equilibrium with the atmosphere could dissolve 0.044 grams of calcium carbonate per liter at 25°C. This would mean that each inch of rain which fell on a limestone area could dissolve 3.1 tons of $CaCO_3$ per square mile.

Water at 0°C and in equilibrium with the atmosphere could dissolve 0.081 grams of $CaCO_3$ per liter, or nearly twice as much as rain water at 25°C.

Ground water is more complex chemically than rain water because of the presence of materials such as organic acids dissolved from soils during percolation. Most ground water contains less than 200ppm of calcium carbonate, though in some cases, it may contain as much as 400ppm. A CO_2 pressure 300 times greater than that prevailing in the atmosphere would be necessary to maintain this concentration of calcium carbonate in solution (Miller, 1952).

Marl Formation

Limestone and marl are formed by precipitation of calcium carbonate or of calcium and magnesium carbonate just as are calcic horizons (Soil Survey Staff, 1975).

Bergquist et al. (1932) defined marl as a loosely consolidated earthy material composed largely of calcium carbonate. It is essentially a form of limestone which has undergone partial consolidation, but it varies considerably in composition from one deposit to another and often within different portions of the same bed. Deposits of marl are widely scattered in the region of the Great Lakes, extending through Canada and southward into the states of Michigan, Wisconsin, and Minnesota and also the northern parts of Indiana, Illinois, and Ohio.

Some of the early work was done by Bergquist (1932) in Michigan. He has observed and described the formation of marl primarily by chemical precipitation and accumulation by plants and animals. As the lime-charged waters flow naturally into the basins or depressions, some of the carbon dioxide is liberated and insoluble calcium carbonate is precipitated and deposited on the floors of swamps, lakes, and stream channels as marl. In some areas precipitation is generally assumed to result from the utilization of carbon-dioxide in photosynthesis. The chemical precipitation of calcium carbonate from the waters of swamps, lakes, and streams has been greatly aided by the growth and activity of certain types of plants and animals. Similarly, many of the lower forms of animal life inhabiting lime-impregnated waters accumulate lime which, in turn, deposited on the floor of the lake or swamp when they die (Bergquist et al., 1932). This is evidenced by the numerous fragments and shells of molluscs and other shell-forming animals found in many of the marl deposits. The wide distribution of these animal and plant remains in marl beds of Michigan indicate that organic agencies have been active in their formation.

Formation of Calcic Horizon

Calcium carbonates in soil may be either geologic or pedogenic (Birkeland, 1974). Differentiation between these origins within a soil is not easy and was not studied in detail. Determination of the solubility of calcium carbonate in the laboratory or in the field (Olsen and Watanabe, 1959; Plummer and Wigley, 1976; Suarez, 1977) did not differentiate between the detrital and pedogenic carbonates, although it may be expected that they react differently in soil processes. For instance, the rate of dissolution is known to be chemical precipitation and accumulation by plants and animals. As the lime-charged waters flow naturally into the basins or depressions, some of the carbon dioxide is liberated and insoluble calcium carbonate is precipitated and deposited on the floors of swamps, lakes, and stream channels as marl. In some areas precipitation is generally assumed to result from the utilization of carbon-dioxide in photosynthesis. The chemical precipitation of calcium carbonate from the waters of swamps, lakes, and streams has been greatly aided by the growth and activity of certain types of plants and animals. Similarly, many of the lower forms of animal life inhabiting lime-impregnated waters accumulate lime which, in turn, deposited on the floor of the lake or swamp when they die (Bergquist et al., 1932). This is evidenced by the numerous fragments and shells of molluscs and other shell-forming animals found in many of the marl deposits. The wide distribution of these animal and plant remains in marl beds of Michigan indicate that organic agencies have been active in their formation.

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Several processes have been proposed to explain the formation of calcic horizons, but they all have one factor in common: water. One of the most important driving forces in soil development is water movement (Barshad, 1964). Water has a particularly strong impact on carbonate translocation because of the relatively soluble nature of $CaCO_3$. The genetic mechanisms of calcic horizon formation involve moisture movement, coupled with carbonate solution, translocation, and reprecipitation.

One of the most commonly reported mechanisms for carbonate enrichment is dissolution and leaching from the upper solum and subsequent precipitation in lower horizons. The carbonates may have been inherited from the parent material (Sehgal and Stoops, 1972) or represent external additions, such as calcareous dust fall (Gile et al., 1966) or result from synthesis from weathering products of Ca-bearing minerals (Marbut, 1951; Harper, 1957; Birkeland, 1974). Increased leaching potential and partial pressure of CO_2 from biological activity in the upper solum promotes carbonate dissolution (Arkley, 1963). The by-products of carbonate dissolution move with the wetting front and subsequently precipiate in the subsoil due to: decreased CO_2 partial pressure, increased pH, and/or decreased water content as the front infiltrates drier soil or moisture is depleted via evapotranspiration (Harper, 1957; Arkely, 1963; Birkeland, 1974). Calcic horizons are often reported to occur at the depth of effective moisture penetration (Joffe, 1949; Marbut, 1951; Harper, 1957; Arkley, 1963).

Another mechanism, proposed by Rostad and St. Arnaud (1970), is a dynamic alternating system of carbonate leaching during wet winter months and reprecipitation of carbonates in the leached zone during drier summer periods. This mechanism explains their observed higher calcite/dolomite ratios in zones of secondary carbonates: both dolomite and calcite are initially leached, while only calcite is reprecipitated in summer months. Such a relationship should be expected to hold only if the soils contained primary dolomite and no secondary forms.

Deposition by capillary rise from shallow ground water has been proposed to account for calcic horizons in some soils (Joffe, 1949; Birkeland, 1974). Harper (1957) used the term "ground water calcisols" for soils developed under impeded drainage conditions that contain calcic horizons due to the above mechanism. He also noted that these soils might contain several calcic horizons, separated by earthy material comparatively low in carbonate. Glinka (1963) noted that "continuous layers of powdery carbonate" in Solonchalks are typical in cases of shallow water tables. As height of capillary rise is generally less than two meters, their mechanism will usually be found in more poorly drained soils (Gillam, 1937; Jenny, 1941; Hillel, 1971).

Lateral distribution of carbonates within a landscape has been postulated to explain carbonate enrichment of soils; this is a secondary concentration mechanism which has been invoked on a large and small scale by a number of workers. Such a redistribution process was termed "capillary concentration" by Muller (1960) who used it to explain the development of Chilean nitrate deposits. In essence, Hsu and Siegenthaller (1969) studied the same mechanism, calling it "evaporative pumping," and used it to explain recent supratidal dolomitization, as have other workers (Zenger, 1972). Redmond and McClelland (1959) suggested a similar mechanism on a more local scale to explain the genesis of calcium carbonate Solonchalks around ponded depressions in North Dakota.

Despite the various names given to the process, it is merely a consequence of basic soil water flow principles, based on water movement from an area of higher potential to one of the lower potential. This mechanism makes use of a concept cited by Jenny (1941) of "locally humid" and "locally arid" soils within a landscape; it involves the generation of greater hydraulic heads in depressions relative to surrounding soils because of greater moisture input and ponding. As a consequence of a potential gradient, soil water will tend to move out to the surrounding soils with the lower hydraulic head, transferring carbonates dissolved from the depressions to the soils surrounding the depressions; upon water withdrawal via evapotranspiration dissolved carbonates would precipitate. This mechanism would be favored in areas of low runoff and reduced deep precolation such as found in the poorly-drained soils of the Saginaw Valley.

The presence or absence of calcic horizons in an area is related to the climate of the region. Jenny and Leonard (1934) were able to establish a positive correlation between rainfall and depth of carbonates, which was related to climatic great soil groups. Arkley (1963) improved on this correlation for soils in California and Nevada by taking the moisture holding capacity of the soil into account. He also calculated water movement in several soils from climatic data and correlated this data with observed carbonate depth functions. Sehgal and Stoops (1972) observed that an increase in rainfall was positively correlated with depth to carbonates in some Indian soils. In the humid parts of the eastern United States carbonate rocks and calcareous variants of alluvium and glacial drift are leached (Brkeland, 1974); it is anomalous to find carbonate enriched soils in areas of high rainfall, indicating that some factor or combination of soil forming factors are acting to retard carbonate loss. Theoretically, any variation in soil forming factors other than climate might disrupt positive rainfall/depth to carbonate correlation (Jenny, 1941). Specifically, upward soil moisture movement, decreased soil permeability, topography, and pore-size discontinuities within the profile are some of the other variables that can retard carbonate leaching.

CHAPTER III

CHARACTERIZATION AND GENESIS OF SOILS WITH CARBONATE RICH HORIZONS IN EAST CENTRAL MICHIGAN

Introduction

One of the soil series mapped by the Tuscola soil survey team in Tuscola County, Michigan, was classified as Typic Calciaquolls (Mausbach, 1982). Secondary carbonate rich horizons below a plow layer were not expected in the humid Saginaw Valley, which receives an average of 762 mm/yr (30") of precipitation. These soils were found in association with Haplaquolls on nearly level terrain or in slight depressions on the glacial lake plain of Saginaw Bay.

Free secondary carbonates usually occur at some position in soils of arid, semiarid, and subhumid regions of the world (Foth, 1984). Arkley (1963) ascribed this occurrence to precipitation insufficient to leach carbonates from the sola. Carbonates are frequently leached from the soils of humid region soils with calcareous parent materials (Birkeland, 1974). Though it is anomalous to find carbonate enrichment near surface horizons in areas of high rainfall, the presence of this horizon is prevalent in some soils with poor or restricted drainage (Harper, 1975; Glinka, 1963; Sehgal and Stoops, 1972; Sobecki and Wilding, 1983). Although Jenny and Leonard (1934) established positive correlations between rainfall and depth of carbonates, this correlation might theoretically be disrupted by some variations in soil forming factors other than climate such as upward soil water movement, topography, reduced soil permeability and poor size discontinuities within the profile (Jenny, 1941).

The objectives of this study were to characterize pedons from the Calciaquoll and Haplaquoll mapping units and to investigate the genesis of the carbonate-rich horizons.

Materials and Methods

Study Area

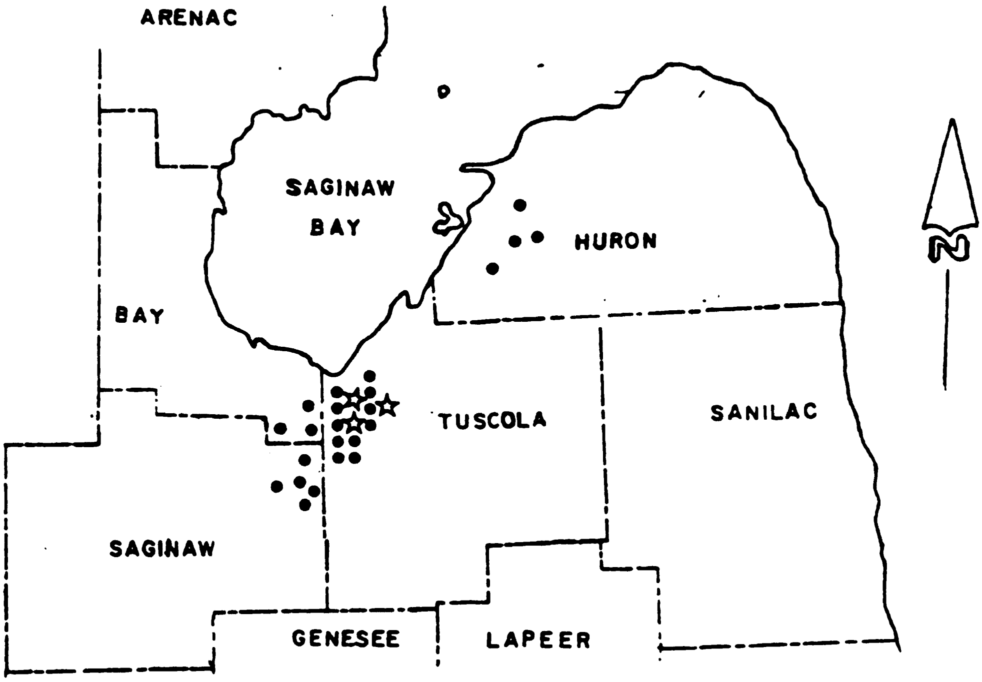
The study was conducted in four counties in east central Michigan (Fig. 1). Sites selected for study were based on soil surveys of Tuscola, Saginaw, Bay, and Huron Counties. Old soil surveys had mapping units of burned muck over clay or marl which were used as a guide for locating transects in Tuscola, Bay, and Saginaw Counties.

The study area is located on the nearly level glacial lake plain of Saginaw Bay at 595 ft. a.s.l. (181 meters). This portion of the glacial lake plain is comprised primarily of somewhat poorly drained and poorly drained soils of loam textures. The materials were laid down by ice and water during the Wisconsin stage of glaciation and were subsequently smoothed over by the waves of glacial lakes.

The area is characterized by long winters, relatively short summers, and fairly low evaporation. The rainfall is generally well distributed throughout the year. Average annual precipitation is approximately 762 mm/yr (30").

Figure 1.--Location of the study area.

Legnd:	4	Covert sand, 0 - 6% slops
	6	Tappan--Wixom complex, 0 - 3% slopes
	8	Tappan--Londo loams, 0 - 2% slopes
	10	Pipestone fine sand, 0 - 4% slopes
	12	Corunna sandy loam
	14	Avoca loamy sand, 0 - 3% slopes
	18	Essexville loamy fine sand
	25	Londo loam, 0 - 3% slopes
	36	Tappan loam
	53	Sloan loam
	55	Cohoctah sandy loam
	58	Thomas muck
	63	Bach very fine sandy loam
	64	Lenawee variant--Tappan complex
	67	Pipestone loamy find sand, loam, loamy substratum, 0 - 4% slopes
	78	Olentangy mucky silt loam



Location of transects

Location of pedons sampled

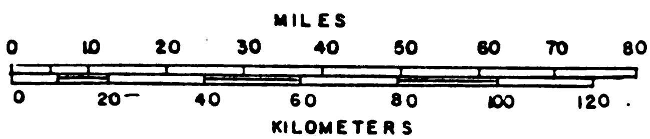


Fig. I. Location of the study area.

Soils

Five pedons were selected and sampled (Fig. 2). They are described in detail in Appendix A. Pedon 1 was located in a Thomas muck mapping unit; Pedons 2 and 4 were located in the Lenawee variant-Tappan complex and Pedons 3 and 5 were in the Tappan loam mapping units. The soil series classifications are as follows:

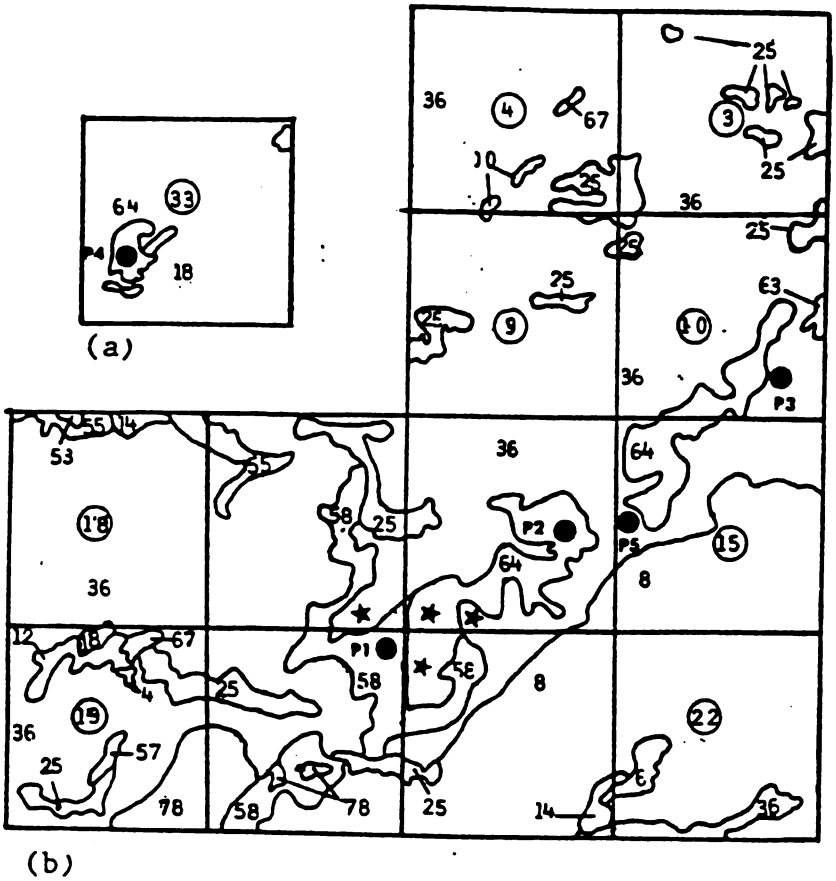
Lenawee variant	Fine-silty, mixed, mesic, Typic Calciaquolls.
Tappan	Fine-loamy, mixed (calcareous), mesic, Typic Haplaquolls.
Thomas	Fine-loamy, mixed (calcareous), mesic, Histic Humaquepts.

Field Methodology

The pedons were described according to the soil survey manual (Soil Survey Staff, 1951). The composition of these mapping units were determined using point-intercept transect method (Mokma, 1972). Transects were located on the basis of being repressentative of a larger area. The observations were made at 75-meter intervals.

Bulk samples were collected from each horizon of each pedon for physical and chemical analysis. The bulk samples were air dried and crushed to pass a 2-mm sieve. In addition, five undisturbed cores were collected from each horizon of each pedon for bulk density and hydraulic conductivity measurements.

For identification of shells present in the carbonate-rich horizons, approximately 15 cm (6") cubes of soil were collected from carbonate-rich horizons of Thomas muck and Lenawee variant in sections 20 and 21, Gilford Township, respectively. The samples were sieved



● Location of pedons sampled.

✱ Pedons described by Tuscola soil survey

(33) Section number

Fig. 2. Soil map of the study area: (1) North Akron and (b) Gildord Townships.

using 2 and 0.5 mm sieves. Shells larger than 2 mm and 0.5-2.0 mm were identified by Professor Barry B. Miller, Department of Geology, Kent State University.

Laboratory Analysis

Particle size distribution was determined by the pipette method (Soil Survey Staff, 1972). Calcium carbonate was removed from most samples with 1 N sodium acetate pH 5 and for highly calcareous samples with 1 N HCl (Jackson, 1956). Organic matter was removed by oxidation with 30% hydrogen peroxide (H_2O_2). Free iron oxides were removed by dithonite-citrate-bicarbonate (Jackson, 1956).

Inorganic carbon content was determined using the titrimetric method (Bundy and Bremner, 1972). Organic carbon was determined using the heat of dilution method (NCR-13 Staff, 1980).

Results and Discussion

Particle Size Distribution

All five pedons have a fine-loamy particle size class (Table 1). Clay contents of individual horizons vary from 12 to 42 percent. In all pedons medium and fine sand predominate in the sand fraction and fine silt in the silt fraction.

Thomas, Lenawee variant-1 and Tappan-1 pedons have developed in two parent materials: lacustrine silt loam and/or silty clay loam over loam glacial till (Table 1). Thomas and Lenawee variant-1 pedons have carbonate-rich horizons below the plow layers.

TABLE 1.--Particle-Size distribution, organic carbon and inorganic carbon contents (%)

Horizon	Depth cm	Total			Sand					Silt		Organic Carbon	CaCO3 Equivalent
		Sand 2-0.5	Silt 0.5-0.002	Clay >0.002	VCS 2-1	VCS 2-1	CS 1-0.5	FS 0.25-0.1	VFS 0.1-0.05	C. Silt 0.05-0.02	F. Silt 0.02-002		
		mm										%	%
						Thomas (Pedon 1)							
Oap	0- 30	24	53	23	0	2	9	10	3	13	40	40.0	10
C	30- 41	37	51	12	0	3	13	16	5	9	42	2.1	70
2Cg1	41- 59	32	31	37	0	2	11	14	5	9	22	0.8	29
3Cg2	59-120	18	60	22	1	1	5	7	4	19	41	0.4	31
4Cg3	120-150	40	38	22	2	3	13	16	6	13	25	0.3	33
						Lenawee variant-1 (Pedon 2)							
Ap	0- 25	13	55	32	0	1	5	5	2	18	37	3.6	45
C	25- 43	2	56	42	0	0	0	1	1	9	47	0.9	76
Cg	43- 70	3	64	33	0	0	0	1	2	25	39	0.9	41
2C	70-125	17	48	35	1	1	4	6	5	23	25	0.4	34
3C	125-170	29	46	25	1	2	10	11	5	14	32	0.4	31
						Lenawee variant-2 (Pedon 4)							
Ap	0- 38	59	27	14	1	5	23	23	7	9	18	1.3	28
Bg	38- 50	50	36	14	1	5	20	18	6	6	30	0.5	27
2Cg	50-115	44	36	20	1	3	14	18	8	6	30	0.4	31
2C	115-150	40	38	21	1	3	13	16	8	12	24	0.3	34
						Tappan-1 (Pedon 3)							
Ap	0- 30	20	40	40	0	1	7	9	3	9	31	3.5	1
Bg	30- 50	17	49	34	1	1	5	7	3	13	36	0.4	20
2Cg	50-100	40	38	22	1	4	12	16	7	13	25	0.3	32
2C	100-150	42	37	21	2	4	13	16	7	13	24	0.2	30
						Tappan-2 (Pedon 5)							
Ap	0- 32	44	32	24	1	3	15	18	7	12	20	2.6	1
C1	32- 45	46	31	23	1	3	15	19	8	13	18	0.5	9
C2	45- 64	43	37	20	1	4	13	17	8	16	21	0.4	33
C3	64-150	43	40	17	1	4	13	17	8	14	26	0.3	33

The thickness of the lacustrine material varies from 50 cm in pedon 3 to almost 120 cm in Thomas and Lenawee variant-2 pedons (Table 1). Similar ranges in thickness were found in the transect observations.

The sand fraction in the loam till is greater (40-59%) than in the lacustrine material (2-37%). In the lacustrine material silt contents range from 49 to 60% and clay contents range from 22 to 42%. In the till silt content range from 27 to 46% and the clay contents range from 14 to 25%. The calcium carbonate-rich horizons above the lacustrine material have 51 or 56% silt and widely varying sand and clay contents.

An abrupt increase in total sand content occurs as the parent material changes from lacustrine to glacial till.

Parent Material Homogeneity

Parent material homogeneity was investigated to support the concepts of multiple parent materials in pedons 1, 2, and 3 and uniform parent material in pedons 4 and 5. Asady and Whiteside (1982) used silt to sand ratios to assess homogeneity of materials. The silt/sand ratio of the overlying horizon was divided by the silt/sand ratio of the underlying horizon and one was subtracted from the quotient. Values between ± 0.37 indicate uniform parent material.

The silt/sand ratios calculated from the five pedons are given in Table 2. Based on these calculations Lenawee variant-2 and Tappan-2 pedons did not show any lithologic discontinuities. Lithologic discontinuities were identified between each horizon in the

TABLE 2.--Silt and sand ratios of nonclay fractions

Horizon	Depth	% Sand 2-0.05 mm	% Silt 0.05-0.002 mm	$\frac{Si}{S}$	$\frac{si/s,\ (1)^{*}}{si/s,\ (3)}$	$\frac{si/s,\ (1)}{si/s,\ (2)} -1$
			Thomas (Pedon 1)			
Oap	0- 30	24	53	2.21	1.60	0.60**
C	30- 41	37	51	1.38	1.42	0.42**
2Cg1	41- 59	32	31	0.97	0.29	-0.71**
3Cg2	59-120	18	60	3.33	3.51	2.51**
4Cg3	120-150	40	38	0.95		
			Lenawee variant-1 (Pedon 2)			
Ap	0- 25	13	55	4.23	0.15	-0.85**
C	25- 43	2	56	28.00	1.31	0.31
Cg	43- 70	3	64	21.30	7.55	6.55**
2C1	70-125	17	48	2.82	1.77	0.77**
3C2	125-170	29	46	1.59		
			Lenawee variant-2 (Pedon 4)			
Ap	0- 38	59	27	0.46	0.64	0.36
Bg	38- 50	50	36	0.72	0.88	-0.12
Cg	50-115	44	36	0.82	0.88	-0.12
C	115-150	41	38	0.93		
			Tappan-1 (Pedon 3)			
Ap	0- 30	20	40	2.00	0.69	-0.31
Bg	30- 50	17	49	2.88	3.03	2.03**
2Cg	50-100	40	38	0.95	1.08	0.08
2C	100-150	42	37	0.88		
			Tappan-2 (Pedon 5)			
Ap	0- 32	44	32	0.73	1.09	0.09
C1	32- 45	46	31	0.67	0.78	-0.22
C2	45- 64	43	37	0.86	0.92	-0.08
C3	64-150	43	40	0.93		

*(1) Overlying horizon; (2) Underlying horizon

**Indicates lithologic discontinuity

Thomas pedon. Lenawee variant-1 pedon has lithologic discontinuities between Ap and C, Cg and 2C1, and 2C1 and 3C2. Tappan-1 pedon has a discontinuity between Bg and Cg. These discontinuities occur where an organic layer overlies a carbonate rich layer, a carbonate-rich horizon overlies lacustrine material and where lacustrine material overlies loam till.

Particle Size Distribution of Carbonates

The percentages of the fine earth total carbonates in a given size separate of Thomas and Lenawee variant-1 pedons are shown in Fig. 3. The $CaCO_3$ rich horizons in both pedons have about equal amounts of clay and silt size carbonates. They have about 20% sand size carbonates.

The lacustrine materials have predominantly silt-size carbonates, ranging from 53-79%. The clay and sand size carbonates increases in the glacial loam till, but the silt size predominates.

Previous studies (Harper, 1957; Rostad and St. Arnaud, 1979; Sobecki and Wilding, 1983) suggested secondary carbonates tend to precipitate in the fine silt and clay fractions. Clay-size carbonates were found to be very unstable in a leaching environment (Sobecki and Wilding, 1983). In this study the high content of clay size carbonates near the surface is thought to result from limited downward water movement because of the naturally high water tables present in these soils.

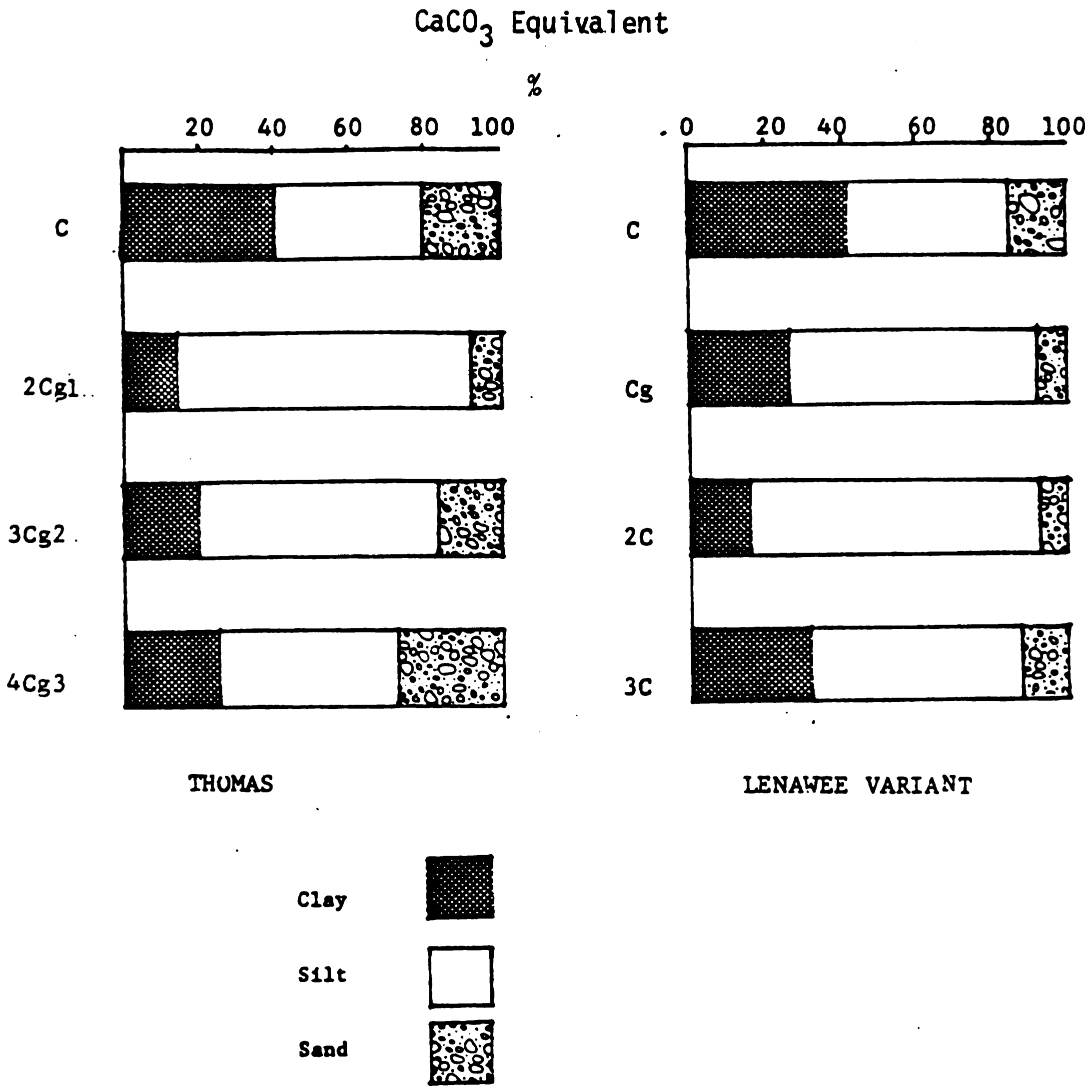


Fig. 3. Particle size distribution of fine earth carbonate.

Organic Carbon

As expected organic carbon contents decrease with depth (Table 1). The contents of organic carbon in the surface horizon range from 40% in Thomas with a histic epipedon to 13% in Lenawee variant-2. An abrupt decrease from the surface horizons (Oap, Ap) to the horizons below and a gradual decrease with depth in subsurface horizons were observed in all the pedons.

Organic carbon is a very dynamic fraction of the soil. It can be built up and destroyed as rapidly through specific soil management practices. A portion of the study area is shown as burned muck over clay or marl in the soil survey of Tuscola, Bay, and Saginaw counties, Michigan (Deeter et al., 1926; Wonser et al., 1931; Moon et al., 1938).

Calcium Carbonate

The calcium carbonate equivalent observed in the soil samples varies widely (Table 1 and Fig. 4). Increasing calcium carbonate equivalents with depth is not observed in all pedons. Thomas and Lenawee variant-1 pedons have the highest calcium carbonate equivalent (70 and 76%, respectively) in the horizon below the surface horizon (Oap or A). In the other pedons the highest calcium carbonate content is found at depth. The mean calcium carbonate equivalent of the till parent material in all pedons is 32% (±2). The range varies from 30% in Tappan-1 to 34% in Lenawee variant-2. The high calcium carbonate content in the Ap horizon in Lenawee variant-1 could be explained by

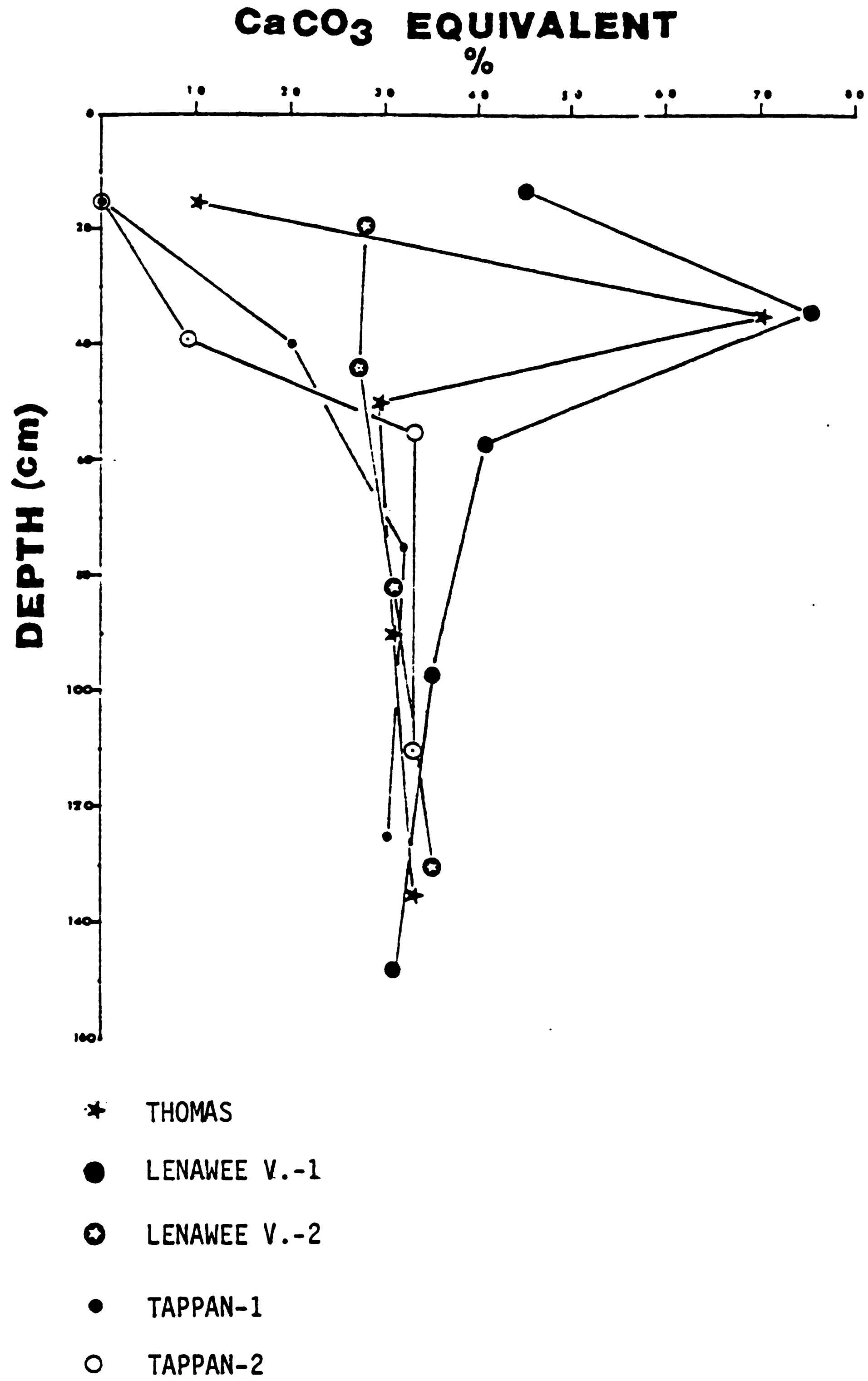


Fig. 4. $CaCO_3$ equivalent of the five pedons.

plowing (38 cm) which might have mixed a calcium carbonate rich layer below the original A into the present Ap.

Based on transect observations carbonate-rich horizons are absent in the Tappan loam mapping unit. The mean calcium carbonate equivalent of the till is 30% (±2) and the lacustrine material is 27% (±5). There is no significant difference between the calcium carbonate content of the two materials.

In the Lenawee variant-Tappan complex mapping unit, 18 of 60 observations had carbonate rich horizons under the surface horizon. The mean calcium carbonate equivalent of these horizons is 55% (±6). The mean calcium carbonate content of the lacustrine materials is 32% (±3) and of the till is 31% (±3). The mean calcium carbonate content of the till and the lacustrine material are not significantly different.

In section 20, T.16N., R.10E. of Winsor Township in Huron County a mapping unit of Bach has high calcium carbonate content, 54% (±7), in the Ap horizons. The calcium carbonate equivalents of subsurface horizons in these soils are 26% (±2). The Tappen loam mapping unit in the same section has low calcium carbonate contents, 13% (±5) in the surface horizons.

Calcium carbonate rich horizons were not observed in the Bay and Saginaw Counties portion of the study area. Lacustrine materials were absent, but a buried organic layer containing many shells at depth (60-100 cm) was observed in section 1, T.12.N, R.6E., of Blumfield Township in Saginaw County. The mean calcium carbonate equivalent of the till in Saginaw County is 28% (±7) where as the till in Bay

County contains 33% (±2). In Bay County the lacustrine material has lower $CaCO_3$ contents, 22% (±1), than the till, 33% (±2).

The calcium carbonate equivalent of the till in the entire study area varies from 5% in Tuscola to 39% in Saginaw County, whereas the mean varies from 26% in Huron to 33% in Bay County. Water samples from Rush Lake in Huron County and from a tile drainage system in Section 21, Gilford Township, Tuscola County, have similar $CaCO_3$ equivalent content, i.e., 862 and 850 ppm, respectively.

Shell Fragments

Throughout the study area the presence of shell fragments was observed; however, the amount varied widely. Abundant shells were observed in areas where carbonate-rich horizons were identified. Shells were identified in samples from the carbonate-rich horizons of a pedon in the Lenawee-Tappan complex and of a pedon in the Thomas muck (Table 3).

Three terrestrial and 13 aquatic species of molluscs and one plant species were identified. Most of these species have been found in other parts of Michigan (Hale et al., 1903; Goodrich, 1932) and in south western Ontario, Canada (Miller et al., 1979).

Shells in the pedon from the Lenawee-Tappan complex were all from aquatic species. This association of species is characteristic of lakes, ponds, or slow-moving portions of rivers. Aquatic species also made up the overwhelming majority of shells found in the pedon from Thomas muck. However, two species of Vertigo and Stenotrema sp., are

TABLE 3.--Molluscs identified in the study area

> 2mm	2 - 0.5mm
Lenawee Variant	
Fossaria decampi	Fossaria cf. decampi
Valvata tricarinata	Valvata tricarinata
Valvata sincera	Valvata sincera
Gyraulus parvus	Pisidium spp.
Gyraulus deflectus	Gyraulus parvus
Pisidium spp.	Cf. Succinia
Lymnaea reflexa	Physa sp.
Helisoma companulatum	Lymnaea cf. reflexa
Physa sp.	
Thomas Muck	
Physea gyrina***	Charaphyte oogonia*
Helisoma trivovis	Vertigo morsei**
Planorbula aronigera	Vertigo ovata**
Fossaria decampi	Valvata triçarinata
Valvata tricarinata	Valvata sincera
Valvata sincera	Fossaria decampi
Helisoma campanulatum	Gyraulus parvus
Lymnaea elodes	Cf. Succinea
Fossaria exigua	Pisidium spp.
Cf. Succinea vetusa	Physa gyrina***
Stenotrema sp.**	Lymanaea Cf. elodes

*Aquatic plant species
**Terrestrial snails
***Inhabit temporary bodies of water

terrestrial snails that probably were washed into the pond or lake that supported the remaining molluscs.

Charaphyte oogonia, a plant species was identified in the Thomas muck sample. Chara, a marl forming algae, may be responsible for the deposition of the fine-textured marl (Johnston et al., 1984). This plant inhabits fresh-water lakes of the temperate region and is known for its tendency to deposit lime. Precipitation is generally assumed to result from the utilization of carbon-dioxide in photosynthesis. Johnson and Williamson (1916) pointed out that in order for carbonates to be precipitated by algae, the water surrounding them must be saturated with respect to calcium carbonate. Chara is often gray because of the lime encrustation and sometimes commits suicide by depositing so much calcium carbonate that the plants are starved due to decrease in the photosynthetic rate (Mathews, 1960).

Although there are 3 individuals that belong to a terrestrial taxon, the overwhelming majority are aquatic forms which typically inhabit permanent bodies of water. Physa gyrina is typical of temporary bodies of water habitats, an environment which certainly would support marl formation. The source of calcium carbonate is undoubtedly the glacial deposits.

The presence of abundant shell fragments, the absence of carbonates as concretions and pendants; the position of calcium carbonate rich horizon in the profile, and the geographic position indicate the carbonate-rich horizons are not pedogenic in origin, but rather are geologic in origin.

Genesis of Soils with Calcium Carbonate Rich Layers

As the glacier retreated from the Port Huron Moraine a ground moraine was formed. During the retreat of the glacier melt waters were trapped between the glacier and the Port Huron Moraine forming a glacial lake. Wave action eroded material from the higher areas on the ground moraine. Deposition of silts and clays occurred in the lower areas. The resulting landscape had less relief than the original ground moraine (see Fig. 5).

With further retreat of the glacier and isostatic rebound, the glacial lake drained. Low areas in the lake plain continued to contain water. Marl formation probably took place post Lake Algoma. The glacial lakes that have covered the study area are listed in Table 4. Marl was deposited by aquatic plants and lower forms of animals over the lacustrine materials. The source of $CaCO3$ was the glacial materials. Rainfall and subsequent runoff could dissolve $CaCO3$ from the glacial materials and transport it to the ponded areas. Ground water flow could also dissolve $CaCO3$ from the glacial materials and transport it to the bodies of water. Lower forms of animals inhabiting such ponds or lakes accumulate $CaCO3$ in their bodies which are deposited on the floor of the waterbody when they die. Chara, known as a marl forming algae (Johnston et al., 1984), increased the accumulation of marl.

Subsequently organic materials accumulated in these ponded areas. Organic soils or mineral soils with histic epipedons were formed. As a result of widespread fires in the Thumb Area of Michigan

TABLE 4. Glacial lakes that have covered the study area

Lake Stage	Elevation		Date (YBP)
	Feet	Meters	
Warren	690-682	210-208	12,700 - 12,200
Wayne	655	199.6m	11,300 - 11,000
Lowest Warren	675	205.7	11,000 - 10,500
Grassmere	640	195.0	10,500 - 10,100
Lundy	620	189.0	10,100 - 9,800
Early Algonquia	605	184.4	9,800 - 9,200
Algonquih	605	184.4	8,900 - 8,000
Nipissing	605	184.4	4,000 - 3,000
Algoma	595	181.4	3,000 - 2,250

Source: Hough, 1958; Farrand and Eschman, 1974.

in 1871 and 1881 (Park, 1953; Schultz, 1964) some of the organic materials were destroyed. At least some of these areas are identified on soil surveys made in the early 1900s in Bay, Saginaw, and Tuscola Counties (Deeter et al., 1926; Wonser et al., 1931; Moon et al., 1938). Development of these soils for crop production include the installation of tile drains and the deep drainage ditches. Rush Lake in Huron County is an existing lake probably similar to the areas included in this study.

The Lenawee variant--Tappan complex and Thomas mapping units occur in the depressional areas while the Tappan mapping unit occurs on the higher areas (595 ft. a.s.l.).

Classification of Pedons

All pedons have organic carbon contents in the surface horizon of greater than 0.6% (Table 1) which is required for mollic epipedon (Soil Survey Staff, 1975). Thomas pedon has a histic epipedon and Lenawee variant-2 and Tappan pedons have mollic epipedons. Lenawee variant-2 failed to have a mollic epipedon because of a 10YR 6/1 dry color (detailed descriptions of the five pedons are given in Appendix A). To waive the color requirements for a mollic epipedon, Lenawee variant-2 pedon should have > 40% finely divided lime and organic carbon content $\geq$ 2.5% (Soil Survey Staff, 1975).

All pedons lack diagnostic subsurface horizons. All pedons have aquic moisture regimes. Based on morphological, physical, and chemical data, Thomas (pedon-1) classified as Histic Humaquepts, fine-loamy, mixed (calcareous), mesic. Lenawee variant-1 and Tappan pedons classify as Typic Haplaquolls; fine-loamy, mixed (calcareous), mesic. Lenawee variant-2 pedon classified as Typic Haplaquepts; fine-loamy, mixed (calcareous), mesic.

Because the carbonate rich horizons present in Thomas and Lenawee variant-1 pedons and possibly Lenawee variant-2 are composed of marl they do not qualify as calcic horizons. Management problems (requirements of P, Zn, and Mn fertilizers and drainage) associated with the soils with carbonate rich horizons are unique. Because Lenawee variant-1 and Tappan pedons are classified in the same family, soils with these problems are combined with those which lack these problems. A limnic subgroup is being proposed to indicate mineral soils with carbonate-rich horizons such as marl, which are geologic rather than pedogenic. This would permit separation of these soils above the soil series level. Using this proposal Thomas pedon would classify as Limnic Humaquepts and Lenawee variant-1 pedon as Limnic Haplaquolls.

Other soil series, for example Harps and Harpster, have been classified as Typic Calciaquolls. However, the presence of snail shells has been described in both soil series (Hallbick and Fehrenbacher, 1971; Alexander and Hallibick, 1974; Steinkamp, 1980; Russel et al., 1974; Voy, 1980; Sherwood and Max, 1982; and Diderikensen, 1983). This suggests the origin of the carbonate-rich horizons may be similar to that in this study. With the proposed amendments these soils may also classify into Limnic subgroups.

Mapping Unit Composition

The Lenawee variant-Tappan complex mapping unit is 30% Lenawee variant and 70% Tappan loam soil. It seems logical to change the mapping unit name to Tappan-Lenawee variant complex since Tappan is dominant in this mapping unit. Thomas Muck mapping unit includes small areas of Tappan soils and Olentangy muck. These included soils make up 4 and 1% of the unit, respectively. Included soils in Tappan loam mapping unit are Londo soils which are found on low knolls. This soil makes up 5% of the unit.

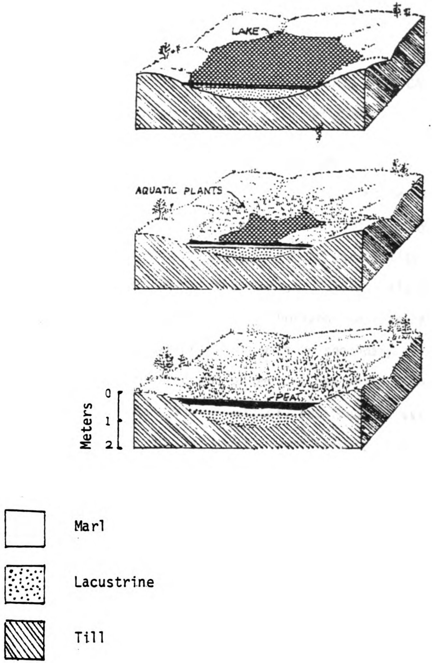


Fig. 5. Stages in the formation of landscape and soils in the study area.

CHAPTER IV

MANAGEMENT PROBLEMS ON SOILS WITH CALCIUM CARBONATE RICH HORIZONS

Introduction

Secondary calcium carbonate rich horizons had not been identified in Michigan until the Tuscola County soil survey team began investigating some mapping units as to the variability of crop yields in the northwestern part of the county. Calciaquolls (poorly drained soils with secondary carbonate rich horizons near the surface) and Haplaquolls (poorly drained soils with no secondary carbonate rich horizons) were identified and mapped. Those soils with secondary carbonate rich horizons (Lenawee variant) are found in association with Tappan loam (Haplaquoll) on nearly level terrain or in slight depressions on the glacial lake plain of Saginaw Bay.

The dominant crops grown on these soils and many others in the county are corn, sugarbeets, and drybeans. However, growth is frequently stunted and yields are low where the carbonate rich layers are near the surface. Plant chlorosis, phosphorus, and micronutrient deficiencies are common (Soil Survey, 1975). High yields have been obtained on these soils with special management.

The purpose of this study was to determine some physical and chemical properties of the soils found in the Lenawee variant-Tappan complex, Thomas Muck and Tappan loam mapping units in the study area (Figs. 1 and 2). The classification of these three soils are given in Table 5.

Procedures

Five pedons were described by standards outlined in the Soil Survey Manual (Soil Survey Staff, 1951) and profile samples were collected in September, 1982. Two pedons of Tappan were located in the Tappan loam mapping unit, two pedons of Lenawee variant were located in the Lenawee variant-Tappen complex and one pedon of Thomas was located in the Thomas muck mapping unit. All pedons are located in nearly flat, poorly drained areas of Saginaw Valley.

Five undisturbed core samples were collected from each horizon (Blake, 1965). Hydraulic conductivity was determined by measuring the volume of water flowing through the saturated core samples under a constant head of 2.54 cm for a specific length of time (Klute, 1965). Bulk density was obtained by dividing the weight of the oven dry soil (after hydraulic conductivity measurement) by the volume of the core (Blake, 1965).

In the laboratory the bulk samples were air dried and crushed to pass a 2 mm sieve. The pH of each sample was determined using a 1:1 soil-solution ratio. Both water pH and salt pH (0.1 KCl) were measured. Soil test method for Bray-1 phosphorus was used (Kundsen, 1975). Extractable phosphorus was measured colorimetrically.

Cation exchange capacity (CEC) and exchangeable bases of each sample were determined using ammonium acetate pH 7 (Soil Survey Staff,

TABLE 5.--Classification of soil series

Soil Series	Family	Parent Material	Soil Mgmt. Group	Capability sub-class
Lenawee Variant Tappan Complex (Pedone 2 & 4)	Typic Calciaquoll fine-loamy, mesic mixed	Lacustrine over loam till	2:5 c-c	IIIw
Thomas Muck (Pedon 1)	Histic Humaquept fine-loamy, mixed (calcareous), mesic	Lacustrine over loam till	2:5 c-c	IIw
Tappan Loam (Pedons 3 & 5)	Typic Haplaquoll fine loamy, mixed (calcareous), mesic	Loam till	2:5 c-c	IIw

1972) as modified by Warncke et al. (1980). The supernatants from the three initial extracts (In Ammonium acetate, pH7) were used in the base saturation determination. The samples were washed with n-propyl alcohol to remove excess ammonium ions. Exchangeable magnesium content was determined colorimetrically. Exchangeable calicum and potassium levels were determined by flame photometry. Zinc and manganese extracted by 0.1 HCl (Whitney, 1980), were determined by using atomic absorption spectrophotometer.

Results and Discussion

Bulk Density and Hydraulic Conductivity

Values obtained for bulk density and saturated hydraulic conductivity are presented in Table 6 and Figs. 6 and 7. Values of bulk density range from 0.62 to 1.90 gm/cc. The pattern, in general, is an increase in bulk density with depth in the profile. All surface horizons have values less than 1.57 gm/cc. Most subsurface horizons have bulk densities greater than 1.50 gm/cc.

The bulk density values are similar to those anticipated. With five exceptions all values represent conditions where crop root growth rate is likely to be limited. Robertson (1976) has suggested that a value of 1.3 gms/cc is a valid threshold number for Michigan crops and soils.

The hydraulic conductivity decreases with depth. In Lenawee variant-2 and Tappan Loam-2 hydraulic conductivity shows a slight change with depth in the loam till, but is very slow in the basal

TABLE 6.--Particle size distribution, hydraulic conductivity, and bulk density

Horizon	Depth	Particle Size Distribution: Sand 2-0.5mm	Silt 0.5-0.002mm	Clay <0.002 mm	Textural Class	Hydraulic conductivity (K) cm/hr	Bulk Density (gm/cc)
		- - - - - % - - - - -					
				Thomas (Pedon 1)			
OAP	0- 30	24	53	23	silt loam	7.05	0.62
C	30- 41	37	51	12	silt loam	1.88	1.23
2Cg1	41- 59	32	31	37	clay loam	0.74	1.81
3Cg2	59-129	18	60	22	silt loam	0.62	1.69
4Cg3	120-150	40	38	22	loam		
				Lenawee variant-1 (Pedon 2)			
Ap	0- 25	13	55	32	silty clay loam	1.79	0.97
C	25- 43	2	56	42	silty clay	1.12	1.03
2Cg	43- 70	3	64	33	silty clay loam	0.28	1.50
3C1	70-125	17	48	35	silty clay	0.15	1.54
4C2	125-170	29	46	25	loam		
				Lenawee variant-2 (Pedon 4)			
Ap	0- 38	59	27	14	sandy loam	2.36	1.57
Bg	38- 50	50	36	14	loam	2.31	1.59
Cg	50-115	44	36	20	loam	1.86	1.74
C	115-150	41	38	21	loam		
				Tappan-1 (Pedon 3)			
Ap	0- 30	20	40	40	clay loam	3.56	1.05
Bg	30- 50	17	49	34	silty clay	0.37	1.65
2Cg	50-100	40	38	22	loam	0.33	1.80
2C	100-150	42	37	21	loam	0.10	1.89
				Tappan-2 (Pedon 5)			
Ap	0- 32	44	32	24	loam	2.95	1.44
Bg	32- 45	46	31	23	loam	2.65	1.58
C1	45- 64	43	37	20	loam	2.13	1.68
C2	64-150	43	40	17	loam	0.30	1.90

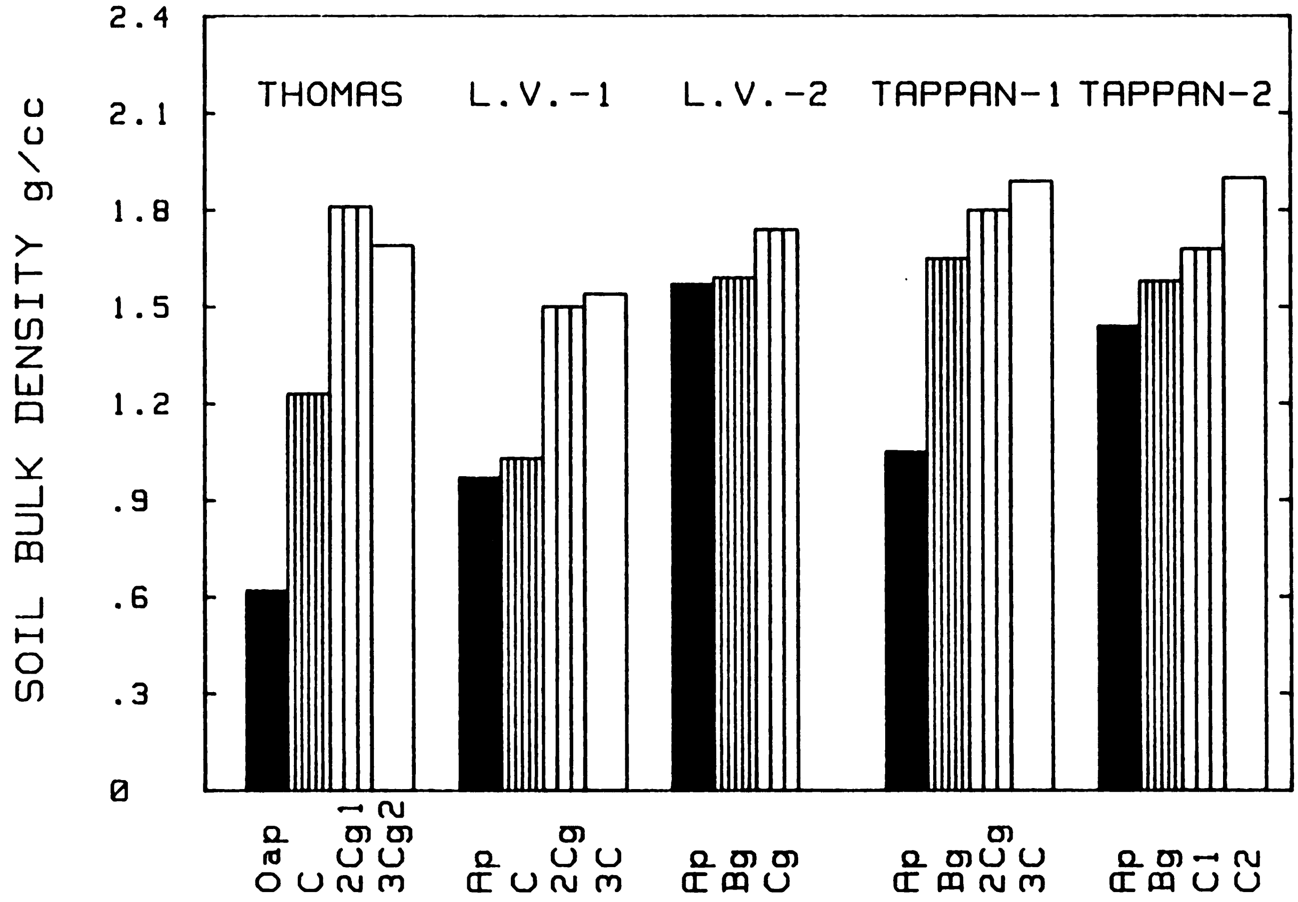


Fig. 6. Soil bulk density of the five pedons.

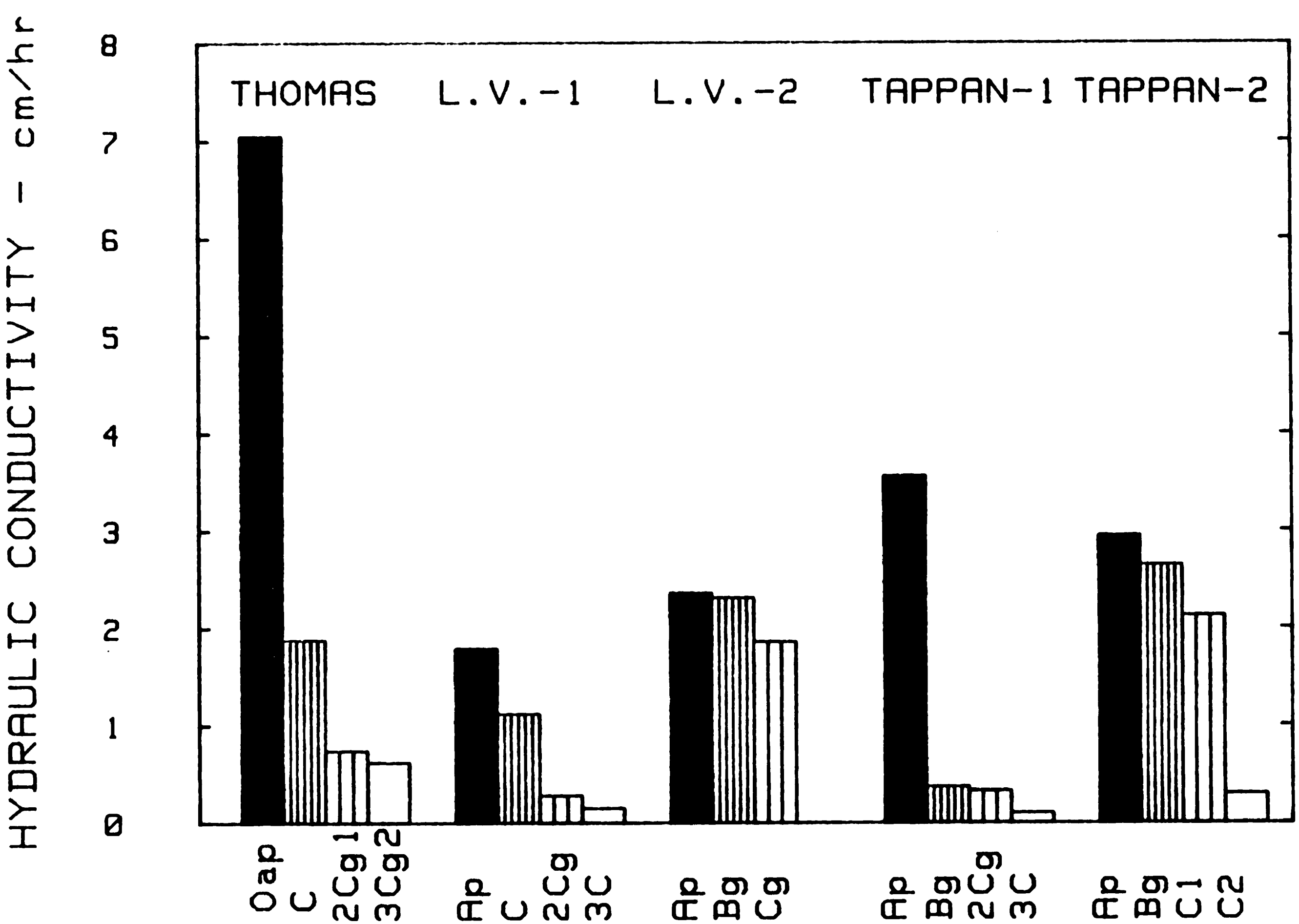


Fig. 7. Hydraulic conductivity of the give pedons.

till where structure is massive. In general, lower conductivity values were associated with soil horizons which had either high bulk density values, high clay contents, or both.

The calcium carbonate rich horizons in Thomas muck and Lenawee variant-2 pedons have bulk density values of 1.23 and 1.03 gm/cc, respectively. These horizons have relatively higher conductivities than the lacustrine and loam till parent material in the same profile. Till parent material has higher bulk densities and lower hydraulic conductivities than the lacustrine material. The till material has higher sand fraction (29-50%), and relatively uniform clay content (17-24%), than the lacustrine parent material.

Soil Reaction

Soil pH levels, in general, are above 7.5 because of free $CaCO_3$. The lowest pH reading obtained was 7.0 in Tappan-2 pedon in the surface and the highest was pH 8.1 in Lenawee variant-2 pedon below the surface horizon.

The pH levels in Tappan and Lenawee variant-2 pedons increase with depth or are constant. The highest levels occur in the calcium carbonate rich horizons in Thomas and Lenawee variant-2 pedons.

All horizons, except the Ap horizon of Tappan-2, had pH values between 7.0 and 7.5 in 0.1N KCl (Table 7).

Cation Exchange Capacity and Base Saturation

Cation exchange capacity and base saturation data provided information about the capacity of the soil to hold nutrients and the

TABLE 7.--Chemical analysis of 5 pedons sampled

Horizon	Depth (cm)	pH H_2O	pH 0.1N HCl	CEC	Exchangeable Bases K	Exchangeable Bases Ca	Exchangeable Bases Mg	$CaCo_3$ Equi-valent	Available $P(P_2O_5)$	Extrac-table Zn	Extrac-table Mn
				meq/ 100gm	lbs/acre			%	lb/acre	ppm	
Thomas (Pedon 1)											
Oap	0- 30	7.5	7.1	72.3	320	7680	763	10.3	62	1	12
C1	30- 41	8.0	7.4	16.8	46	7680	341	70.0	1	1	30
2Cg1	41- 59	7.9	7.4	7.8	145	7360	395	28.8	22	1	44
3Cg2	50-120	7.9	7.4	5.3	114	6933	459	30.8	1	1	59
4Cg3	120-150	7.8	7.3	3.6	114	6827	448	33.2	1	1	48
Lenawee variant-2 (Pedon 2)											
Ap	0- 25	7.8	7.2	36.3	272	12160	492	45.21	6	1	17
C1	25- 43	8.0	7.5	19.8	160	7253	554	76.41	1	1	38
2Cg	43- 70	8.0	7.3	9.2	152	7253	373	41.13	3	1	23
3C1	70-125	8.0	7.3	7.2	114	6721	352	34.26	1	1	50
4C2	125-170	7.7	7.4	7.5	53	6933	207	30.96	1	1	26
Lenawee variant-2 (Pedon 4)											
Ap	0- 38	7.9	7.3	5.6	224	7040	245	27.69	2	1	40
Bg	38- 50	8.1	7.4	5.4	53	6827	226	26.68	2	1	40
Cg	50-115	8.1	7.4	4.8	76	6720	301	31.65	3	1	49
C	115-150	8.1	7.5	4.7	107	6400	395	33.53	1	1	49
Tappan-1 (Pedon 3)											
Ap	0- 30	7.8	7.1	36.0	320	13013	751	0.75	227	6	36
Bg	30- 50	7.9	7.2	13.4	200	6400	554	20.23	21	1	19
2Cg	50-100	7.9	7.4	4.2	76	6613	341	31.98	1	1	44
2C	100-150	7.9	7.5	3.9	99	6507	384	29.75	2	1	46
Tappan-2 (Pedon 5)											
Ap	0- 32	7.0	6.7	32.9	152	11947	775	0.8	270	14	29
Bg	32- 45	7.3	7.0	12.9	114	5330	566	9.4	26	1	12
C1	45- 64	7.6	7.2	8.0	99	6507	459	32.5	7	1	25
C2	64-150	7.9	7.4	4.0	76	6507	331	33.1	1	1	43

amount of nutrients that are being held by the soil. The CES's of subsurface horizons, except calcium carbonate rich (marl) horizons, are generally less than 10 meq/100 gm (Table 7). The higher CEC values (72.3 meq/100 gm) in the plow layer of Thomas pedon is due to organic matter. The calcium carbonate rich horizons in Thomas and Lenawee variant-1 pedons have CEC values of 16.8 and 19.8 meq/100 gm, respectively. The higher than expected CEC values could be due to some dissolution of free $CaCO_3$ by the 1$\underline{N}$ NH_4OAC extracting solution (Carpena et al., 1972). A decrease in CEC with depth is primarily related to a decrease in organic matter.

Base saturation is high (100%) in all the pedons, except in the surface horizons of pedons 1 and 2. This is the result of the presence of free carbonates. Calcium and magnesium are the most abundant extractable bases, with lesser amounts of potassium.

Exchangeable Potassium

Potassium comprises less than 2% of the total exchangeable bases and varied from 0.3 to 1.8 percent. The test levels showed a wide range varying from 152 to 320 lb/acre in the subsurface horizons (Table 7). The calcium carbonate rich horizon (marl layer) in Thomas pedon shows the lowest exchangeable potassium. This could be due to low clay content (12%).

The levels of exchangeable potassium in the silt loam or silty clay loam materials (lacustrine) tend to be higher than the loam textured materials (till). The average levels tend to decrease with depth except on those soils with different parent material.

Potash (K_2O) recommendations by Warncke and Christenson (1981) are given in Table 9. Most of the crops grown in the study area do not need potash fertilizer unless one plans to obtain the maximum yields (40-60 bu/acre dry beans, 24-28 tons/acre sugarbeets, 180-240 bu/acre corn grain). Soil test of Tappan-2 indicates 152 lbs/acre, therefore, additional potash fertilizer is required for most crops.

Exchangeable Magnesium

Magnesium is the second dominant cation in all pedons and accounts for greater than 8% of the total exchangeable bases. Exchangeable magnesium varied from 4.7 to 14.9%. As shown in Table 7, quantities of exchangeable magnesium vary between kinds of soil and also within pedons. The highest level in all pedons is on the surface horizon varying from 245 lb/acre in Lenawee variant-2 pedon to 775 lb/acre in Tappan-2 pedon.

Currently, fertilizer recommendations for magnesium are made when exchangeable Mg level is less than 75 lb/acre or when the soil Mg as a percent of total bases is less than 3% or when the K level exceeds Mg. According to these criteria, all horizons have greater than 75 lb/acre of Mg and also greater than 3% soil magnesium. As a result, application of dolomite or any magnesium carriers is not recommended.

Exchangeable Calcium

Calcium is the dominant cation occupying approximately 90% of the total exchangeable bases. The range varied from 84.2 to 94.9% (Table 7). In some of the pedons a tendency to decrease with depth is

TABLE 8.--Phosphorus (P_2O_5) recommendations for corn, sugarbeets, and dry beans on mineral soils

Phosphorus Test Level	Corn Yield (bu/acre)				
	90-119	120-149	150-179	180-209	210-240
	Phosphorus recommendations, lb P_2O_5/acre				
0-19 lb P/acre	75	100	125	150	175
20-39	50	75	100	125	150
40-59	25	50	75	100	125
60-79	25	25	50	75	100
80-99	25	25	25	50	75
100-119	25	25	25	25	50
120-139	0	0	0	25	25
140 +	0	0	0	0	0

Yield, ton/acre	Sugarbeets (ton/acre)		Drybeans (bu/acre)	
	18-23	24-28	20-40	40-60
Phosphorus Test Level	Phosphorus recommendation, lb P_2O_5/acre			
0-19 lb P/acre	150	200	50	75
20-39	125	150	25	50
40-59	100	125	0	25
60-79	75	100	0	25
80-99	50	75	0	25
100-119	25	50	0	25
120-160	0	25	0	25
160 +	0	0	0	25

Source: Warncke et al., 1981.

observed. This might be due to the presence of a calcium carbonate rich horizon (marl) just below the surface in some of the pedons; calcareous nature of the parent material; and/or continual application of liming materials. These cause higher levels of calcium in the upper horizons. The difference in total exchangeable calcium within the profile could also be due to differences in parent material. Normally, in the absence of calcium carbonate rich (marl) layers, calcium levels tend to increase with depth in the profile. This was explained by the initial calcareous nature of the soil material and continual leaching of carbonates and bases from the upper horizons.

Because of the very high test levels of exchangeable calcium in all the soils, the need of a test for this nutrient is not necessary. However, excess levels of this nutrient are detrimental to plant growth. High pH as a result of excessive calcium carbonate will create nutritional problems. At pH above 7 the activity of calicum is high and as a result favours the precipitation of relatively insoluble dicalcium phosphate and other basic calcium phosphates. In order to alleviate this problem, band applications of acid forming fertilizers tend to increase the availability of nutrients. The extended use of high rates of N fertilizers is likely to decrease pH levels, expecially on sandy soils, low in organic matter.

Calcium Carbonate Equivalent

The calcium carbonate equivalent in the soil samples varies widely (Table 7). Pedons on Thomas and Lenawee variant-1 have the highest calcium carbonate equivalent (70% and 76%, respectively) below the surface horizon. On the other pedons, the highest carbonate content is found at depth. The mean calcium carbonate equivalent of the till parent material in all pedons is 32% (±2). The relatively high content of carbonates in the surface horizon of Lenawee variant-2 pedon could be due to deep plowing (38 cm) which might have mixed a calcium carbonate rich layer below the original A in the present Ap.

Calcium carbonate rich horizons (marl) were not found in the Tappan loam mapping unit. The carbonate rich (marl) horizons were found in localized areas in Thomas and in the Lenawee variant-Tappan complex mapping units.

Available Soil Phosphorus

Available soil phosphorus levels in the plow layers varied from 2 to 270 lb/acre (Table 7). Test levels range from 1 to 26 lbs/acre in the subsurface horizons. In general, the average phosphorus levels were much higher in the Ap horizon than the lower horizons.

The very high available phosphorus levels in the surface horizon (Ap) of Tappan pedons are due to higher phosphorus fertilizer application. The mapping units of Lenawee variant-Tappan complex and Tappan loam are found adjacent to each other in the same fields. In the Lenawee variant-Tappan complex mapping unit, the two soils are in areas so small or intricately mixed that it is not practical to separate them in mapping. As a result, farmers apply the same rates of fertilizer uniformly in the field. If a single soil sample of a composite soil sample is taken only from an area of Lenawee variant for soil testing, an excess of phosphorus fertilizer will be applied to the areas of Tappan soils. The very high phosphorus levels in Tappan pedons suggest this may have been done.

The free calcium carbonates decrease the availability of phosphorus fertilizer. The phosphate ions are adsorbed to the surface of finely divided $CaCO_3$ and subsequently converted to insoluble apatite or they are precipitated as insoluble calcium phosphates directly from the soil solutions. The presence of large amounts of carbonates in the Ap horizons or Lenawee variant pedons explains the very low available phosphorus levels (Table 7). Studies have shown band placement reduces the surface of contact between the soil and fertilizer with a consequent reduction in the amount of fixation.

Warncke and Christenson (1981) do not recommend phosphorus fertilizers be applied for corn when the soil test level is above 140 lb P/acre. For dry beans and soybeans soil test levels above 60 lb P/acre indicate no need for phosphorus fertilizers. When sugar-beets are to be grown and the test level is above 160 lb P/acre, the addition of phosphorus fertilizers is not recommended. The recommendations for application of phosphorus were based on soil tests, crops to be grown and yeild goal as shown in Table 8.

Extractable Zinc

Only the Ap horizons of Tappan loam pedons have more than 5 ppm extractable Zn (Table 7). These two horizons also have the highest levels of phosphorus and the lowest $CaCO_3$ equivalent. Zinc deficiencies have been related to soil pH in Michigan (Robertson et al., 1981).

Zinc deficiencies are common on calcareous soils in Michigan (Mokma et al., 1978; Robertson et al., 1981). Zinc is adsorbed by carbonates of calcium and magnesium. In the study area calcium carbonate rich subsoils (marl) have been mixed with surface soils during tillage, resulting in adsorption of zinc by the carbonates. According to Warncke et al. (1981), soils in the study area need 3 to 5 lbs Zn/acre depending in the pH of the soil and type of crop to be grown (Table 11).

Extractable Manganese

Extractable manganese levels vary from 12-40 ppm in the surface horizons (Table 7). The high amounts of extractable manganese are found at depth in the soil profiles. Most of the pedons show an increase with depth except where there are lithologic discontinuities (parent material changes). This trend may result from manganese being soluble in reducing poorly drained environments and subsequent leaching to the lower horizons.

Precise determination of the manganese availability is difficult since its availability changes with oxidation state. However, general guidelines for manganese applied in bands with starter fertilizers have been prepared (Table 10) (Warncke and Christenson, 1981). The Thomas and Lenawee Variant-1 pedons need applications of 4 lb Mn/acre. The Tappan loam and Lenawee variant-2 pedons do not show the need for manganese fertilizer.

TABLE 9.--Potassium (K_2O) recommendations for corn, sugarbeets, and dry beans on mineral soils

Potassium Test Level	Corn Yield (bu/acre)				
	90-119	120-149	150-179	180-209	210-240
	Potassium recommendations, lb K_2O/acre, on loams, clay loams, and clays.				
0-99 lb K/acre	150	200	300	400	400
100-149	100	150	200	300	350
150-199	50	100	150	200	250
200-249	0	50	100	150	200
250-274	0	0	50	100	150
275-299	0	0	0	50	100
300-324	0	0	0	0	50
325 +	0	0	0	0	0

Potassium Test Level	Yield			
	Sugarbeets (ton/acre)		Drybeans (bu/acre)	
	18-23	24-28	20-40	40-60
	Potassium recommendations, lb K_2O/acre on loams, clay loams, and clays			
0-49 lb K/acre	200	300	100	150
50-59	150	200	50	100
100-149	100	150	25	50
155-199	75	100	0	25
200-249	50	75	0	0
250-299	0	50	0	0
300+	0	0	0	0

Source: Warncke et al., 1981).

TABLE 10.--Manganese fertilizer needs as indicated by soil tests (0.1N HCl extractable) for responsive crops

Soil Test (ppm Mn)	Mineral Soils		Organic Soils	
	pH 6.0-6.5	Above pH 6.5	pH 5.8-6.4	Above pH 6.4
	Pounds Mn/acre			
Below 5	6	8	12	16
5-10	4	6	8	12
11-20	0	4	4	8
21-40	0	0	0	4
Above 40	0	0	0	0

Source: Warncke et al., 1981.

TABLE 11.--Zinc fertilizer needs for mineral soils as indicated by soil tests (0.1N HCl extractable) for responsive crops

Soil Test (ppm Zn)	Below pH 6.7	pH 6.7 to 7.4	Above pH 7.4
	pounds Zn/acre		
Below 2	2	3	5
3-5	0	3	3
5-10	0	2	3
11-15	0	0	2
Above 15	0	0	0

Source: Warncke et al., 1981.

Suggestions to Improve Management

In fields which are composed of two or more mapping units such as the Lenawee Variant-Tappan complex and Tappan soils, representative soil samples form each mapping unit should be collected separately for evaluating nutrient imbalances and also for measuring trends in nutrient levels (Shickluna, 1983). The Lenawee variant soil had abundant shell fragments on the surface while the Tappan soil has few or no shells. Thus, in collecting soil samples the distribution of shell fragments on the surface of these soils is one of the major ways of differentiating them from each other. Fertilizers should also be applied on the basis of soil test results. Where separate fertilizer applications of banded planting time fertilizer on each soil type is not practical, broadcast treatments became feasible. Then a single low rate of banded planting time fertilizer can be used on all soils. This permits the use of micronutrients in the planting time fertilizer. Where rates of micronutrients are wide, foliar treatments may be used where high rates are needed.

Deeper plowing in the Lenawee variant soil will usually mix the underlying marl layer with the surface layer. This may lead to additional phosphorus fixation and micronutrient deficiencies.

One of the major problems with the Thomas Muck soil is wind erosion. If erosion is not controlled, the thickness of the plow layer (histic epipedon) decreases. Furthermore, continued plowing at the same depth (30 cm) mixes the underlying marl layer with the plow layer, increasing the problem of phosphorus fixation as in Lenawee Variant-Tappan complex soils.

Tappan loam with its better structure has a relatively higher hydraulic conductivity than does the Lenawee variant soil with its poor structure. Narrower spacing of tile may be needed on the Lenawee variant--Tappan xomplex than the Tappan loam soil to achieve adequate drainage. Removal of surface water with surface drainage will also reduce the wetness problem. Improved drainage both surface and subsurface will help to reduce compaction as a result of tillage when the soil is wet.

CHAPTER V

SUMMARY AND CONCLUSIONS

The study was carried out to characterize pedons from the Calciaquoll and Haplaquoll mapping units and to investigate the genesis of the soils with carbonate-rich horizons. Pedons were described and sampled in Thomas, Lenawee variant-Tappan complex and Tappan mapping units. On the basis of field and laboratory data the following conclusions were reached:

1. Lithologic discontinuities were observed between layers of organic, calcium carbonate, lacustrine and till materials.

2. The mean calcium carbonate equivalent in the marl layers is 54.2 ± 7.7. Carbonate rich horizons have high clay and silt size carbonates. The laxustrine materials have predominantly silt-size carbonates. The high contents of clay size carbonates near the surface are probably the result of limited downward water movement because of high water tables.

3. The shells of thirteen aquatic and three terrestrial species of molluscs and one plant specie were identified in the calcium carbonate rich layers. The few terrestrial snails were probably washed into the pond or lake from adjacent higher areas. The plant species is Chara, a marl forming algae. The aquatic molluscs are found in permanent water habitats, an environment in which marl would form.

4. The presence of abundant shell fragments in the carbonate rich horizons, the absence of carbonate as concretions and pendants and the glacial history of the inland lakes in Michigan suggest the calcium carbonate layers are of geologic origin rather than pedogenic origin.

5. The topography resulting from glaciation was undulating with many undrained depressions. These depressions are filled by deposition of silty material from the relatively high areas by wave action. Subsequently, marl was deposited on top of the lacustrine materials by aquatic plants and lower forms of animals. As wet land plants grew and their remains decomposed, organic materials accumulated. Severe fires of 1871 and 1881 in the Thumb Area of Michigan destroyed some of the organic materials. The Thomas and Lenawee variant-Tappan complex mapping units occur in depressional areas while the Tappan mapping unit occurs on the higher areas.

6. In order to separate mineral soils, with and without marl layers, that are classified in the same family above the soil series level a limnic subgroup is proposed. This would also indicate the carbonate rich horizons are geologic in origin.

7. The Tappan loam soil occupies 70% of the Lenawee variant-Tappan complex mapping unit. As a result, it is suggested that the mapping unit be renamed Tappan-Lenawee variant complex.

8. The presence of calcium carbonate-rich layer below the surface, in the Thomas and Lenawee variant-Tappan complex mapping units has raised the pH of the soil.

9. Tappan loam soils had very high levels of available phosphorus and relatively high levels of extractable zinc and manganese. These high levels suggest a high rate of fertilizer application has been used than is suggested by soil test results.

10. Application of acid forming fertilizers in a band near planted crops will increase the availability of several essential nutrients in a highly calcareous soil.

11. Surface drainage and subsurface drainage with shorter spacing of tiles will help to remove surface water and to control wetness on all soils.

APPENDICES

APPENDIX A

PROFILE DESCRIPTIONS

PEDON 1

Pedon classification	:	Histic Humaquepts
Series classification	:	Histic Humaquepts; fine loamy, mixed (calcareous), mesix
Soil series	:	Thomas muck (58)
Location	:	Tuscola County, Michigan; 396 ft west and 792 ft south of NE corner of section 20, T.13 N., R7E.
Climate	:	Average annual precipitation is about 30 inches. Mean annual air temperature is about 47°F.
Vegetation & Land Use	:	Potatoes
Parent material	:	Lacustrine clay & silt loam over loam till.
Physiography	:	Lake plain. Elevation $\simeq$ 595 ft.
Topography	:	Level, gradient is 0%.
Drainage	:	Poorly drained
Ground water	:	> 150 cm
Erosion	:	None
Permeability	:	Very slow

Oap 0-30 cm (0-11.8 inches); Black (10 YR 2/1) and rubbed sapric material; weak medium granular structure; friable; common fine roots; moderate effervescence; common shell fragments (10 YR 8/1); abrupt smooth boundary.

C 30-41 cm. light gray (5 Y 7/1) silt loam; massive very few fine roots; vertical cracks of Oap in C; friable; violent effervescence; common shell fragments (10 YR 8/1); abrupt wavy boundary.

Cg1 41-59 cm. Olive gray (5 Y 5/2) clay laom to clay; massive; firm; medium effervescence; very few very fine roots; abrupt wavy boundary.

Cg2 59-120 cm. light brownish gray (2.5 Y 6/2) stratified silt loam and clay loam; Many coarse prominent yellowish brown (10 YR 5/6) and dark yellowish brown (10 YR 4/6) mottles; massive; firm; very few very fine roots up to 75 cm; 2% rock fragments; mild or moderate effervescence; used auger below.

Cg3 120-150 cm. light brownish gray (2.5 Y 6/2) loam; massive; firm; moderate effervescence.

PEDON 2

Pedon classification : Typic Calciaquoll

Series classification: Typic Calciaquoll; fine loamy, mixed (calcareous), mesic.

Soil : Lenawee variant-Tappan complex (64)

Location : Tuscola County, Michigan; 2508 ft north and 1320 ft west of south east corner of section 16, T. 13N, R7E.

Climate : Average annual precipitation is about 30 inches. Mean annual air temperature is about 47°F.

Vegetation & Land Use: Sugarbeets.

Parent material : Till

Physiography : Lake plain

Topography : Nearly level, gradient is 0-1%. Elevation is 595 ft.

Drainage : Poorly drained

Ground water : Deeper than 150 cm on 9-6-82.

Erosion : None

Permeability : Very slow

Ap 0-25 cm. very dark gray (10 YR 3/1) gray; (10 YR 5.5/1) dry, loam; strong fine and very fine granular and strong medium subangular blocky structure; friable; common fine white (10 Yr 8/1) sea shell fragments; common fine roots; strong effervescence; abrupt smooth boundary.

C 25-43 cm. light gray to white (10 YR 7.5/1), white (5 YR 8/1) dry, silty clay; massive; firm; very few fine roots; many (10 YR 8/1) white shell fragments; violent effervescence; vertical cracks of Ap in C and closer cracks all the way in C; abrupt wavy boundary.

Cg 43-70 Cm. Olive gray (5 Y 5/2) slity clay to clay; massive; firm; no roots but many pores; has some C material in its upper part; closer cracks all the way in Cg; strong effervescence; clear wavy boundary.

2C1 70-125 cm. light gray (10 YR 7/2) very fine sand and Olive gray (5 Y 5/2) clay loam; many medium prominent yellowish brown (10 YR 5/6) mottles; massive; friable; strong effervescence; gradual wavy boundary.

2C2 125-170 cm. gray (10 YR 5/1) + brown (10 YR 5/3) clay loam; massive; firm; many medium prominent yellowish brown (10 YR 5/6) mottles; strong effervescence.

PEDON 3

Pedon classification :	Typic Haplaquoll
Series classification:	Typic Haplaquoll; fine-loamy, mixed (calcareous), mesic
Soil :	Tappan laom (36)
Location :	Tuscola County, Michigan; 1056 ft north and 1320 ft west of south east corner of section 10, T.13N., R.7E.
Climate :	Average annual precipitation is about 30 inches. Mean annual air temperature is about 47°C.
Vegetation & Land Use:	Wheat, beans, and corn. Cropland.
Physiography :	Lake plain
Topography :	Nearly level. Gradient 0-1%
Drainage :	Poorly drained or (sw poor)
Ground water :	Greater than 150 cm on 9-7-82
Erosion :	None
Permeability :	Moderately slow

Ap 0-30cm. Black (10 YR 2/1) loam; moderate coarse granular structure; friable; common fine roots; slight effervescence; abrupt smooth boundary.

Bg1 30-50 cm, Olive gray (5 Y 5/2) silty clay; weak fine and medium angular blocky structure; firm; common fine distinct yellowish brown (10 YR 5/6) mottles around pores; vertical cracks; cray fish channels 3 cm wide; very few white (10 YR 8/1) sea shell fragments; few fine roots in cracks; 2% coarse fragments; slight effervescence; clear irregular boundary.

Cg1 50-100 cm. yellowish brown (10 YR 5/4) clay loam to loam; weak medium angular blocky structure; firm; very few very fine roots; 7% coarse fragments; cray fish channels; strong effervescence; pockets of light brownish gray (2.5 Y 6/2) very fine sandy loam; friable with strong effervescence; clear irregular boundary.

2C 100-150 cm. Yellowish brown (10 YR 5/4) loam; weak medium and coarse platy structure; very firm; 3-5% coarse fragments; basal till; strong effervescence.

PEDON 4

Pedon classification	:	Typic Calciaquoll
Series classification	:	Typic Calciaquoll, fine-loamy, mesic, mixed
Soil	:	Lenawee variant
Location	:	Tuscola County, Michigan, 1188 ft east and 1584 ft north of south west corner of section 33, T.15 N., R. 8E.
Climate	:	Average annual precipitation is about 30 inches: mean annual air temperature is about 47°F.
Vegetation & Land Use	:	Beans & corn.
Parent material	:	Loam till
Physiography	:	Lake plain
Topography	:	Nearly level, gradient greater than ½% elevation 585 ft.
Drainage	:	Poorly drained
Ground water	:	Greater than 150 cm on 9-9-83
Erosion	:	None
Permeability	:	Very slow

Ap 0-38 cm. Very dark grayish brown (10 YR 3/2), gray to light gray (10 YR 6/1) dry, loam; clods parting to weak fine granular structure; friable common fine white (10 YR 8/1) shell fragments very few soft very pale brown (10 YR 7/4) cinders or ash; violent effervescent: abrupt smooth boundary.

Bg 38-50 cm. grayish brown (5 Y 5/1) loam; weak fine granular structure; very friable; cray fish channels; common fine white (10 YR 8/1) snail shells; violent effervescent; few fine prominant red (10 R 5/6) coating on Reds; abrupt irregular boundary.

C1 50-115 cm. Dark yellowish brown (10 YR 4/6) loam; weak fine angular blocky structure; friable; many medium prominent gray (10 YR 4/6) coatings on reds; cray fish channels; strong effervescent; 7% coarse fragments; clear wavy boundary.

C2 115-150 cm. Brown (10 YR 5/3) loam; weak medium angular blocky structure; common, fine, distinct yellowish brown (5 Y 5/1) mottles and light brownish gray (10 YR 6/2) coatings on peds; firm; strong effervescent. 7% coarse fragments.

PEDON V

Pedon classification	:	Typic Haplaquoll
Series classification	:	Typic Haplaquoll fine-loamy, mixed (calcareous), mesic.
Soil	:	Tappan laom
Location	:	Tuscola County, Michigan; 2244 ft south and 264 ft east of north west corner of section 15; T13N, R7E.
Climate	:	Average annual precipitation is about 30 inches. Mean annual air temperature is about 47°F
Vegetation & land use	:	Beans harvested and plowed.
Parent material	:	Loam till
Physiography	:	Lake plain
Topography	:	Nearly level. Gradient 0-1% Elevation is ≃ 595 ft.
Drainage	:	Poorly drained
Ground water	:	Greater than 150 cm on 9-11-82
Erosion	:	None
Permeability	:	Slow to very slow

Ap 0-32 cm. Black (10 YR 1/2) loam; friable; moderate fine granular structure; many very fine roots; 2% rock fragments: slight effervescence; abrupt smooth boundary.

Bg 32-45 cm. Gray (5Y5/1) loam; moderate medium and coarse angular blocky structure; friable; few to common fine distinct yellowish brown (20 YR 5/6) mottles; few very fine roots; 2% coarse fragments; very dark gray (10 YR 3/1) root channels or animal burrows; few decomposed stones; slight effervescence; clear wavy boundary.

C1 45-64 cm. Olive (5Y5/3) loam; weak medium to coarse angular blocky structure; friable; few very fine roots; 2% coarse fragments; very dark gray (10 YR 3/1) root channels or animal burrows; few decomposed rocks; very few shell fragments; strong effervescence; gradual wavy boundary.

C2 64-150 cm. Reddish brown (5Y5/3) loam; friable; massive; few decomposed stones; very dary gray (10 YR 3/1) animal burrows; 7% coarse fragments; very strong effervescence.

APPENDIX B

CALCIUM CARBONATE EQUIVALENTS DETERMINED

Transect No.	Location
1	NW 1/4, NW 1/4, Section 20, T. 16 N., R. 10 E. (Huron)
2	NW 1/4, NE 1/4, Section 20, T. 16 N., R. 10 E. (Huron)
3	NE 1/4, NW 1/4, Section 17, T. 15 N., R. 10 E. (Huron)
4	SE 1/4, SE 1/4, Section 25, T. 13 N., R. 6 E. (Bay)
5	SW 1/4, NE 1/4, Section 31, T. 13 N., R. 6 E. (Bay)
6	NE 1/4, SW 1/4, Section 36, T. 13 N., R. 6 E. (Bay)
7	NW 1/4, SW 1/4, Section 2, T. 12 N., R. 6 E. (Saginaw)
8	NE 1/4, SE 1/4, Section 3, T. 12 N., R. 6 E. (Saginaw)
9	NW 1/4, NE 1/4, Section 7, T. 12 N., R. 6 E. (Saginaw)
10	SE 1/4, SE 1/4, Section 7, T. 12 N., R. 6 E. (Saginaw)
11	SW 1/4, NW 1/4, Section 33, T. 14 N., R. 8 E. (Tuscola)
12	NW 1/4, SE 1/4, Section 33, T. 14 N., R. 8 E. (Tuscola)
13	SE 1/4, SW 1/4, Section 10, T. 13 N., R. 7 E. (Tuscola)
14	SW 1/4, NE 1/4, Section 10, T. 13 N., R. 7 E. (Tuscola)
15	NW 1/4, NW 1/4, Section 15, T. 13 N., R. 7 E. (Tuscola)
16	NW 1/4, NE 1/4, Section 15, T. 13 N., R. 7 E. (Tuscola)
17	NE 1/4, SW 1/4, Section 16, T. 13 N., R. 7 E. (Tuscola)
18	NW 1/4, NE 1/4, Section 16, T. 13 N., R. 7 E. (Tuscola)
19	NE 1/4, NE 1/4, Section 20, T. 13 N., R. 7 E. (Tuscola)
20	NE 1/4, NW 1/4, Section 20, T. 13 N., R. 7 E. (Tuscola)
21	SE 1/4, NW 1/4, Section 30, T. 13 N., R. 7 E. (Tuscola)
22	NW 1/4, SW 1/4, Section 21, T. 13 N., R. 7 E. (Tuscola)
23	SE 1/4, NE 1/4, Section 8, T. 13 N., R. 7 E. (Tuscola)

Transect Obs.	Depth (cm)	CaCO3 Equivalent %
1-1	0- 28	7
	28- 60	24
	60-110	25
1-2	0- 30	19
	30- 45	27
	45- 58	32
	58- 82	26
	82- 90	27
	90-110	29
2-1	0- 25	51
	25- 35	48
	35- 65	19
	65- 85	37
	85-105	25
2-2	0- 25	62
	25- 41	57
	51- 56	33
	56- 78	35
	78- 97	34
	97-130	26
2-3	0- 25	30
	25- 32	31
	32- 49	31
	49- 62	21
	62- 90	26
3-1	7- 27	25
	27- 43	27
	43- 60	24
	60- 98	15
	98-120	25
3-2	0- 32	22
	32-100	26
	100-120	16
4-1	0- 25	4
	25- 50	4
	50- 80	21
	80-115	34
	115-150	37

Transect Obs.	Depth (cm)	$CaCO_3$ Equivalent %
4-2	0- 30	6
	30- 50	15
	50- 85	19
	85-115	26
	115-150	32
5-1	0- 23	6
	23- 45	10
	45- 85	15
	85-130	32
5-2	0- 20	5
	20- 50	20
	50-110	32
	110-140	32
6-1	0- 30	4
	30- 70	20
	70- 90	36
	90-130	37
6-2	0- 30	5
	30-100	10
	100-140	31
6-3	0- 25	5
	25-110	8
	110-140	31
7-1	0- 30	1
	30- 70	15
	70-140	15
7-2	0- 30	2
	30- 90	37
	90-140	38
7-3	0- 30	9
	30- 75	39
	75-135	39
8-1	0- 30	1
	30- 90	1
	90-120	28
8-2	0- 30	-
	30- 90	-
	90-15-	24

Transect Obs.	Depth (cm)	CaCO3 Equivalent %
8-3	0- 30	1
	30- 75	28
	75-140	33
9-1	9- 30	15
	30- 50	17
	50- 60	23
	60-110	27
	110-140	31
9-2	0- 30	15
	30- 45	19
	45-100	24
	100-150	30
10-1	0- 30	24
	30- 45	27
	45-130	29
10-2	0- 30	22
	30- 55	25
	55- 80	27
	80-100	28
	100-150	35
10-3	0- 30	24
	30- 75	28
	75-110	35
	110-145	36
11-1	0- 30	37
	30- 50	35
	50-125	33
11-2	0- 35	35
	35- 50	29
	50-150	28
11-3	0- 25	33
	25- 50	34
	50-150	30
12-1	0- 30	33
	30- 40	35
	40-150	34
12-2	0- 30	23
	30- 50	24
	50-15-	29

Transect Obs.	Depth (cm)	CaCO3 Equivalent %
12-3	0- 30	34
	30- 50	35
	50-150	33
13-1	0- 25	13
	25- 35	25
	35- 45	30
	45- 90	25
	90-130	30
13-2	0- 25	12
	25- 42	31
	42- 68	29
	68-130	30
13-3	0- 25	17
	25- 50	29
	50- 90	30
	90-110	32
14-1	0- 30	2
	30- 40	13
	40- 50	30
	50- 85	30
	85-150	28
14-2	0- 30	9
	30- 50	24
	50- 85	32
	85-130	30
14-3	0- 35	6
	35- 50	20
	50-110	28
14-4	0- 32	34
	32- 45	49
	45- 65	28
	65-110	34
	110-150	29
15-1	0- 25	11
	25- 50	30
	50- 90	31
	90-145	34

Transect Obs.	Depth (cm)	CaCo3 Equivalent %
15-2	0- 30	9
	30- 50	26
	50-150	32
	100-150	37
15-3	0- 25	3
	25- 50	28
	50- 85	34
	85-150	37
16-1	0- 30	26
	30- 40	30
	40- 50	33
	50- 85	33
	85-150	32
16-2	0- 30	1
	30- 50	7
	50- 85	25
	85-130	31
16-3	0- 30	2
	30- 50	10
	50- 80	11
	80-130	31
17-1	0- 25	28
	25- 47	53
	47- 65	50
	65- 90	25
	90-120	30
17-2	0- 30	36
	30- 43	60
	43- 55	45
	55-125	35
	125-150	29
17-3	0- 25	14
	25- 50	28
	50- 60	30
	60-120	27
18-1	0- 25	--
	25- 50	1
	50- 80	25
	80-150	31

Transect Obs.	Depth (cm)	CaCO3 Equivalent %
18-2	0- 25	1
	25- 50	8
	50-130	28
18-3	0- 25	--
	25- 50	5
	50-140	30
19-1	0- 30	6
	30- 44	52
	44- 65	31
	65-105	23
19-2	0- 30	18
	30- 43	54
	43- 54	36
	54-120	24
	120-180	27
19-3	0- 33	7
	33- 48	42
	48- 65	30
	65-130	29
	130-150	29
20-1	0- 30	21
	30- 40	71
	40- 60	33
	60- 75	10
	75-110	38
	110-140	34
20-2	0- 30	--
	30- 40	--
	40- 85	1
	85-120	27
21-1	0- 30	1
	30- 40	1
	40- 85	11
	85-125	15
	125-150	33
21-2	0- 30	1
	30- 65	18
	65- 95	33
	95-130	37

Transect obs.	Depth (cm)	CaCO3 Equivalent %
22-1	0- 25	19
	15- 41	65
	41- 55	36
	55- 75	31
	75-110	33
	110-150	30
22-2	0- 25	45
	25- 40	50
	40- 55	49
	55-130	34
	130-150	34
22-3	0- 25	52
	25- 40	61
	40- 55	40
	55-130	35
	130-150	34
23-1	0- 30	3
	30- 55	16
	55-100	32
	100-150	34
23-2	0- 30	1
	30- 55	1
	55- 75	22
	75-115	22
	115-150	27
23-3	0- 30	17
	30- 37	32
	37- 90	26
	90-150	33
23-4	0- 30	19
	30- 45	29
	45- 90	34
	90-150	34

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