

PROPERTIES, GENESIS AND CLASSIFICATION OF TEXTURAL
SUBSOIL HORIZONS IN SOME MICHIGAN SOILS

By

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AN ABSTRACT

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ABSTRACT

The characteristics, genesis and classification of textural sub-soil horizons in some Podzol and Gray-Brown Podzolic soils of Michigan were studied.

A series of three soil profiles having textural bands from the lower, central and upper part of Michigan's lower peninsula, in addition to a maximal Podzol profile (void of such textural bands) were described in detail in the field. Bag samples from selected horizons of these profiles were taken for further laboratory studies. Laboratory analyses included pH, exchange capacity, exchangeable hydrogen, organic matter, "free iron oxide", mechanical composition, and total specific surface.

A series of mineralogical analyses were also undertaken. The dominant sand fractions of the soil horizons were analyzed for quartz, K and Na feldspars, using an x-ray geiger counter spectrometer. Clay minerals present in the less than 2 micron fractions were identified using both an x-ray geiger counter spectrometer and differential thermal analysis apparatus. Heavy mineral separations of dominant sand fractions were also conducted.

Finally artificial columns containing pure quartz and sub-soil material from the Coloma fine sand profile, with or without artificial limy layers, were set up. Columns were leached with distilled water, suspensions containing natural clay material previously decanted from the same subsoil

material and dilute oxalic acid solution. Visual changes in the columns after leaching, changes in the clay content of suspensions after moving through soil columns and changes in the clay distribution in columns themselves were recorded.

Field observations showed textural layers to be more reddish in color as well as finer textured than sandier horizons immediately above or below them. They may cut across geologic strata and their vertical cross-sections are often wavy and discontinuous. Some textural layers are calcareous, do not follow surface configuration and do not cut across geologic strata.

Physical, chemical and mineralogical studies in the laboratory showed non-limy bands to contain a higher concentration of silicate clay minerals, higher organic matter and "free iron oxide", lower pH, higher total specific surface, higher exchange capacity and exchangeable hydrogen.

The studies indicated that most of the textural horizons were pedo-petrogenetic in origin; i.e. original stratification of parent material had been modified by soil development processes.

The pedogenetic modifications may result from independent or simultaneous movement of silicate clay minerals, iron oxide, and organic matter. As evident from uniform distribution of clay minerals in some soil profiles and artificial soil column experiments in the laboratory, bulk clay movement is a major factor in clay translocation in coarse textured

soils. Bulk silicate clay movement alone, however, will not account for the high organic matter and "free oxides" in the textural bands or the variations in mineralogical compositions of some of the bands. Movement of a silicate clay mineral-organic matter-iron oxide combination; a silicate clay acid or iron oxide-organic matter complex; or organic matter and an iron oxide-clay mineral combination are also possible mechanisms.

Soil clay minerals and organic matter have a net negative charge, while iron oxide (hydrated) has a net positive charge. All or any of the three combinations mentioned above will be able to move simultaneously through the silicate soil skeleton if all assume a negative electrical charge.

Free lime, alternate wetting and drying of soil as influenced by evapo-transpiration, may bring about the deposition of mobile constituents in suspension. Changes in the chemical characteristics of the moving clay complexes; e.g. electrical charge, brought about by addition or removal of one or more of the constituents by the soil matrix through which they move, may cause flocculation and deposition. A change in the electric charge of an organic-iron complex as it moves through soil body could cause its flocculation and also deposition of silicate clay coming in contact with it.

Some of the "free iron oxide" found in soil horizons is attributed to that which is derived from lattices of clay minerals.

Mineralogical discontinuities in these soil profiles do not alone account for the formation of textural bands in situ, i.e. weathering in place, but may indicate the possibility of this as a contributing factor.

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INTRODUCTION

In evaluation of a soil characteristic, both the petrogenic history of the parent rock and the pedogenic history of the soil may be important. Horizonation may be due to pedogenic processes, stratification of the parent rock material (petrogenic) or both. Ordinarily, the older the soil, (parent material, climate, vegetation and relief remaining relatively constant) the stronger will be the pedogenic and the weaker will be the petrogenic influence in the soil profile make-up. Soils developed from glacial materials in areas repeatedly glaciated are apt to be stratified due to fluvial activity prior to or during the latest transportation and deposition of the materials.

This study deals with the characteristics of textural subsoil bands found in some soils of Michigan and their probable mode of origin. The strong influence of parent rock material, due to the relative youth of the soils, and the strong eluviation associated with the prevailing climate are taken into account.

A series of soil profiles having textural bands, from the lower, central and upper part of Michigan's lower peninsula were described in detail in the field and bag samples were taken from selected horizons for further laboratory studies. An attempt was also made to reproduce textural bands in artificial soil columns in the laboratory.

Knowing the physical and chemical properties of the textural bands as well as their mode of occurrence in the field, an hypothesis was developed which might explain the origin and development of textural bands in many soil profiles of Michigan.

Finally, proposals for designating these horizons to make clear their properties and genesis are presented.

REVIEW OF LITERATURE

A number of investigations into the nature and origin of color or textural subsoil bands have been reported in the last few decades, but more intensive studies have been started in the last few years. Following is a summary of some of the literature dealing with: A. X-ray diffraction and thermal analyses of soils; B. Chemical reactions of periodic nature; and C. Textural (or color) bands in soils, (a) soils containing textural B horizons, (b) textural band formation in soils, composition and genesis, (c) general aspects of iron and clay movement and deposition in soils, and (d) clay minerals present in podzolic soils.

A. X-ray Diffraction and D. T. A. Analyses of Soils.

Grim (1953) offers a comprehensive review of the methods available for the x-ray determination of soil clay minerals. Whiteside (1948) used x-ray film patterns for a quantitative mineralogical study of soil silt fractions. Working with Sangamon loess, he found that for quartz, the L.S.D. at the five percent level was 3.63 percent, and for feldspar 2.19 percent. Phillippe and White (1950) used an x-ray geiger counter spectrometer to estimate quantitatively minerals in fine sand and silt fractions of soils. For silt fractions they found the standard deviation to be 2.19 percent for quartz, 0.89 percent for albite and 3.24 for microcline. They assert that by substituting a geiger counter for the film, a

linear relationship exists between intensity of recorded impulse and amount of crystalline material present. Pollack and Whiteside (1954) used an x-ray geiger counter spectrometer in a quantitative estimation of quartz in soils. Their investigation emphasizes the importance of a careful standardization of working conditions and frequent checking of standard samples to detect possible errors in determinations. At the five percent level, a 4.9 percent difference in quartz samples was significant. Cann and Whiteside (1955) used quartz to evaluate quantitative changes in a soil profile. They used an x-ray geiger counter spectrometer, standard quartz, and a particle size range of two-to-fifty microns. They reported no significant effect due to particle size in diffraction intensities, over this range in particle sizes.

Grim (1953), Grim and Rowland (1942), Speil, et al. (1945) and Kerr, et al. (1949) offer a detailed study of the differential thermal analyses (D.T.A.) of clay minerals. Grim and Rowland (1942) found montmorillonite to give endothermic peaks at $100-250^{\circ}\text{C}$, $600-700^{\circ}\text{C}$, and 900°C . The first endothermic peak is due to planar water loss, while the second and third peaks are due to lattice water loss and lattice decomposition respectively. Illite gave endothermic peaks at $100-200^{\circ}\text{C}$, $500-600^{\circ}\text{C}$, and 900°C . Kaolinite has an endothermic peak at 550°C , and an exothermic peak at $950-1000^{\circ}\text{C}$. Both Grim and Rowland (1942) and Speil, et al. (1945) stress the importance of uniform packing and position of thermo-

couples in getting reproducible results. Both agree that the degree of accuracy lies within ten percent, and that additional x-ray work or petrographic studies are necessary in order to definitely corroborate qualitative or quantitative D.T.A. work. According to Speil, et al. (1945) rate of temperature rise has little effect on the endothermic peak, while particle size of clay affects its sharpness and position. Kerr, et al. (1949) state that the relative amplitude and shape of peaks are a function of the concentration of the specific clay mineral present. According to them, for semi-quantitative work, amplitude is accurate enough although areas under peaks are more accurate.

B. Chemical Reactions of Periodic Nature

Liesegang, in 1896, demonstrated band formation in gels that have since been called Liesegang-rings. Holmes (1918) obtained a periodic precipitation of concentric rings (bands) in test tubes of a gel containing chromate ion when a solution of a copper salt was placed on top of the gel in the tubes. According to Holmes, the reason for the gap between precipitation layers is the slow diffusion of chromate ions in gelatin, limiting precipitation to specific depths. Once a ring precipitate was formed, copper ions in excess diffuse to areas of higher chromate ion concentration to bring about a new precipitation. From Holmes's explanation it seems that differential diffusion rates of ions in a specific medium can cause a periodic precipitation if the ions present combine to form

insoluble salts once they are in contact with each other. Morse (1930) worked with supersaturated solutions of various salts. He observed that slightly supersaturated solutions may stand indefinitely without precipitation, while highly supersaturated solutions show rapid precipitation and ring formations in capillary tubes. Morse concluded that supersaturation up to a certain point followed by rapid precipitation caused rhythmic ring formation in the absence of any colloidal material. Similar reactions might reasonably be expected to occur in capillary or colloidal systems such as soils and could conceivably result in color or textural bands differing in chemical composition from adjoining layers.

C. Textural Bands in Soils

a.) Soils containing textural B horizons in the North-central United States

Veatch (1932) established a transition zone between the Podzol region of the northern part of Michigan and the Brown Forest (Gray-Brown Podzolic) region of the southern part of the state. Veatch and Millar (1934) first recognized the bisequa* soil profiles in Michigan. Cline (1949) in describing the bisequa profiles in New York state, visualized the upper Podzol profile as developing in a siliceous A₂ horizon of an older Gray-Brown Podzolic soil. He thus suggests a

*Soil profiles containing more than one kind of illuvial horizon and associated eluvial horizons. This term has recently been proposed by G. D. Smith for such profiles.

chrono-sequence relationship between the two sequa. Nygard, et al. (1952) working in the northern portion of the Lake states characterized Podzols as being highly acid and having a high exchangeable hydrogen percentage due to intensive leaching and movement of organic acids. Stobbe (1952) working in Eastern Canada visualized a Brown Forest--Gray-Brown Podzolic --Brown Podzolic--Podzol chronosequence. According to Stobbe on non-calcareous materials only Brown Podzolic and Podzol soils are formed. Gardner and Whiteside (1952) worked with soils of the Podzol--Gray-Brown Podzolic transition region of Michigan. Their investigations showed that soils developed on loamy sand to sandy loam materials have bisequa profiles, with an upper Podzol sequum underlain by a Gray-Brown Podzolic sequum. Both sequa were derived from the same limy parent material and they believed might be developing simultaneously. In the Marlette bisequa profile, investigated by Cann and Whiteside in 1955, they believed both sequa to be developing simultaneously. Holt and McMiller (1956) working in the Gray-Brown Podzolic--Podzol transition zone in Minnesota do not mention any trace of bisequa profiles. According to these authors, the soils all had a low overall base-saturation, being lowest in the B horizon. Bailey (1956) made a mineralogical study of the parent rock materials of a number of Michigan soils. He found quartz to be the dominant mineral species in all the sand and silt fractions studied while K-feldspar and plagioclase were the other important coarse minerals.

b.) Textural band formation in soils; composition and genesis

Smith, et al. (1950) discussed in detail the genesis and classification of Upper Mississippi Valley Prairie soils. They describe textural bands in soils developed from sandy parent material. These bands were located at a depth of 60 to 80 inches. Mechanical analyses showed their clay fractions to consist mostly of particles less than 0.2 microns in size. Smith, et al. considered these layers to be genetic, formed by clay movement from overlying materials into these layers. The cause of accumulation at specific depths, it was postulated, might be due to free iron oxide flocculating downward migrating clay. They were thus assumed to move to their present position in the absence of any flocculating agent previous to the encountering of free iron oxide.

Folks and Riecken (1956) demonstrated the ability of an organic acid i.e. oxalic acid to mobilize free iron oxide present in the soil. The rhythmic precipitation, it is postulated, is caused by increased withdrawal of the organic ion from solution by absorption on the soil material through which it moves. The organic ion concentration finally goes below the minimum necessary to hold iron in suspension and iron oxide precipitates. This accumulation of positive iron colloid will in time cause clay flocculation out of a downward moving clay suspension by mutual flocculation. This, according to Folks and Riecken, is the mechanism by which clay-iron bands are formed.

Jenny and Smith (1935) used artificial quartz sand columns through which ferric oxide or aluminum oxide sols and clay suspensions were alternately passed. Incipient formation of a clay-pan was evident in these columns. No such evidence was found by a mere leaching of quartz sand columns with clay suspension. The finer the sand in the columns the more rapid was the formation of an incipient clay pan by alternate clay and free oxide leaching. The authors also observed that a previous leaching of the sand columns with an electrolyte solution of various mono- and di-valent ions, enhanced clay accumulation in all cases. Jenny and Smith concluded that conditions favorable for clay-pan formation in the field are: (a) alternate movement of electropositive and electronegative colloidal suspensions, i.e. ferric hydroxide and clay in suspension, (b) flocculation of clay particles by electrolytes or free oxides, and (c) deposition of fine clay coating along minute movement channels causing sieving action and deposition of materials in pores and blocking any future material movement.

c.) General aspects of iron and clay movement and deposition in soils

Anderson and Byers (1933) tested the interaction of free oxides such as iron and aluminum oxides with various decomposition products of organic matter (i.e. peat, muck) as well as the organic fraction of mineral soils. They found that both aluminum and iron hydroxides yielded iron and aluminum to the organic materials and formed strong complexes with them. They also observed that a ferrous salt gave a stronger combination

with the organic materials than the ferric salt did. Anderson and Byers postulate therefore that under cool humid climates, ferrous ions released from silicate minerals by hydrolysis, form ferrous hydroxide while humic acid is produced by the decomposition of organic matter. These compounds react to form a resistant iron-organic matter combination which in turn is leached downward in the soil profile. It was further postulated that under strong oxidizing conditions and/or lowering of acidity, ferric hydroxide and organic radicle separate to form the B horizon of a Podzol soil.

Winters (1940) worked with gelatin, agar, silica gel and a 5 percent bentonite gel. He observed no diffusion through any of the materials on contact with ferric hydroxide suspensions. All of the gels except silica flocculated on addition of ferric or aluminum hydroxide. This Winters attributes to the positive charge associated with the metal hydroxide as compared to the negative charge of the gels. On contact of peat extract with the gels, diffusion of the extract was clearly evident. This in turn, it was postulated, was due to the common negative charge of the materials. Adding a small amount of organic colloid to ferric hydroxide did not affect its indiffusibility, but when the organic matter--iron ratio was greater than one, iron sol diffused slowly through agar, yet bentonite gel still caused it to flocculate. Winters concluded that the movement of iron sols by diffusion through soils is negligible, and that most of it moves by

convection through pores and channels. He also found that by the placing of a powdered iron bearing silicate on top of bentonite gel, diffusion of iron in the ferrous form took place. This Winters attributes to "surface migration" on clay surfaces by exchange with adsorbed ions.

Deb (1950 a, b) used acid and alkali extracts of peat humus and Podzol B horizon. He found that during the addition of humus to precipitated iron hydroxide a gradual change in the charge of the colloid took place. With increased amounts of humus added, the stability of a sol as a negative colloid increased, i.e. increased amounts of negative ion were needed to flocculate the iron hydroxide sol. Deb also observed that once the iron sol was completely peptized divalent cations (calcium) had a strong flocculating effect on it. On the other hand according to Deb, exchangeable calcium ions in Podzol soils have no flocculating effect on iron-humus complexes. He concludes, by process of elimination of possibilities considered, that it is the microbial activity in soils which causes the breakdown of humus-iron complexes and the precipitation of ferric-hydroxide in Podzols.

Bloomfield (1953 a, b) working with leachates of Scotts pine and Kauri leaves demonstrated their ability to mobilize iron and aluminum oxides even under strong aerobic and neutral conditions. As to how long organic material can hold on to the iron, Bloomfield states, is a function of the intensity of aerobic conditions and the pH of the medium. Bloomfield concluded that the deposition of iron in soils from the organic

complex is due to both pH and aerobic conditions and not to microbial activity. In 1954 Bloomfield demonstrated the complexing action of aspen and ash leaf leachates on iron even in alkaline conditions. According to him, different organic compounds mobilize iron under coniferous and deciduous vegetation. Bloomfield (1954) upholds the theory that clay accumulation in Podzolic soils is due both to the resynthesis from eluviated free oxides as well as bulk clay movement. Aqueous solutions of ash and aspen leaf leachates were found by Bloomfield to have a marked deflocculating effect on kaolin and to a lesser extent on montmorillonite clays.

Delong and Schnitzer (1955 a, b) in their study of iron transport in soils used leachates of aspen, maple, beech and birch leaves and ferric-hydroxide. They found these leachates to mobilize iron (determined as metallic element) in suspension, from A₂ and B₂ horizons of Podzol and Gray-Wooded soil profiles. According to them, there exists a narrow range of organic matter-iron (metallic form) concentration ratio in which maximum iron uptake will take place. This ratio centers around a 100 percent saturation of the organic exchange capacity with ferric ions. Delong and Schnitzer also found the acidic polysaccharides present in the leachates to be the main contributors to the iron hydroxide mobilizing ability of the leaves.

Bodman and Harradine (1938) experimenting with soil columns eight inches high of various textures, leached them

with distilled water and dilute electrolyte solutions. They found that columns containing sandy loam to clay loam materials allowed movement of material finer than fifteen microns. Columns containing loamy-sand to sandy loam materials allowed movement of material finer than fifty microns. The five to two micron material showed no regularity of trend in depth distribution within any of the columns after leaching. From this study the authors conclude that particle migration in soils is controlled by porosity of soil as well as chemistry of colloidal material present. Clay accumulation, they believed, takes place by physical translocation as well as free oxide movement of previously hydrolyzed clay minerals and recombination at greater depths.

Bray (1934) worked with soils developed in loessial material in Illinois. Chemical analysis of the fine colloid fraction (less than 0.1 microns) showed the different properties of that fraction when compared with the "whole colloid" i.e. less than two micron material. This fine colloid, according to Bray, is a decomposition product of the coarse clay size particles or may be formed by weathering of coarse minerals in the soil. Bray concludes that breakdown of material to fine clay size particles and their subsequent movement will cause profile differentiation. Even breakdown of coarse clay material to fine clay size and subsequent eluviation he believes causes a differentiation in the types of clay minerals in different soil horizons.

Nikiforoff and Alexander (1942) studied the clay-pan and hard-pan of the San Joaquin soil in California. The clay-pan was situated below the surface but above the hard-pan. Chemical analyses showed iron and silica to be the main cementing agents in the hard-pan. Their presence in the hard-pan was due at least in part to crystallizing in place, according to the authors, as secondary growth of quartz was evident. According to Nikiforoff and Alexander the formation of the clay pan is due to weathering in place of silt size particles, with some of the free oxides recombining to form clay and some leaching down from higher in the profile and recombining there to form new clay minerals. The hard-pan underneath the clay-pan, is postulated, to have formed earlier than the clay pan due to micro-relief variation which caused ground-water to deposit salts and free oxides during summer evaporation. The authors sum up their findings by saying that under the prevailing climatic conditions weathering in place as well as sesquioxide translocation causes the formation of a clay pan above the already existing hard-pan.

Nikiforoff and Drosdoff (1943) worked with the Dayton clay-pan soil in California. According to them, chemical analysis indicated independent migration of sesquioxides from the A horizon to the B horizon of the soil. High total iron and low free iron content of B horizon was attributed to the incorporation of the iron in the newly formed clay minerals. The "gain" in clay in the B horizon was far greater than the "loss"

in sesquioxides from the A horizon. The authors concluded therefore that part of the clay in the B horizon is due to weathering of soil particles in situ as well as movement of free oxides from the A horizon and their translocation to the B horizon. In the B horizon recombination of the free oxides takes place with the formation of clay minerals.

Brown, et al. (1933) studied Chernozem-like soils having clay-pan formations. Chemical and physical analyses showed the clay content to increase downward with a maximum clay content just above the free lime horizon, where pH was observed to rise sharply. From their study Brown, et al. concluded that clay was translocated downward from the surface by dispersion and subsequently flocculated due to high calcium ion content above the free lime horizon. From silica:alumina and silica:iron ratios as well as water of hydration, Brown, et al. concluded that the same kind of clay existed throughout soil profiles of most soils, and that this serves as further proof for the bulk clay translocation.

Marshall and Haseman (1942) used the heavy mineral fraction of fine sand fractions to study qualitative and quantitative changes in a soil profile during its development. They used zircon as an index of weathering. They found that the increase in volume and weight of the B horizon of the Grundy silt loam profile was due partly to an increase of clay brought about by weathering, in situ, and partly by movement of clay from the A₂ horizon above.

Thorp, et al. (1957) prepared artificial columns of Miami clay loam B₂ horizon materials. These columns were leached with leachates of beech leaves as well as oxalic acid and tannic acid. Analyses of the columns after leaching showed a definite indication of fine clay movement out of their upper parts. Clay was present in leachates from all columns. Analysis of that clay showed the presence of illite, vermiculite, chlorite and montmorillonite. From this the authors concluded that clay movement in the columns was in bulk form. Tannic acid leachates showed the highest iron content and was considered as a stronger iron mobilizer than oxalic acid.

d.) Clay minerals present in Podzolic soils

Alexander, et al. (1939) reported illite to dominate in several representative Gray-Brown-Podzolic soils. Grim (1942) and Bidwell and Page (1950) concluded that it is unlikely that illite forms in soils and is therefore a remnant of original parent material. Kaolinite and montmorillonite, however, they believe, are formed during soil profile development. Grim (1953) stated that montmorillonite and illite are the main clay constituents of calcareous sediments. He believed that no alteration takes place until carbonates are all removed. Coleman and Jackson (1945) in their work on soils of Southeastern United States found no correlation between pH of soil and clay minerals present. Walker (1949) visualized a progressive weathering of mica to a mixture of mica and vermiculite and finally vermiculite. This is brought about by loss

of potassium, expansion of this layer, magnesium replacing iron in the lattice and absorption of water in the interlayer surface. Albareda, et al. (1950) working with Spanish soils developed under a variety of climatic conditions, found kaolinite, montmorillonite, hematite and goethite to accumulate in fine clay fractions, while mica and illite prevailed in the coarser clay fraction. Jackson, et al. (1952) in studying the weathering sequence of clay size minerals visualized podzolization as a depotassification with resilication. Mica is converted to montmorillonite and vermiculite by removal of iron and magnesium and the addition of silica. Tamura and Swanson (1954) identified illite, vermiculite and chlorite in New England Brown-Podzolic soils.

METHOD OF ATTACK

Introduction

During the 1954 soil survey of the Tri-Township area in Kalkaska County, Michigan, it was observed that a large number of soils developed from coarse textured parent rock materials i.e. sand, loamy sand and sandy loam, had textural and/or color bands in their subsoil. Similar bands were also observed by other soil surveyors in Central and Southern Michigan. A study of these bands was undertaken in the following manner:

A. A careful and detailed field study of the mode of occurrence as well as the observable field characteristics of textural bands was made. On the basis of these observations, four soil profiles were selected and after detailed field descriptions were obtained, bag samples from selected horizons were collected.

B. These samples were brought to the laboratory and analyzed for specific physical, chemical and mineralogical properties. The analyses included: (a) Micropedological study of large aggregates from specific textural bands in order to observe spatial relationships between soil matrix and mobile components present in the soil. (b) Some general chemical and physical characteristics associated with textural or color bands compared to other horizons in the soil profiles, e.g. specific-surface, pH, exchange capacity and base-saturation. (c) Mobile components, their relative concentration in the textural bands as compared with the horizons immediately above or

below them, i.e. less than two micron clay, "free iron oxide" content, organic carbon content and types of clay minerals present in the less than two micron clay fraction. (d) Tests of the uniformity of original parent rock material from which both textural bands and horizons between them were formed. For that purpose a series of mineralogical investigations were undertaken which included quartz, feldspar and heavy mineral content of dominant sand fractions, and particle size distribution within the greater than two millimeter fraction.

C. Using artificial soil columns containing soil materials from the subsoil of one of the soils investigated or quartz sand, a number of attempts were made to reproduce textural bands in the laboratory. Observations were made on the changes which took place in soil columns as well as in the different leaching solutions and suspensions. Due to the lack of time, large quantities of leachate were used over a relatively short interval so as to speed up any reaction which might otherwise take place over a prolonged period.

In the light of these analyses and experiments, and keeping in mind previous investigations on the subject, a hypothesis was developed which might explain properties observed as well as the genesis and occurrence of the textural bands.

Soils Studied

After field study, four soil profiles were sampled. The profiles of Montcalm loamy sand and Wallace sand were obtained in the Northern Podzol region of Michigan's Lower Peninsula in

Kalkaska County, Michigan. This Montcalm profile showed a definite series of finer textured bands below the upper Podzol sequum of this bisequa soil profile. The Wallace profile had no textural subsoil bands and was derived from relatively uniform sand parent rock material. It is a maximal Podzol. The Montcalm fine sand was sampled in the Podzol-Gray Brown Podzolic transition zone in Kent County, Michigan. This profile showed a clear differentiation into numerous thin finer textured subsoil layers below a weakly developed Podzol B and the remains of a plow layer. A Coloma fine sand profile was sampled in the Gray-Brown Podzolic region of the Southern part of Michigan (Calhoun County, Michigan). The Coloma profile showed a large number of thin fine textured subsoil bands with only traces of an overlying Podzol B horizon. No free lime was encountered at any depth in the Wallace sand, Montcalm fine sand or Coloma fine sand profiles.

Montcalm loamy sand

Location T26N R8W Section 34 NE1/4, NE40, NE corner. Boardman twp. Kalkaska County, Michigan.

Native vegetation . . Northern hardwood i.e. sugar maple, beech, and northern red oak.

Drainage Well drained

Slope 10 percent

Physiography Rolling, glacial moraine, Mankato age

Montcalm loamy sand (continued)

Sample number	Depth	Horizon	Description*
M1	0-8"	Ap	Grayish yellowish brown(10YR4/2, moist); loamy sand; weak, medium, granular; soft; pH 6.4.
M2	8-10"	A2	Light yellowish grayish brown(9YR6/2, moist); sandy loam; medium, platy; soft; pH 6.6.
M3	10-17"	Bhir	Dark yellowish brown to moderate yellowish brown(10YR4.5/3, moist); sandy loam; medium, crumb; slightly hard; pH 6.2.
M4	17-24"	A2	Light grayish yellowish brown to yellowish gray(10YR6/5, moist); sandy loam; medium platy; soft; pH 6.2.
M5	24-30"	Bt-1a	Grayish brown to grayish yellowish brown (7.5YR4/2-10YR5/3, moist); sandy clay loam; medium angular blocky; hard; pH 5.6.
M6	30-35"	Bt-1b	Light yellowish brown to moderate yellowish brown(7.5YR5/4-10YR5/4, moist); sandy loam; medium, angular blocky; hard; pH 6.6.
M7	35-39"	A2	Light yellowish brown(10YR7/4, moist); sand; single grain; loose; pH 6.9.
M8	39-41"	Bt-2a	Strong brown to strong yellowish brown (7.5YR5/6-5YR4/8, moist); sandy loam; medium, angular to subangular blocky; hard; pH 6.8.
M9	41-43"	Bt-2b	Light grayish brown(7.5YR5/2, moist); sandy loam; medium, subangular blocky; hard; pH 6.4.
M10	43-48"	A2	Light grayish yellowish brown(10YR7/3, moist); sand; single grain; loose; pH 7.4. Thickness varies from 2-5 inches; calcareous in spots.
M11	45-50"	Bt-3	Strong yellowish brown(7.5YR5/7, moist); loamy sand; weak, blocky; soft; pH 7.6. Thickness varies from 2-5 inches; calcareous in spots.
M12	48-52"	A2	Light yellowish brown(10YR7/3, moist); sand; single grain; loose; pH 8.0; calcareous.

* ISCC-NBS color names are used in the following descriptions, taken from: "ISCC-NBS Method of Designating Colors and a Dictionary of Color Names", U.S. Department of Commerce, Bureau of Standards, Circular 553, 1956. pH measurements were done with a glass electrode.

Montcalm loamy sand (continued)

<u>Sample number</u>	<u>Depth</u>	<u>Horizon</u>	<u>Description</u>
M13	52-58"	Bt-4a	Strong yellowish brown(7.5YR5/7, moist); loamy sand; weak, angular blocky; slightly hard; pH 7.8; calcareous.
M14	56-60"	Bt-4b	Strong yellowish brown(7.5YR5/7, moist); loamy sand; weak, angular blocky; slightly hard; pH 7.8; calcareous.
M15	58-62"	A2	Light yellowish brown(10YR7/3, moist); sand; single grain; loose; pH 8.0; slightly calcareous.
M16	62-69"	Bt-5	Strong yellowish brown(7.5YR5/7, moist); loamy sand; weak, angular blocky; slightly hard; pH 7.6; slightly calcareous

Montcalm fine sand

Note: The selection of this location was motivated by the very clear differentiation of the lower soil profile into thin, finer textured layers, in between much thicker sandy horizons. Because of their horizontal layering, these bands give the strong impression of being a result of the original stratification of the parent rock material. Some removal of the upper horizons had occurred in the road cut and they were not sampled therefore. Due to the thinness of the textural bands, sample descriptions refer to specific depths rather than to the total thickness of each horizon. This profile is the coarse textured extreme of the Montcalm series.

Location T6N R8W Section 1 NE1/4, SW corner. Along highway M21, 2.5 miles southwest of Ada, Ada twp., Kent County, Michigan.

Native vegetation . . Mixed Northern Hardwood and Oak Hickory.

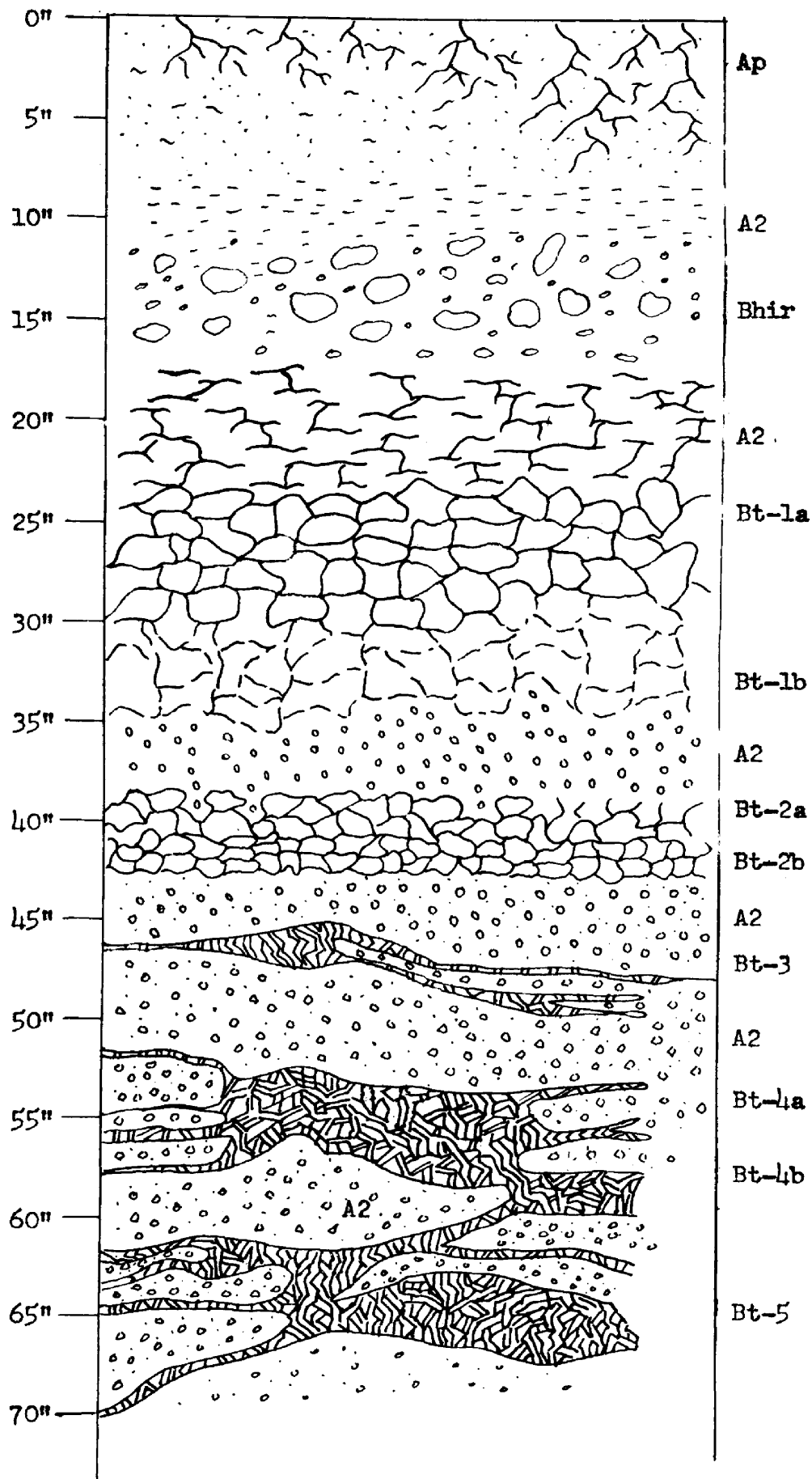
Drainage Well drained.

Slope 20 percent.

Physiography Hilly glacial moraine, Cary age

Figure. 1 Montcalm loamy sand;
profile diagram

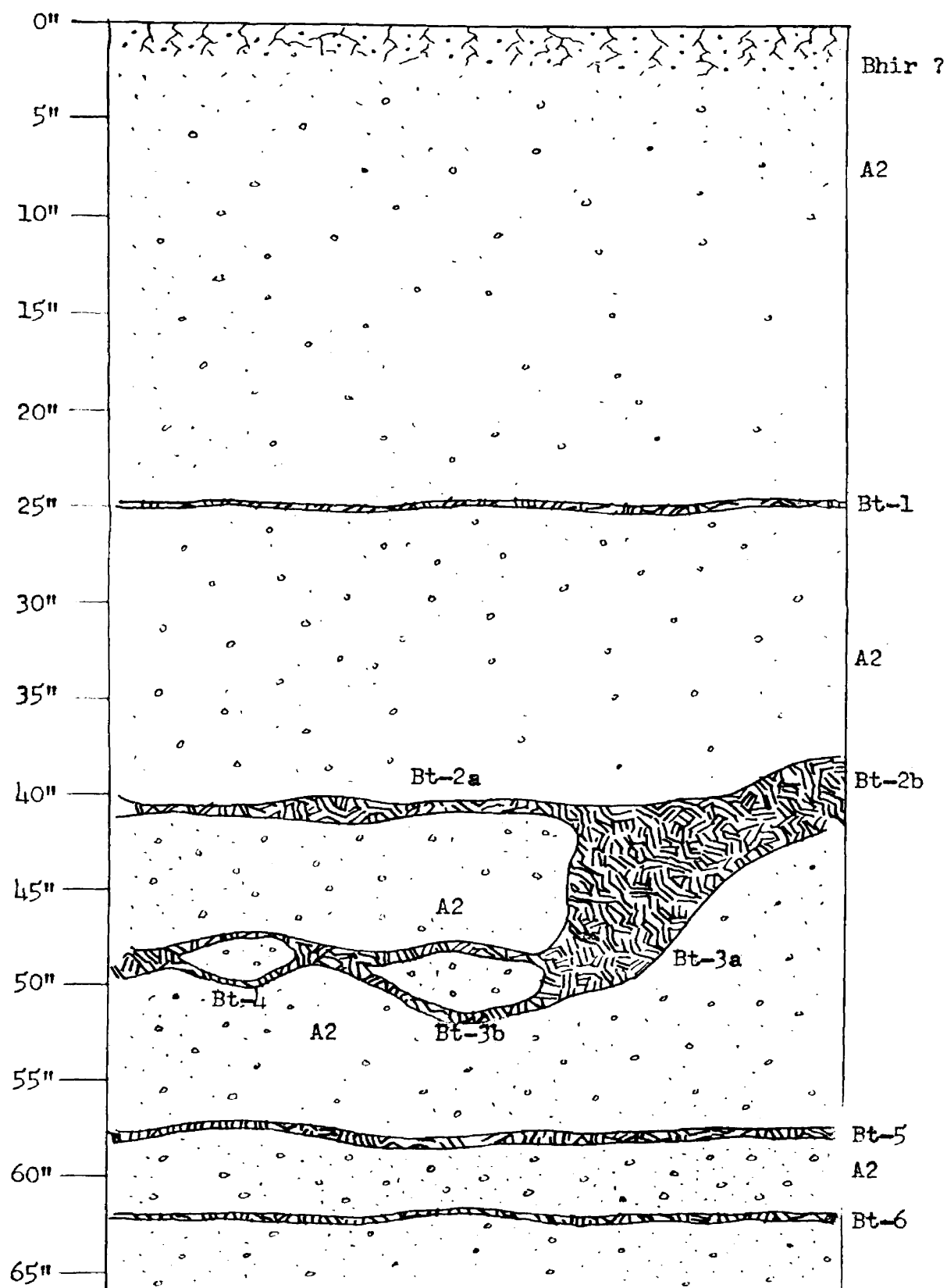
23.



Montcalm fine sand (continued)

Sample number	Depth	Horizon	Description
K1	0-2"	Bhir ?	Moderate yellowish brown(10YR5/3-5/4, moist); fine sand; crumb; friable; pH 7.2.
K2	17"	A2	Moderate yellowish brown to light yellowish brown(10YR5/4-6/4, moist); loamy fine sand; massive to slightly blocky; soft; pH 6.7.
K3	25"	Bt-1	Strong yellowish brown(7.5YR5/7, moist); loamy fine sand; very weak, angular blocky; soft; pH 6.7.
K4	38"	A2	Light yellowish brown(10YR6.5/6, moist); fine sand; massive to slightly blocky; soft; pH 7.1.
K5	41"	Bt-2a	Light brown(7.5YR5/5-5/6, moist); fine sandy loam; weak, medium, angular blocky; friable; pH 6.8.
K6	43"	Bt-2b	Light brown(7.5YR5/4-5/6, moist); fine sandy loam; weak, medium, angular blocky; soft; pH 6.4.
K7	47"	A2	Light yellowish brown(10YR6/5, moist); loamy fine sand; slightly massive; soft; pH 7.3.
K8	49"	Bt-3a	Strong yellowish brown(7.5YR5/6-6/6, moist); fine sandy loam; weak, moderate, angular blocky; soft; 6.2.
K9	53"	Bt-3b	Strong yellowish brown(10YR5/8, moist); fine sandy loam; moderate, angular blocky; soft; pH 6.6.
K10	51"	A2	Light yellowish brown(10YR7/3, moist); fine sand; single grain; loose; pH 7.4.
K11	51"	Bt-4	Strong yellowish brown(7.5YR5/8, moist); loamy fine sand; moderate, angular blocky; pH 6.8.
K12	51"	A2	Light yellowish brown(10YR7/4, moist); fine sand; single grain; loose; pH 7.1.
K13	54"	A2	Light yellowish brown(10YR7/4, moist); fine sand; single grain; loose; pH 7.9.
K14	58"	Bt-5	Strong yellowish brown(7.5YR5/8, moist); loamy fine sand; weak, angular blocky; soft; pH 6.7.
K15	60"	A2	Light yellowish brown(10YR7/4, moist); fine sand; single grain; loose; pH 7.4.
K16	62"	Bt-6	Strong yellowish brown (7.5YR5/8, moist); loamy fine sand; weak, angular blocky; soft; pH 6.7.

Figure. 2 Montcalm fine sand;
profile diagram



Coloma fine sand

Note: The top two feet of the profile represented recent wind blown deposits. Depth designations are from the top of the deposit.

Location T3S R7W Section 3 NW1/4, NE40, SE corner
Newton twp., Calhoun County, Michigan

Native vegetation . . Oak Hickory

Drainage Well drained

Slope 6 percent

Physiography Rolling glacial moraine, Cary age

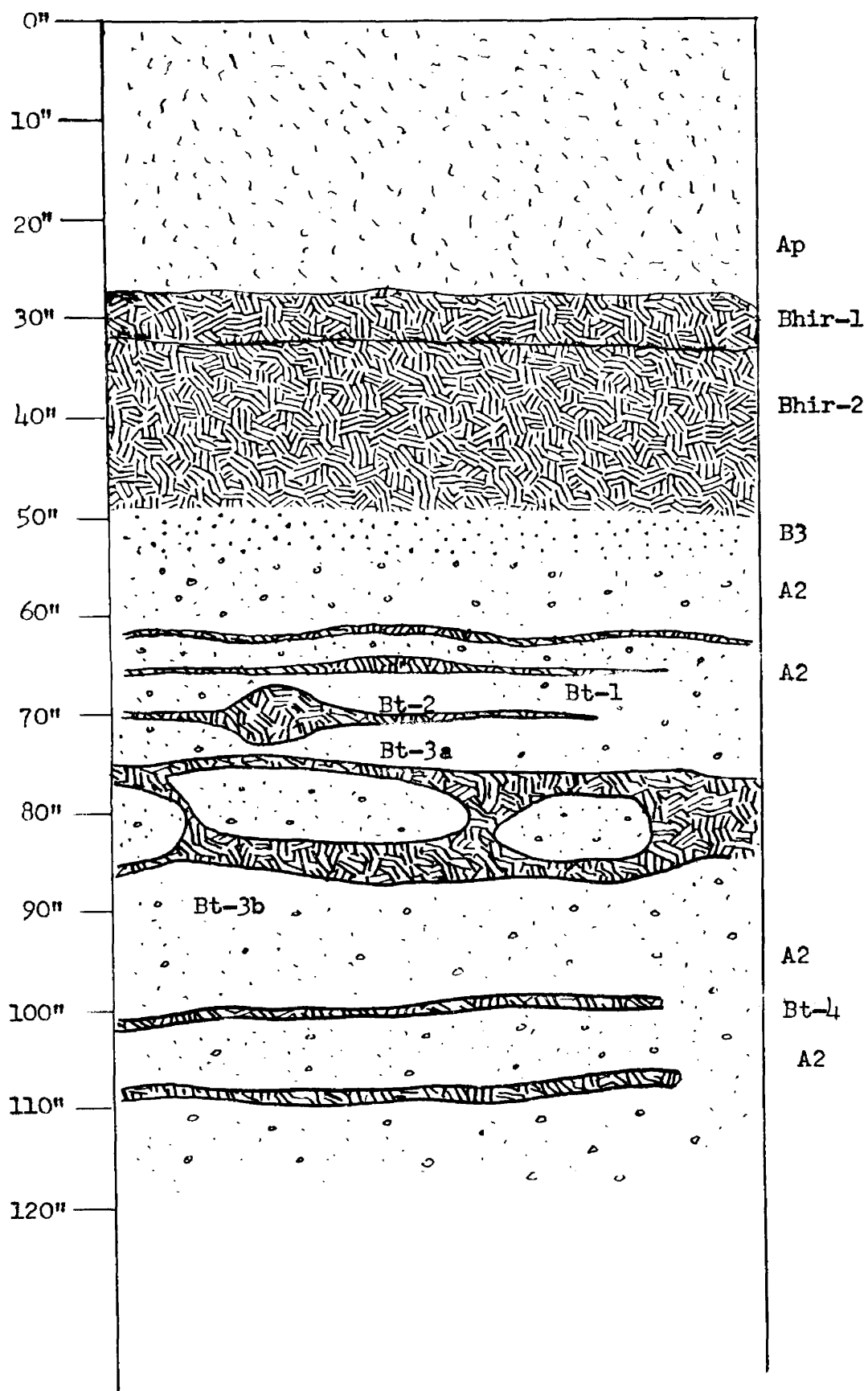
<u>Sample number</u>	<u>Depth</u>	<u>Horizon</u>	<u>Description</u>
-	0-24"	/	
C1	25"	Ap	Grayish yellowish brown(10YR4/2, moist); fine sand; single grain; loose; pH 7.7.
C2	30"	Bhir-1	Strong yellowish brown(10YR5/8, moist); loamy fine sand; very weak, angular blocky; soft; pH 7.6.
C3	40"	Bhir-2	Dark orange yellow(10YR6/8, moist); loamy fine sand; weak, massive; soft; pH 7.4.
C4	52"	B3	Moderate orange yellow(10YR7/8, moist); fine sand; single grain; loose; pH 7.4.
C5	57"	A2	Light yellowish brown to moderate orange yellow(10YR7/6, moist); fine sand; single grain; loose; pH 7.5.
C6	63"	A2	Light yellowish brown to moderate orange yellow(10YR7/6, moist); fine sand; single grain; loose; pH 7.4.
C7	65"	Bt-1	Light brown(7.5YR5/4, moist); loamy fine sand; very weak, fine, angular blocky; soft; pH 6.4.
C8	68"	A2	Light yellowish brown to moderate orange yellow (10YR7/6, moist); fine sand; single grain; loose; pH 7.0.
C9	70"	Bt-2	Light brown(7.5YR5/4, moist); loamy fine sand; very weak, fine, angular blocky; soft; pH 6.4.

Coloma fine sand (continued)

<u>Sample number</u>	<u>Depth</u>	<u>Horizon</u>	<u>Description</u>
C10	73"	A2	Light yellowish brown to moderate orange yellow (10YR7/6, moist); fine sand; single grain; loose; pH 5.5.
C11	76"	Bt-3a	Light brown(7.5YR5/4, moist); loamy fine sand; very weak, fine, angular blocky; soft; pH 5.5.
C12	80"	Bt-3b	Light brown(7.5YR5/4, moist); loamy fine sand; very weak, fine, angular blocky; soft; pH 5.5.
C13	95"	A2	Light yellowish brown to moderate orange yellow (10YR7/6, moist); fine sand; single grain; loose; pH 6.2.
C14	101"	Bt-4	Light brown(7.5YR5/4, moist); loamy fine sand; very weak, fine, angular blocky; soft; pH 5.5.
C15	106"	A2	Light yellowish brown to moderate orange yellow (10YR7/6, moist); fine sand; single grain; loose; pH 6.0.

Figure. 3 Coloma fine sand;
profile diagram

28.



Wallace sand

Location T26N R8W Section 14 SW1/4, NW40,
SW10, SW corner. Boardman twp.
Kalkaska County, Michigan.

Native vegetation Northern Hardwood i.e. Sugar maple,
Beech and Northern Red Oak

Drainage Well drained

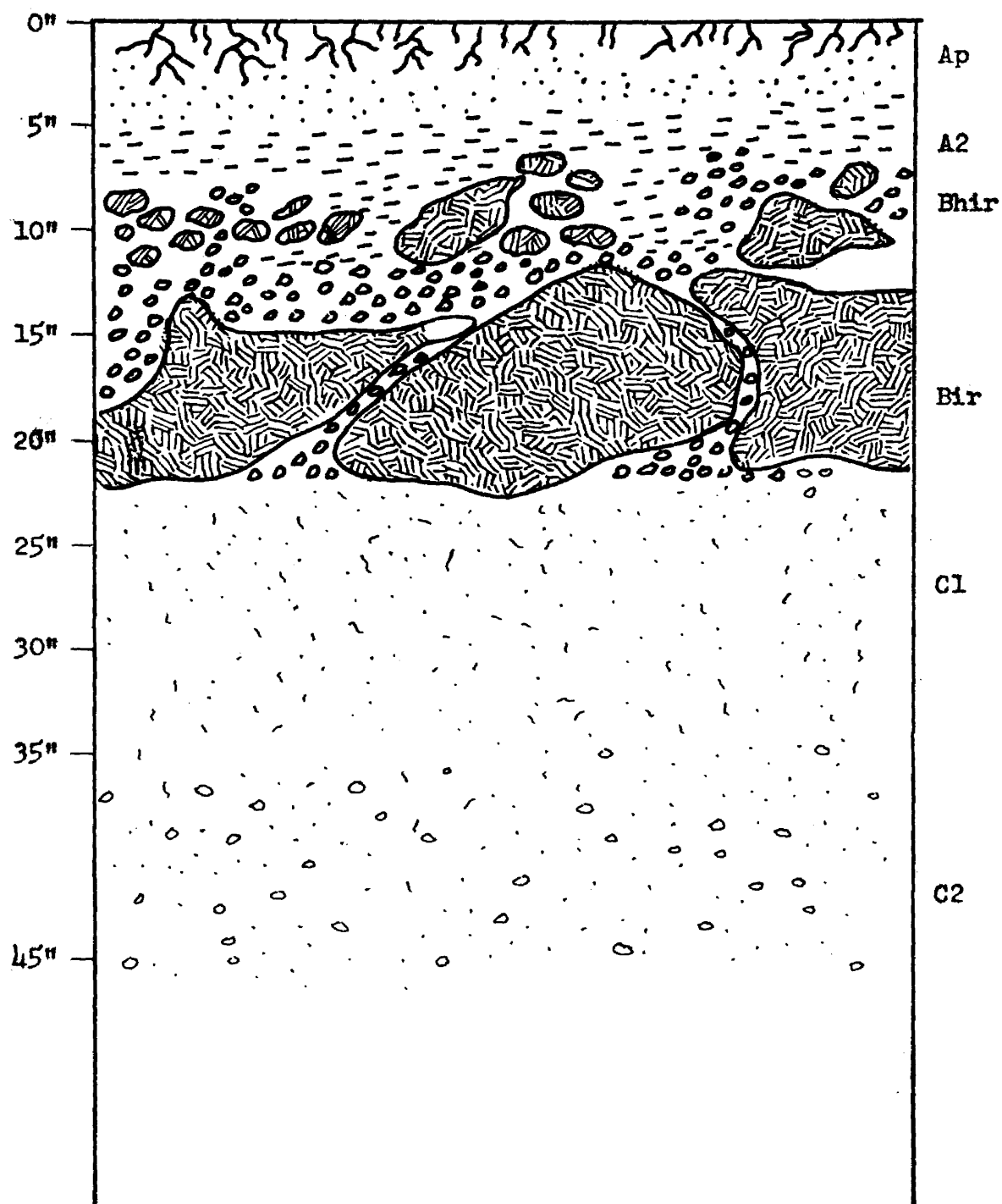
Slope 8 percent

Physiography Rolling glacial moraine, Mankato
age.

<u>Sample number</u>	<u>Depth</u>	<u>Horizon</u>	<u>Description</u>
W1	0-5"	Ap	Brownish gray(10YR4/1, moist); sand; single grain; loose; pH 6.5.
W2	5-7"	A2	Brownish pink(7.5YR7/2, moist); sand; single grain; loose; pH 6.1.
W3	7-12"	Bhir	Grayish brown(7.5YR4/2, moist); sand; massive; ortstein, mixed with orterde; hard; pH 5.3.
W4	12-22"	Bir	Strong yellowish brown(7.5YR5/8, moist); sand; massive; ortstein; hard; pH 5.5.
W5	22-35"	C1	Light yellowish brown(10YR7/6, moist); sand; single grain; loose; pH 6.4.
W6	35/	C2	Pale orange yellow(10YR8/3, moist); sand; single grain; loose; pH 6.4.

Figure. 4 Wallace sand;
profile diagram

30.



Methods of Analysis

Introductory Note

Due to the large number of samples on hand, only specific horizons were picked for detailed laboratory analysis, after field description. The choice of horizons and the respective analyses were motivated by their particular nature and position in the soil profile as revealed by field observations. The bulk samples from each horizon were sieved and the larger than two millimeter material collected and weighed. The less than two millimeter material was crushed using a wooden rolling pin and used for the remainder of the analyses.

pH Measurements:

Fifty gram samples were mixed with fifty milliliters of distilled water and left standing for half an hour. Determinations were made using the Beckman Glass Electrode pH meter, Model M2. Samples were run in duplicate.

Mechanical Analyses

Duplicate twenty-five gram samples were used. Organic matter was destroyed by overnight digestion with 200 ml. 10 percent H_2O_2 , followed by short hot digestion with 20 ml. of 30 percent H_2O_2 . Carbonates were destroyed by overnight digestion with 100 ml. of 1.0 N HCl. The samples were then leached free of chloride with distilled water and titrated with 0.1 N NaOH to phenolphthalein end point and shaken overnight. A 300 mesh sieve was used to separate the sand fractions. The sand was sieved to give various size fractions.

The less than fifty micron material was diluted to 1000 ml. in large glass cylinders and inserted in a constant temperature bath. Total less than fifty micron and less than two micron samples were withdrawn at appropriate times and depths. The mechanical analyses are reported on a lime free, organic matter free and oven dry basis.

Cation Exchange Capacity

The conductometric titration method proposed by Mortland and Mellor (1954) was used. Duplicate ten gram samples were leached with 150 ml. of BaCl_2 solution (buffered pH 8.0). The excess chloride was removed by washing with distilled water. The Ba saturated soil was transferred to a beaker containing 150 ml. ethyl alcohol and 150 ml. distilled water. This suspension was titrated using 0.2 N MgSO_4 .

Exchangeable Hydrogen

The barium acetate method as proposed by Parker (1929) was used. Duplicate twenty-five gram samples were leached with 250 ml. neutral barium acetate. Leachates were collected and titrated to pH 7.0 using 0.1 N NaOH and a Beckman glass electrode pH meter.

Total Specific Surface

The ethylene glycol method as proposed by Bower and Geschwend (1952) was used. Samples were pretreated with H_2O_2 to remove organic matter.

Organic Carbon

The wet combustion method was used. Duplicate ten gram

samples were treated with 10 ml. of 1.0 N potassium dichromate followed by 20 ml. of concentrated sulfuric acid. They were shaken and allowed to stand for half an hour. Then 250 ml. of distilled water, 10 ml. phosphoric acid and one milliliter of diphenylamine were added. This solution was titrated using 1.0 N ferrous sulfate. A 75 percent recovery was assumed. Organic matter values were obtained by multiplying percentage organic carbon by 1.724.

Total Carbon

The combustion train method was employed. Ascarite was used as the carbon dioxide absorption material, while sodium hydroxide, concentrated sulfuric acid and phosphorus pentoxide were used to absorb moisture and carbon dioxide from incoming oxygen. Zinc foils were used to absorb oxides of sulfur and copper metal was inserted in furnace to insure conversion of all carbon monoxide to the dioxide form before being absorbed by the ascarite.

"Free Iron Oxide"

A modification of Deb's (1950) method, as suggested by Kilmer* was used. Duplicate four gram samples were mixed with 75 ml. of distilled water and four grams of sodium hyposulfite ($\text{Na}_2\text{S}_2\text{O}_4$). The suspension was shaken overnight, after which the pH was adjusted to 3.3-4.0, if necessary, using 10 percent HCl. The suspension was then diluted to 140 ml. and

*Personal communication

filtered. Thirty-five milliliters of clear suspension were then diluted to 100 ml., treated with 10 percent H_2O_2 and left on a hot plate. KCNS was used to detect traces of ferrous ion. H_2O_2 addition was continued until no traces of ferrous ion were detected. 1:1 NH_4OH was added and heating continued until no traces of peroxide were left. $\text{Fe}(\text{OH})_3$ formed was dissolved using 1:1 HCl and heating to 90°C . While hot, fresh stannous chloride was added dropwise until all yellow coloration disappears. The solution was cooled and 15 ml. of saturated HgCl_2 solution were added. If correct amount of stannous chloride was added, a silvery white precipitate would form. Solution was then diluted to 150 ml., 5 ml. of 85 percent phosphoric acid and ten drops of diphenylamine sulfonate added. Final solution was titrated to violet blue end point with 0.1 N $\text{K}_2\text{Cr}_2\text{O}_7$.

1 ml. 0.1 N $\text{K}_2\text{Cr}_2\text{O}_7$ = 0.0056 gm. Fe or 0.008 gm. Fe_2O_3

Heavy Mineral Content

Tetra-bromo-ethane and nitrobenzene sp.g. 2.80 was used. Samples were run in duplicate.

X-ray Determination of Quartz and Feldspar

A Norelco x-ray unit with a wide range geiger counter goniometer and a Brown electronic recorder were employed. The x-ray tube contained a tungsten filament and a copper target. A nickel filter, 1° divergent slit, 0.003" receiving slit and 1° scatter slit made up the collimating system. The diffraction unit was operated at 20 milliamperes, 35 kilovolts; the

recording unit was operated at a time constant of four and multiplier of one and scale factor 8. The goniometer scanned between 25 and 30 degrees, at a speed of one degree per minute. Sand samples to be analyzed were ground to pass a 300 mesh sieve and mounted in a shallow cup which fits into the specimen spinner on the goniometer. Peak heights representing quartz ($3.35\text{\AA}^0$), K-feldspar ($3.25\text{\AA}^0$) and oligoclase ($3.19\text{\AA}^0$) were recorded. A standard quartz sample was irradiated at intervals during study of the unknown samples.

X-ray Determinations of Clay Minerals

Fifteen ml. of Na clay suspensions, obtained by decantation of samples after acid treatment and titration with NaOH, containing 0.03 gm. of clay were treated with five drops of glycerol, shaken and left standing overnight. A porous ceramic plate was placed in a holder and attached to a vacuum. The clay suspension was poured on the porous plate and suction applied. A few more drops of glycerol were added. The plate was then removed and left overnight in a dessicator containing anhydrous. The sample was then mounted on the Norelco x-ray spectrometer. In the clay mineral analyses, the slit system included a $1/4$ " divergent slit, 0.003" receiving slit, $1/4$ " scatter slit. The diffraction unit was operated at 20 milliamperes and 35 kilovolts using a copper target tube. The recording unit circuit panel was set at time constant four, multiplier one and scale factor four. Clay samples were scanned from two to thirteen degrees at a speed of one degree per minute. After irradiation, glycerol treated clay was removed,

leached with KCl, put in 110° C oven for two hours and left to cool in a dessicator. The sample was then scanned again. Following that, it was heated to 550° C for two hours, cooled and scanned for the third time. Areas under the peaks obtained at each scanning were measured and recorded.

Differential Thermal Analysis of Clay Minerals

A differential thermal analysis unit, Model DTA-CS-2 Plus DTA FM, built by R. L. Stone of Austin, Texas, was employed. Attached to it was a Brown recorder. Clay samples were run at atmospheric pressure with a resistance of fifty ohms in the recording unit and a heating rate of twelve degrees per minute. Aluminum oxide was used throughout as standard reference material. A background curve was obtained by running aluminum oxide against itself. The amplitude of the various endothermic and exothermic peaks was obtained from the thermo-charts, using the background curve as a reference line.

Microscopic Examination of Natural Soil Aggregates ("Debris Preparations")

Where possible, larger chunks of soil material, one to four inches in diameter, were collected during field description of soil profiles. Chunks were taken to the laboratory and examined under the binocular microscope, using a six power magnification. The fabric of soil aggregates with size distribution of the various constituents was investigated.

Artificial Soil Column Experiments

A series of percolation experiments using artificial

soil columns were set up. In these experiments, quartz sand or a mixture of non-limy Coloma fine sand subsoil material with textural bands was used. The effect of height of column, different volumes of inflowing clay suspensions and types of solutions on the concentrations and volumes of outflowing suspensions were studied. Natural clay material was obtained by decantation of a separate sample of the Coloma fine sand subsoil material suspended in distilled water.

Experiment 1. Quartz sand columns: Four quartz sand columns of different heights were leached with distilled water or dilute clay suspensions. Effluents were collected, their volumes measured and they were analyzed for the concentration of clay present.

Experiment 2. Coloma fine sand, C horizon, columns: Fourteen columns of Coloma fine sand were used. The heights of the columns and concentrations of clay in the influents were varied. Here too effluents were collected, their volumes measured and they were analyzed for the concentration of clay present.

Experiment 3. Six glass tubes 25 mm. in diameter containing Coloma fine sand subsoil material were used. Four of the columns were leached with 2000 ml. of distilled water (= 408 cm. of rain or 160 inches). The other two were wet up by capillarity by insertion of the bottom of the column in an open bath of distilled water. On completion of the leaching, all six columns were cut into segments and the contents of each segment analyzed for silt and clay content.

Experiment 4. Four, 110 cms. long columns of Coloma fine sand material, with or without some bands of calcareous materials were set up. The columns were leached with 400 ml. of 0.01 N oxalic acid, in 50 ml. daily increments over a period of eight days. Column 1 contained non-limy fine sand differentiated subsoil material with three strata of calcareous Montcalm loamy sand C horizon material. The three strata were at depths of 27-31 cms. (4 cm. thick), 44-51 cms. (7 cm. thick) and 65-74 cms. (9 cm. thick). Column 2 contained fine sand with one calcareous stratum at 17-24 cms. (7 cm. thick). Column 3 contained fine sand with a calcareous stratum at 93-101 cms. (8 cm. thick). Column 4 contained only fine sand. Leachates were collected from all four columns during that period. The columns were then left to dry for a period of one week.

RESULTS

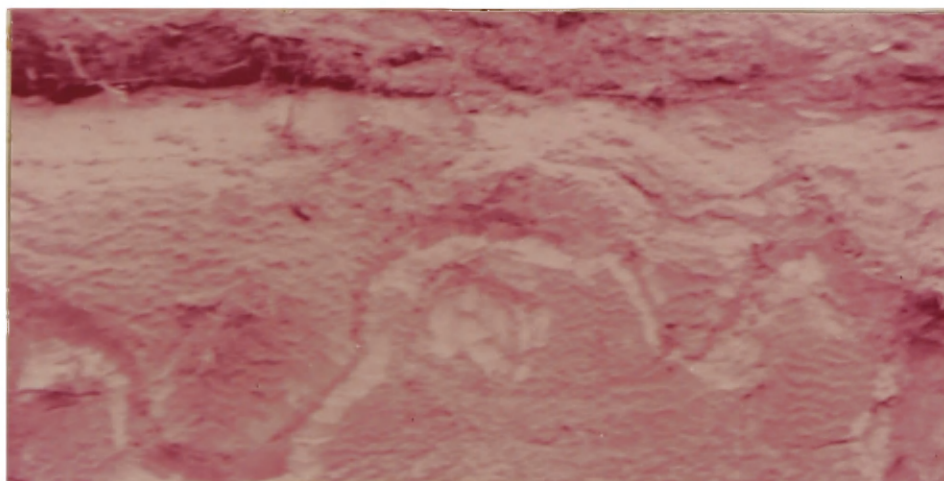
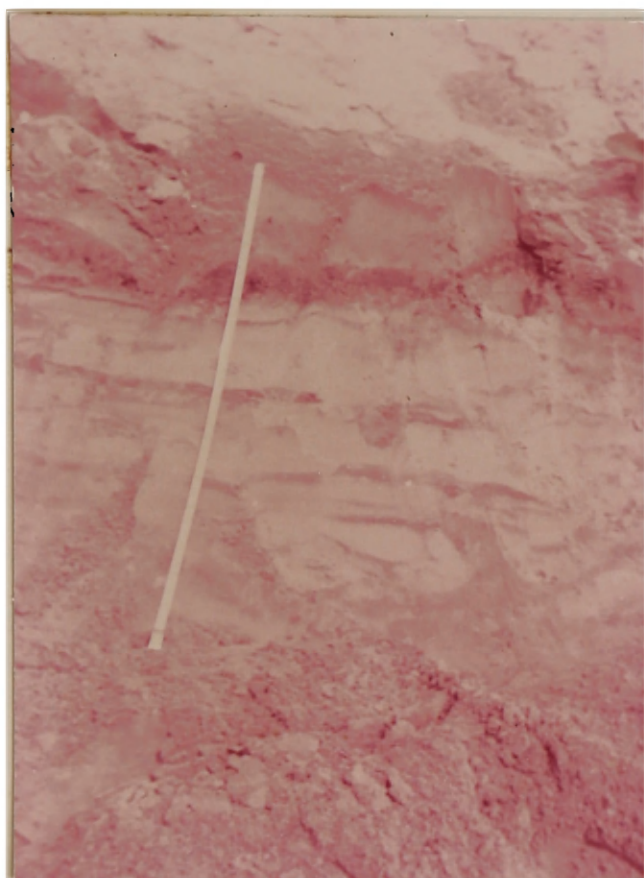
Field Observations

In Michigan, soils developed from parent rock materials of loamy sand to sandy loam texture, very often show textural bands in their subsoils. There exists a striking difference in color as well as texture of the bands and the material above or below them.

The occasional limy textural bands usually occur as massive, more or less horizontal layers two to eight inches thick and yellowish red to yellowish brown (5YR5/6-7.5YR5/6, moist). They do not cut across strata of the original materials and contain free lime indicating little alteration by weathering or other soil forming processes and are therefore believed to be petrogenic. *

The non-limy textural bands, lack any well developed structure, are usually brown to strong brown (7.5YR5/8-5/4, moist) and wavy in nature. They often cut across strata in the original materials. These non limy bands vary in thickness from 0.1 to 2 inches. They often appear in clusters and may be at any distance or angle to each other. When they appear in clusters, they seem to converge at certain points at which a general thickening of the bands take place. The bands themselves usually occur as thin lenses which thin out in a direction which is at right angles to the vertical direction of the soil profile. They often are discontinuous and overlap each other as illustrated in Figure 5.

Figure 5. Illustrations of textural bands in Northern Michigan



In the bisequa soil profiles, the textural bands occur below the Podzol sequum. In case of non-limy materials, there is a general thinning out of the bands with depth although there were instances in which two or three non-limy bands with a series of thinner bands above and below them. Sometimes, a thick limy textural band will be underlain by a series of thin, coarse non-limy bands. Often it is hard to be sure whether a textural band is a result of parent material stratification, or a result of pedogenetic processes. From field observations alone one can safely say that many of the textural bands are the product of interaction between an initial stratification of the parent rock material and its alteration by soil development i.e. eluviation, illuviation and weathering in place.

Physical and Chemical Properties of Soil Samples

The following graphs show the physical and chemical properties of selected horizons from the soil profiles described previously. For the tabular presentation of this data see the Appendix.

Figure 6. Montcalm loamy sand;
mechanical analysis.

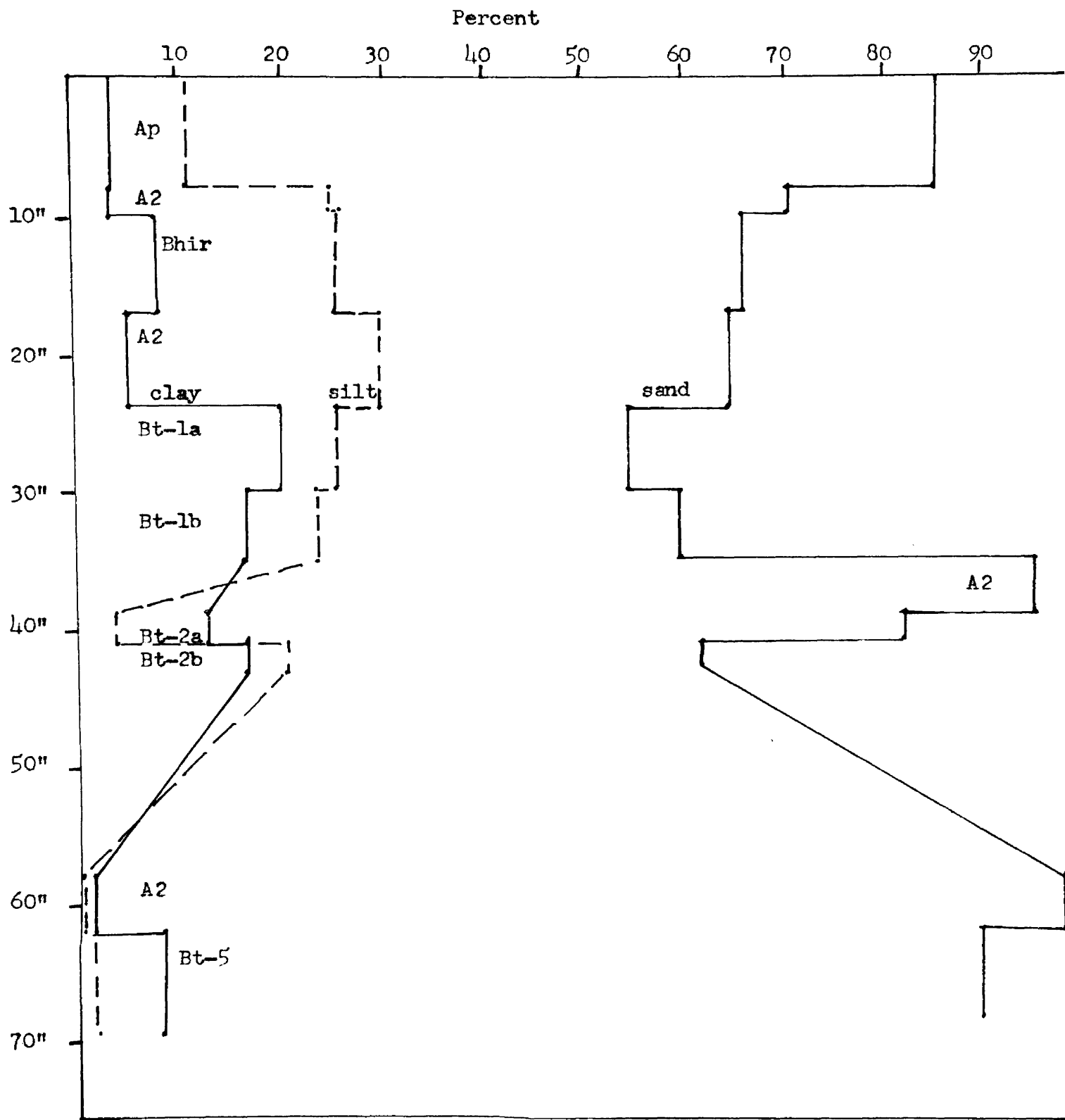
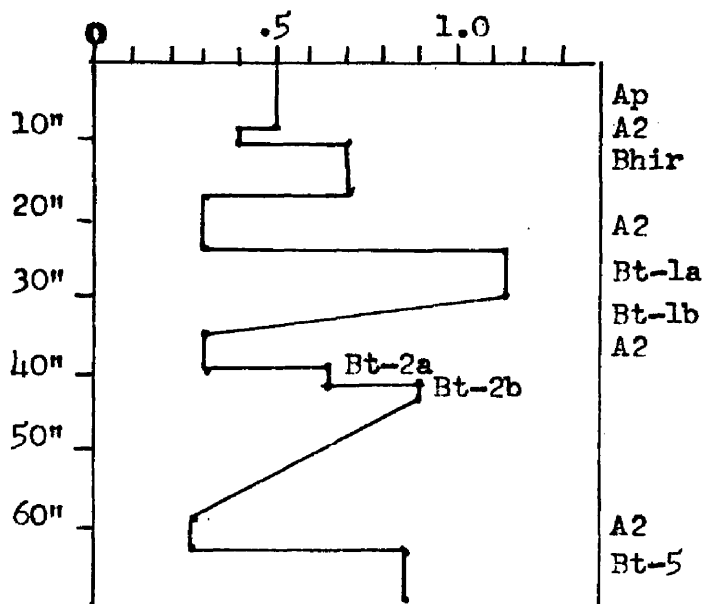
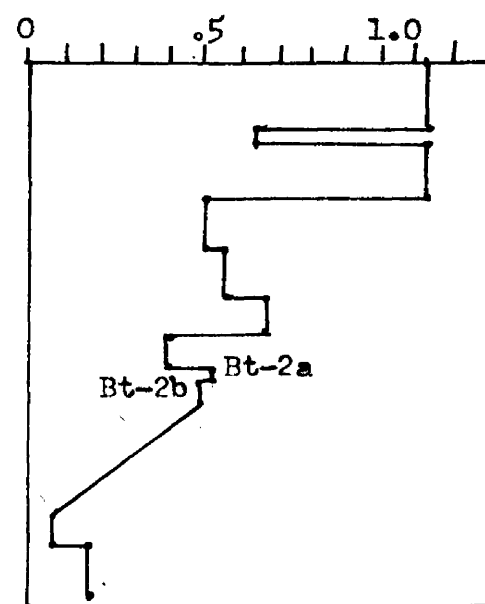


Figure 7. Montcalm loamy sand; "free iron oxide", organic matter, pH and exchangeable hydrogen.

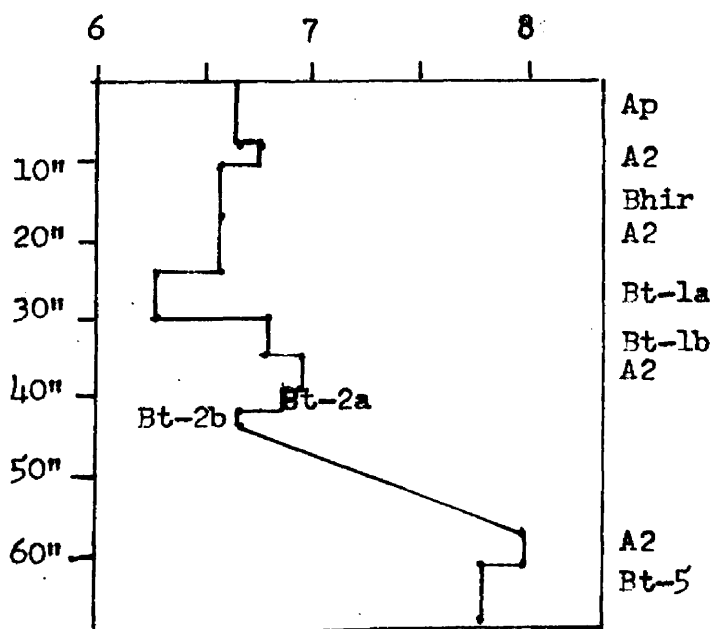
7A. "Free iron oxide(Fe_2O_3), percent.



7B. Organic matter, percent



7C. pH measurements



7D. Exchangeable hydrogen, m.e./100 gm.

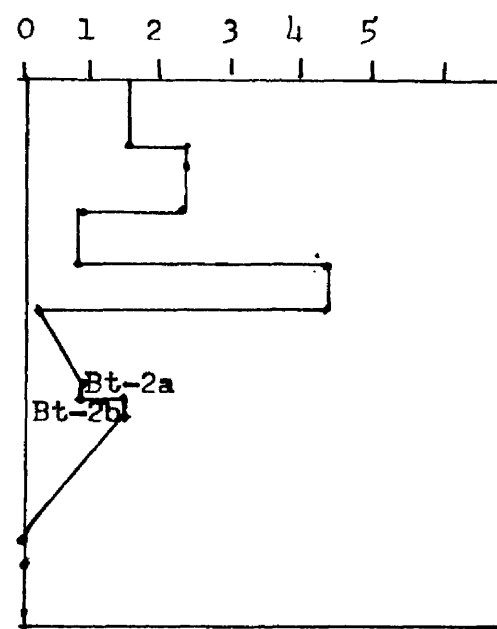
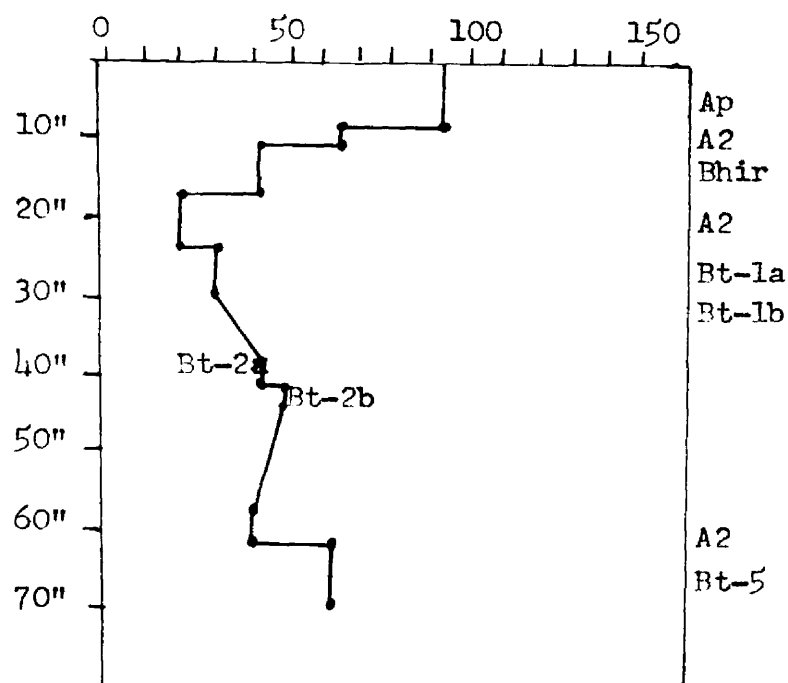
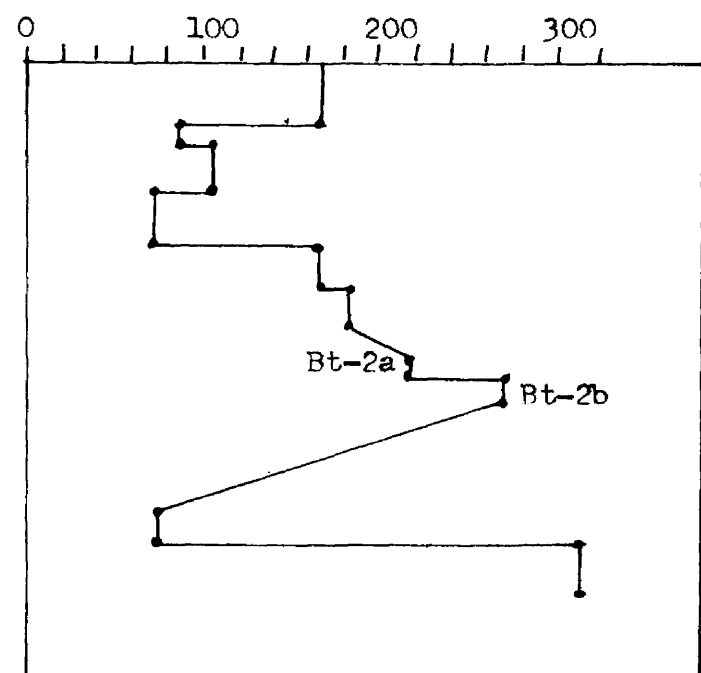


Figure 8. Montcalm loamy sand; exchange capacity/clay ratio, specific surface/clay ratio, "free iron oxide"/clay ratio, and organic matter/clay ratio.

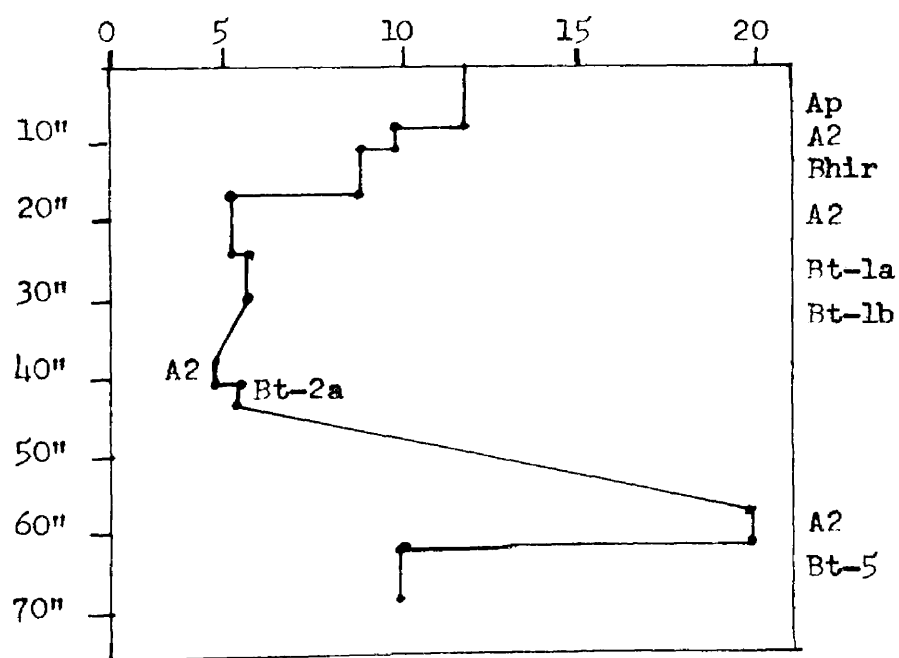
8A. M.E. exch. cap./100gm. clay



8B. Sp. surface, M²/gm. clay



8C. "Free iron oxide(Fe₂O₃)" gm./100gm. clay



8D. Organic matter gm./100gm. clay

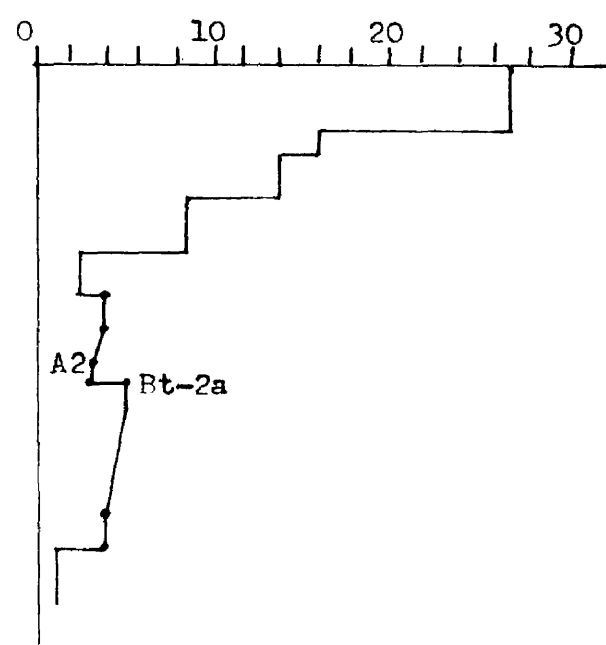


Figure 9. Montcalm fine sand;
mechanical analysis

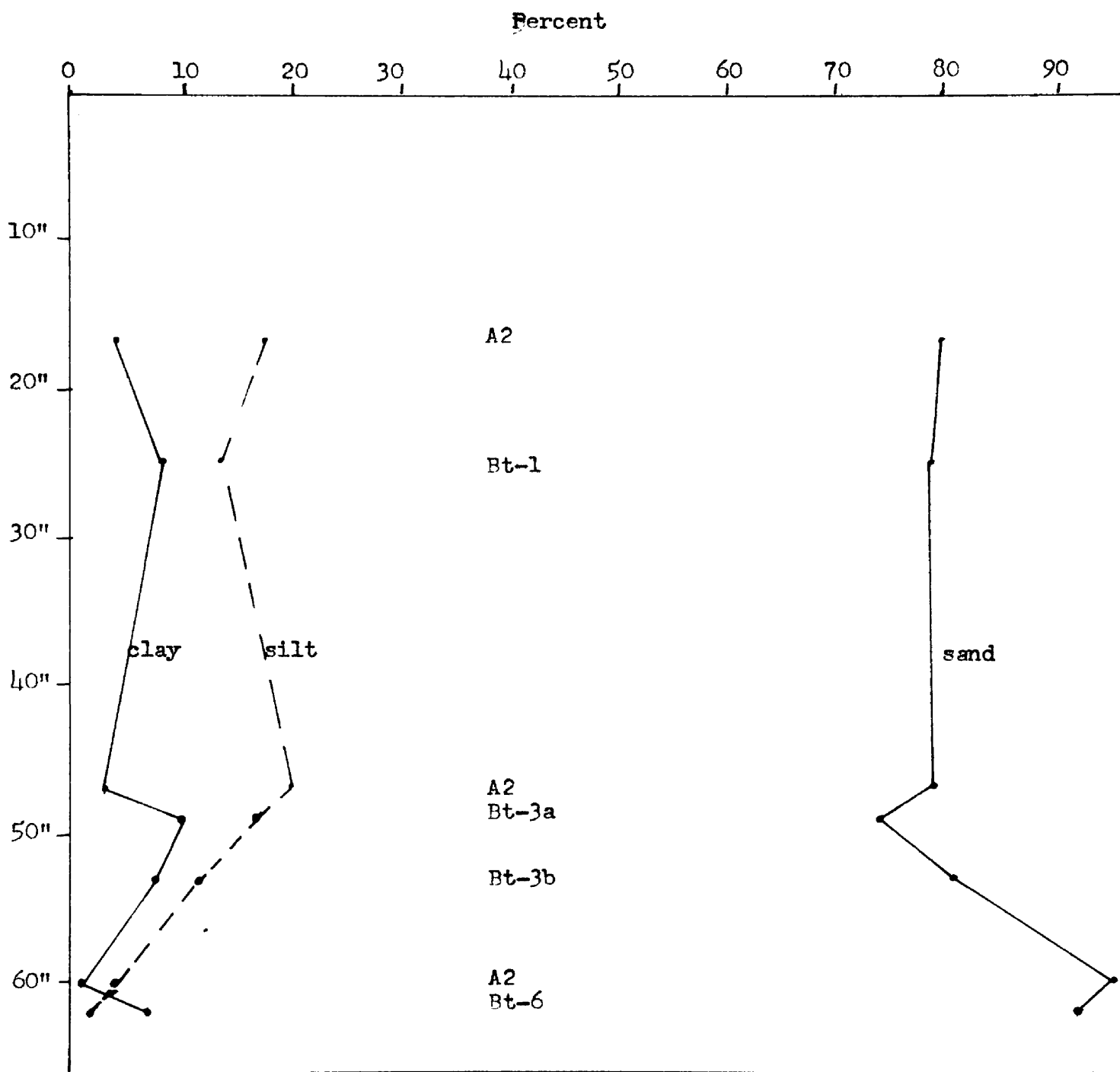
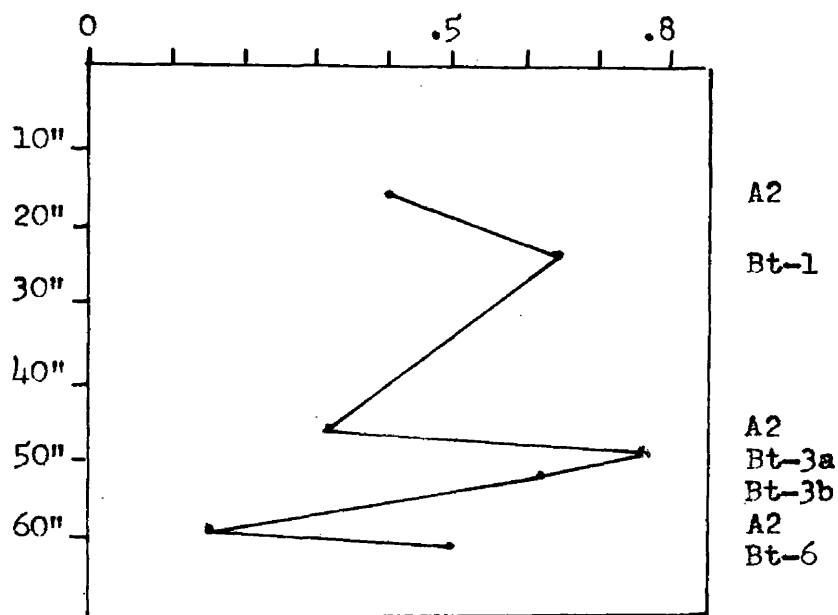
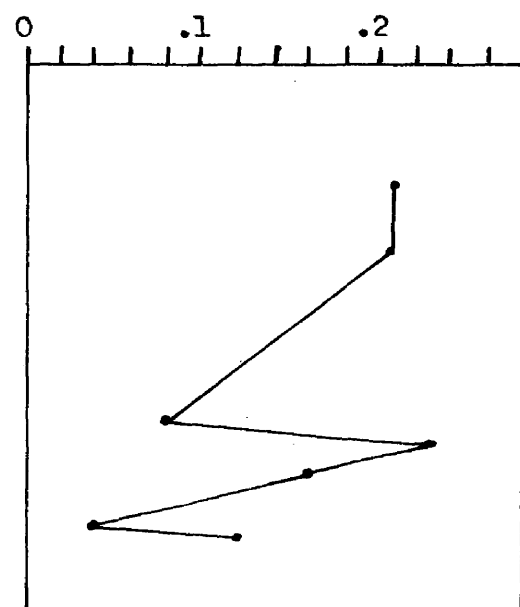


Figure 10. Montcalm fine sand; "free iron oxide", organic matter, pH and exchangeable hydrogen.

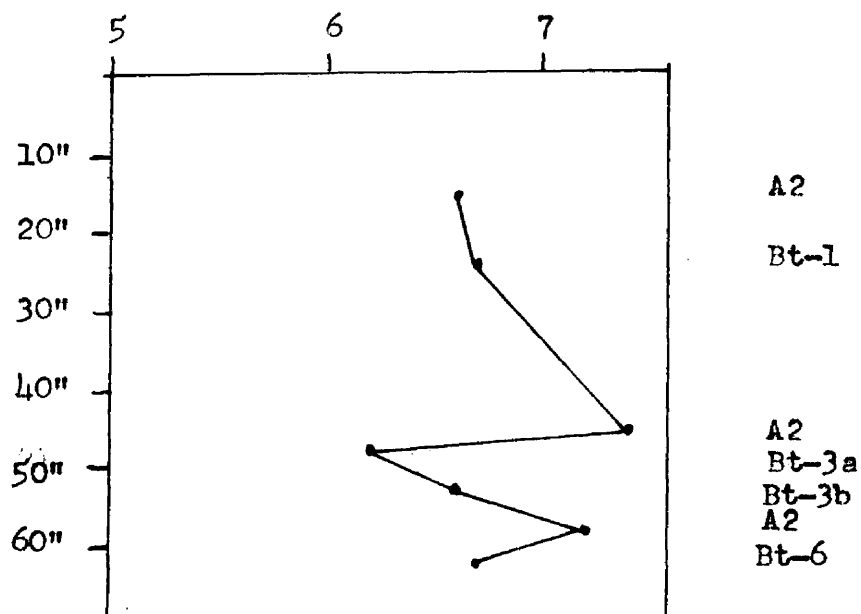
10A. "Free iron oxide" (Fe_2O_3), percent.



10B. Organic matter, percent.



10C. pH measurements



10D. Exchangeable hydrogen, m.e./100 gm.

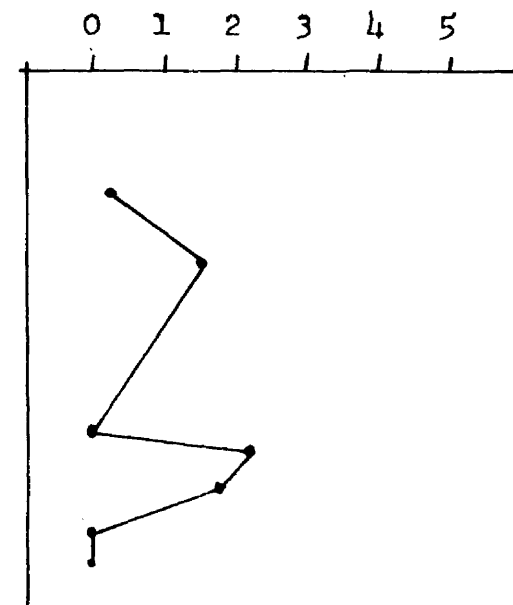
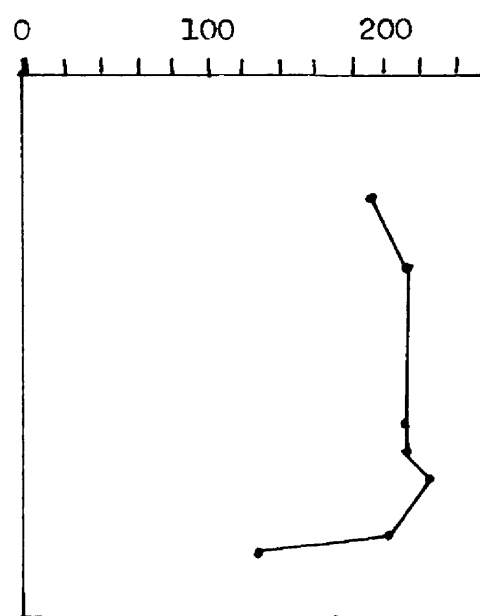
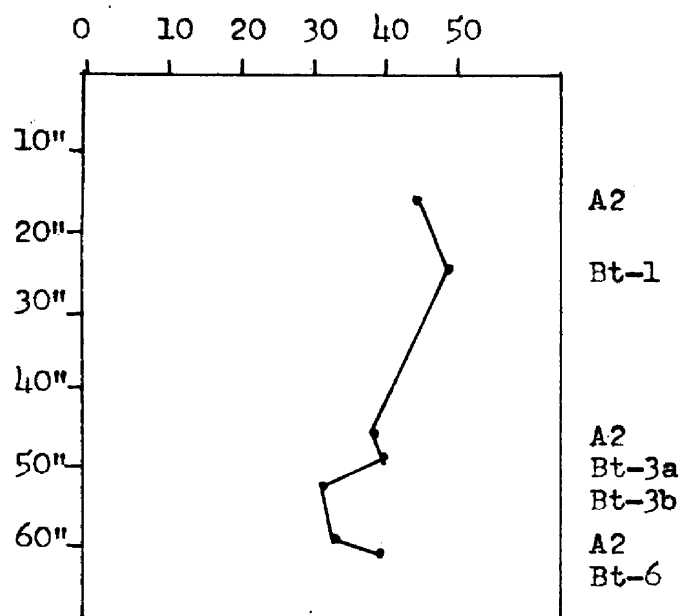


Figure 11. Montcalm fine sand; exchange capacity/clay ratio, specific surface/clay ratio, "free iron oxide"/clay ratio, and organic matter/clay ratio.

11A. M.E. exch. cap./100gm. clay

11B. Sp. surface, M^2 /gm. clay



11C. "Free iron oxide" (Fe_2O_3), gm./100gm. clay

11D. Organic matter, gm./100gm. clay

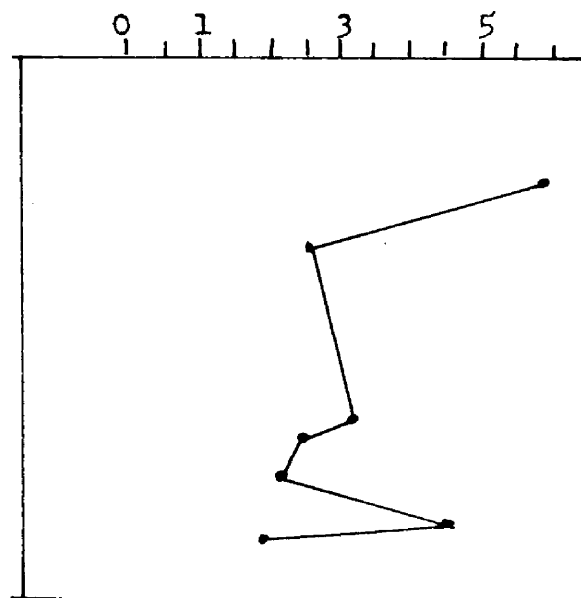
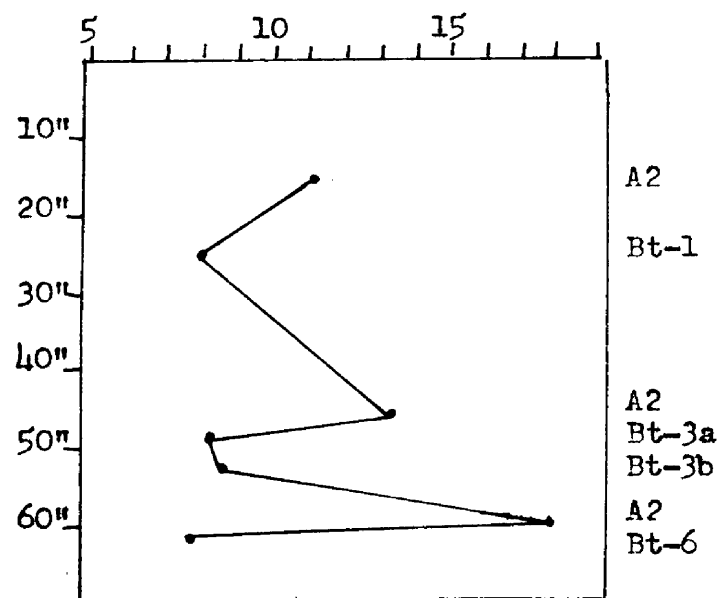


Figure 12. Coloma fine sand;
mechanical analysis

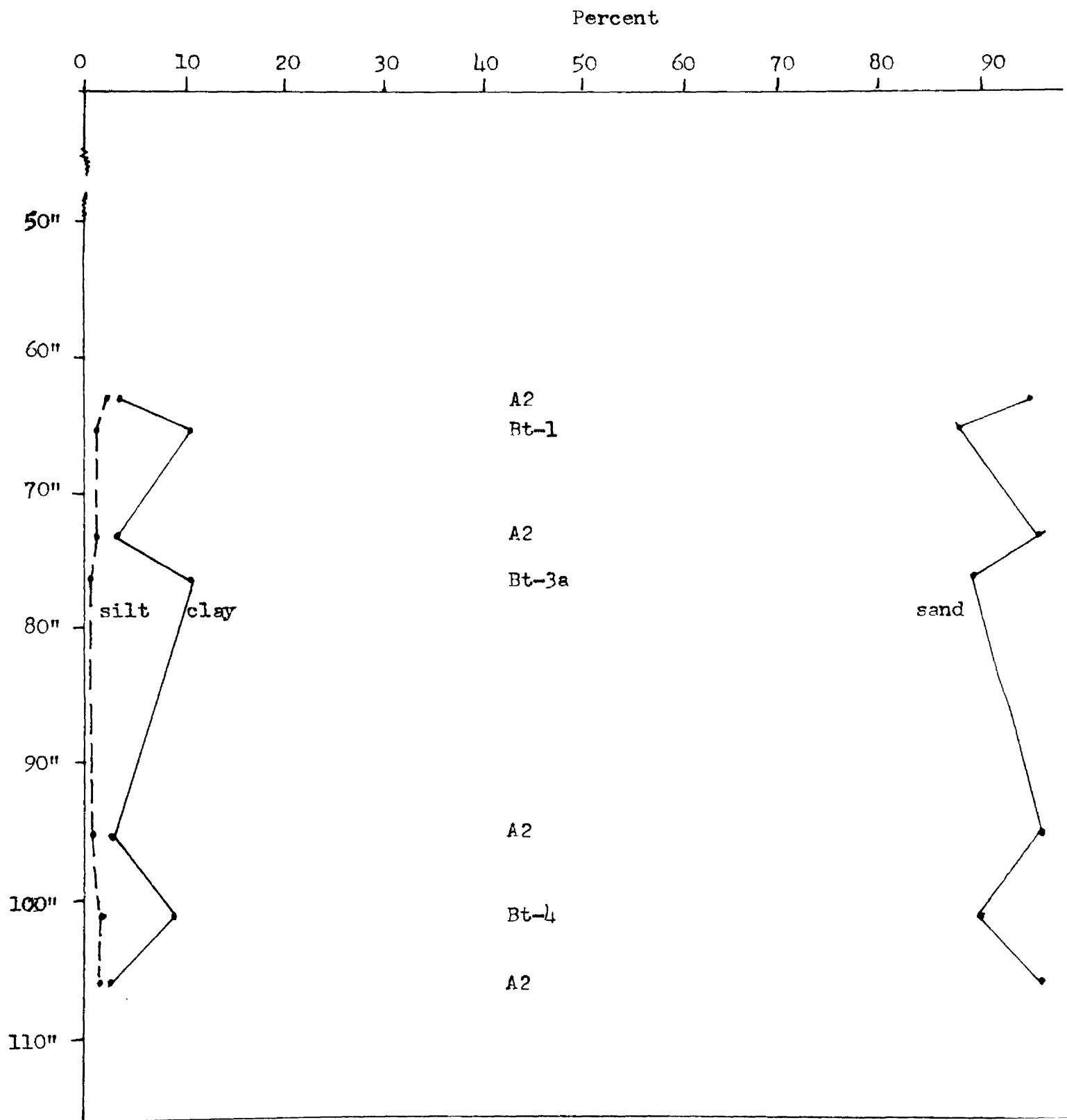
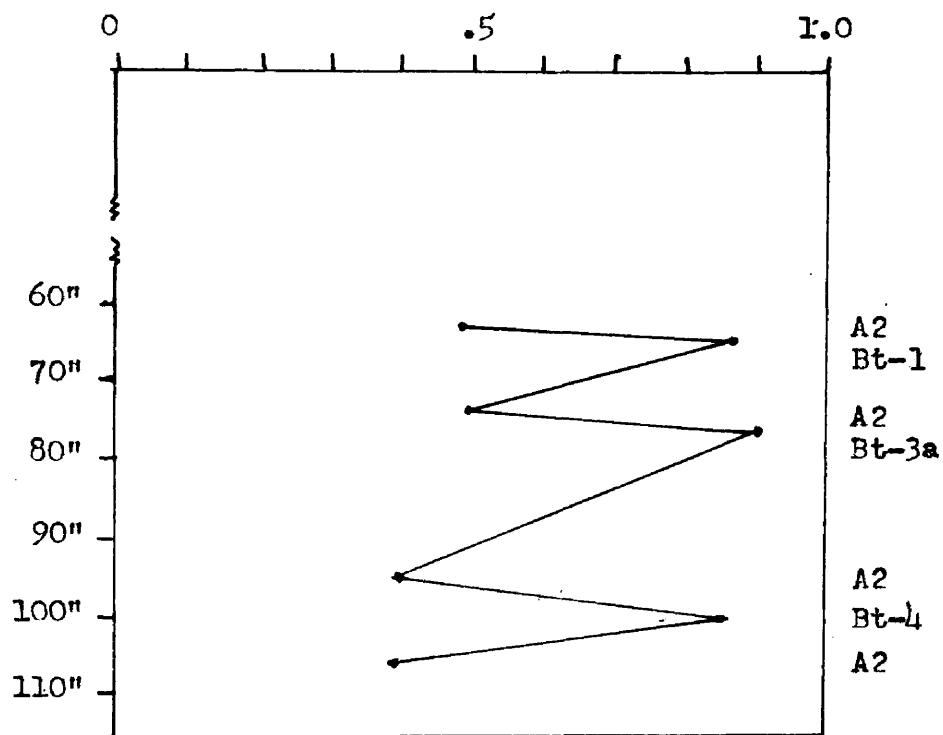
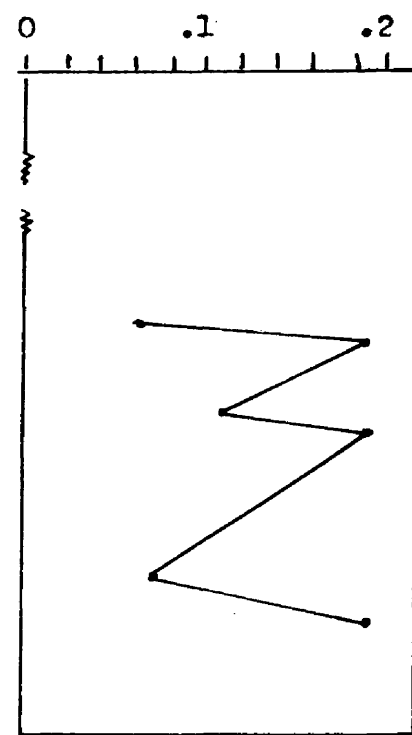


Figure 13. Coloma fine sand; "free iron oxide", organic matter, pH, and exchangeable hydrogen.

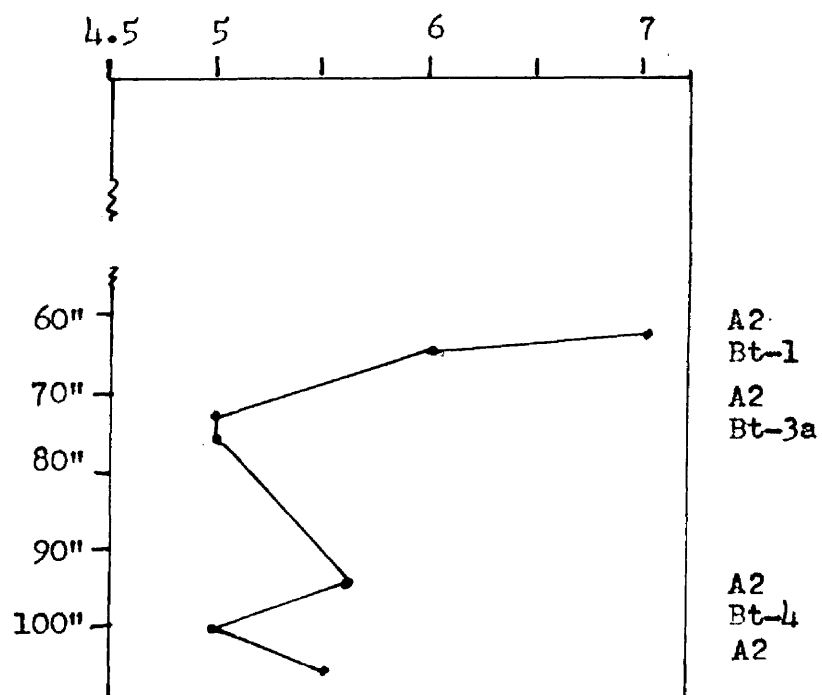
13A. "Free iron oxide" (Fe_2O_3), percent



13B. Organic matter, percent



13C. pH measurements



13D. Exchangeable hydrogen, m.e./100gm.

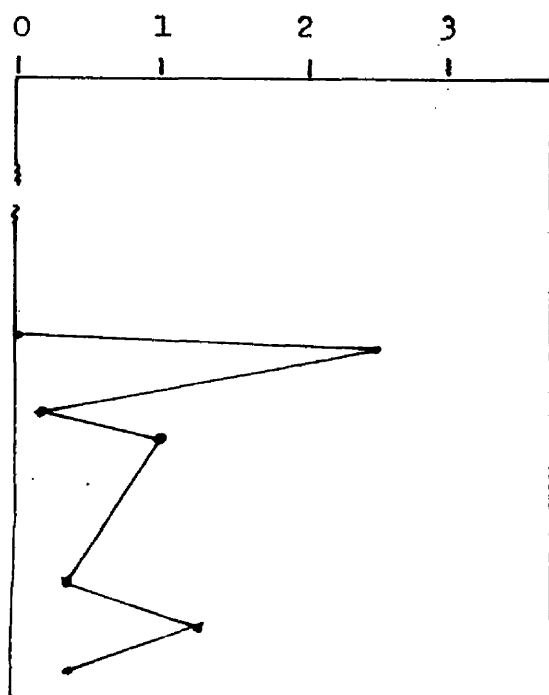
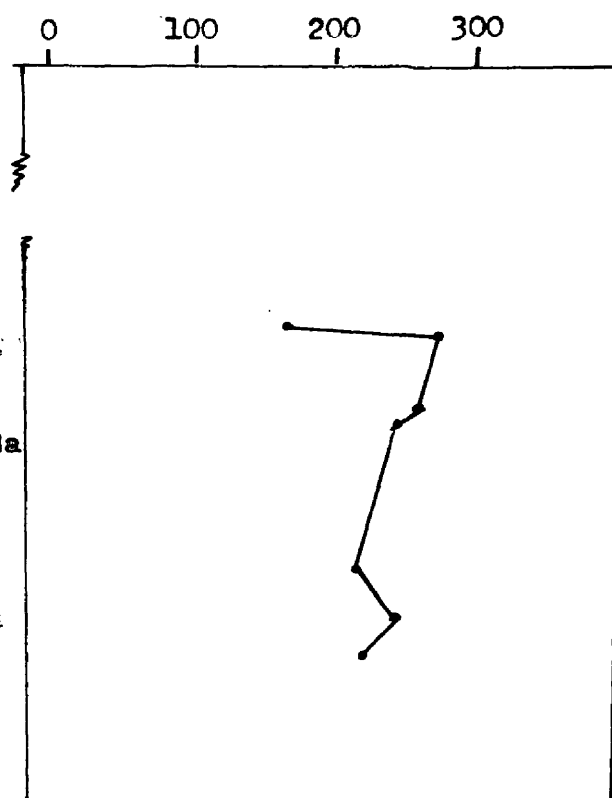
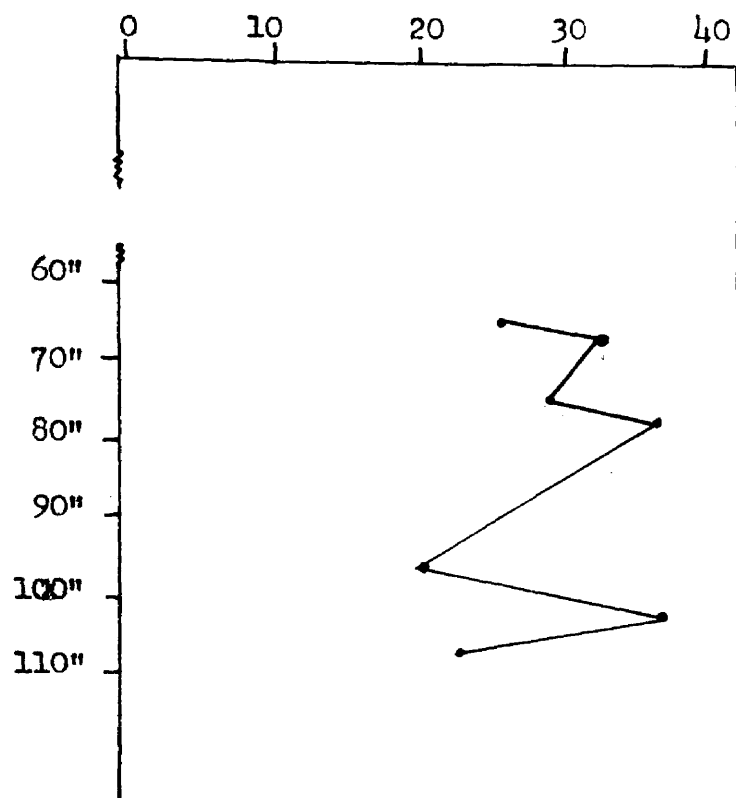


Figure 14. Coloma fine sand; exchange capacity/clay ratio,
specific surface/clay ratio, "free iron oxide/clay ratio,
and organic matter/clay ratio.

14A. M.E. exch. cap./100gm. clay

14B. Sp. surface, M^2 /gm. clay



14C. "Free iron oxide" (Fe_2O_3),
gm./100gm. clay

14D. Organic matter,
gm./100gm. clay

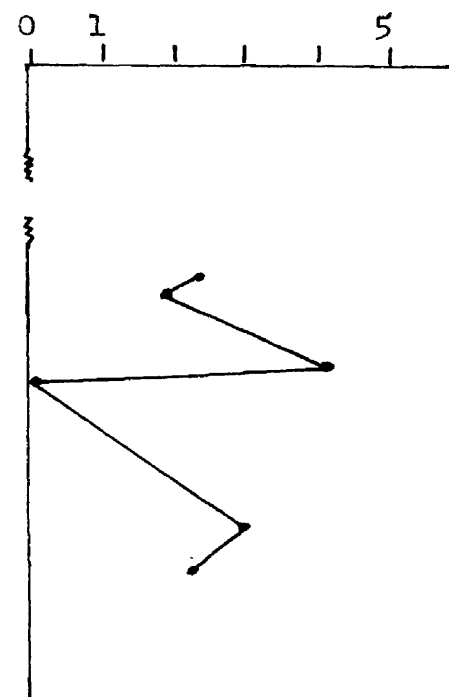
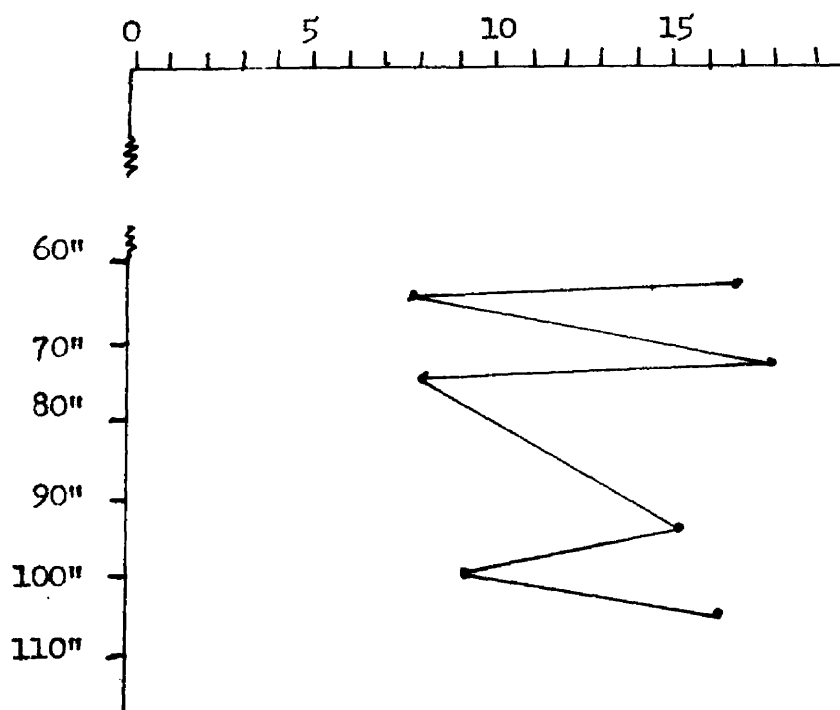


Figure 15. Wallace sand;
mechanical analysis

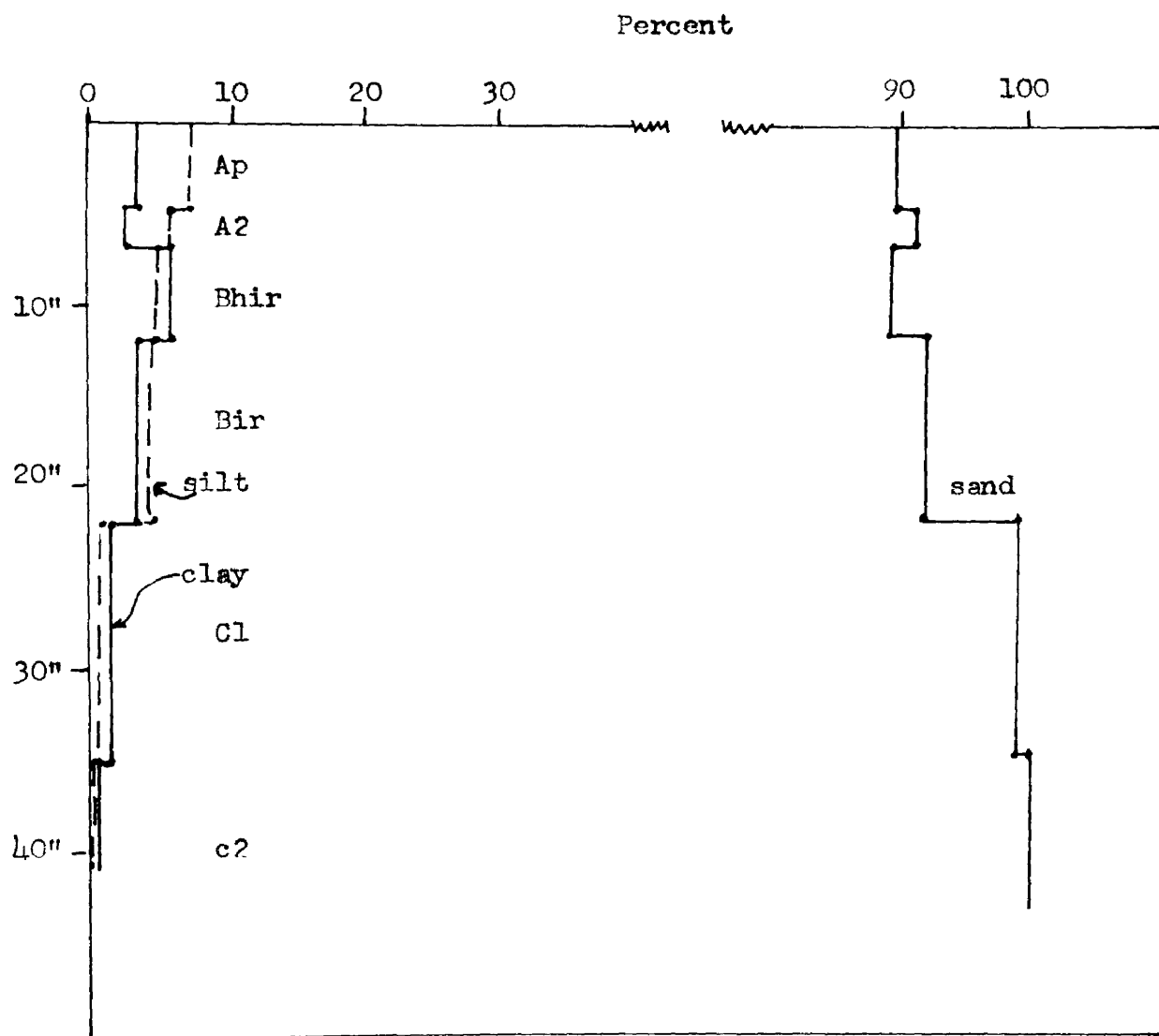
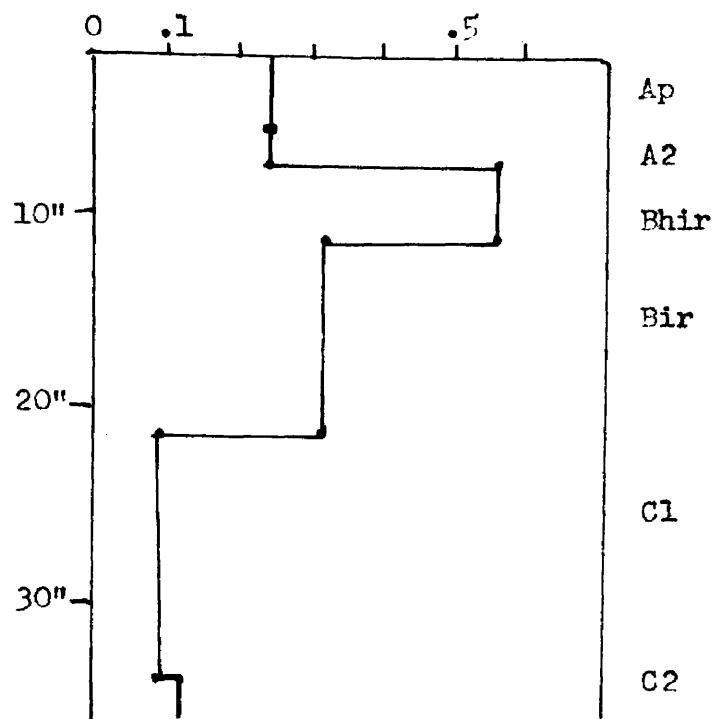
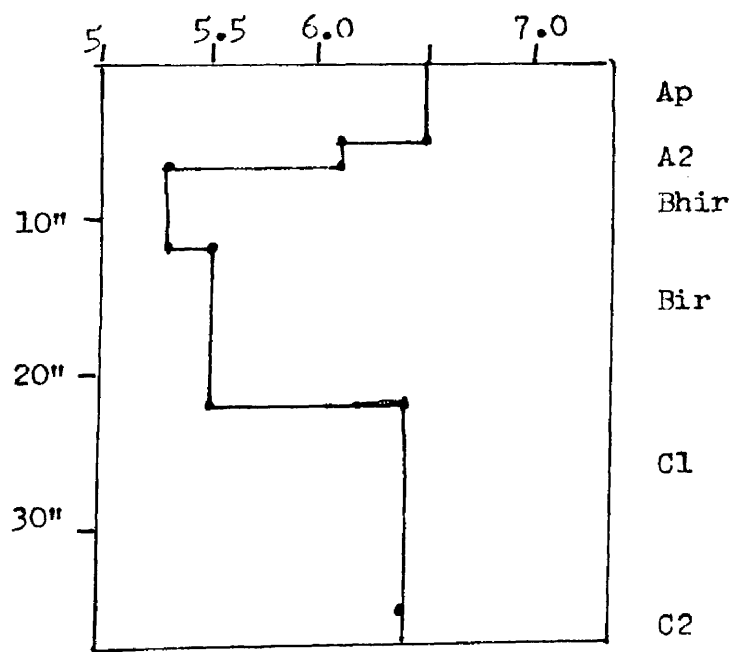


Figure 16. Wallace sand; "free iron oxide", organic matter, pH and exchangeable hydrogen.

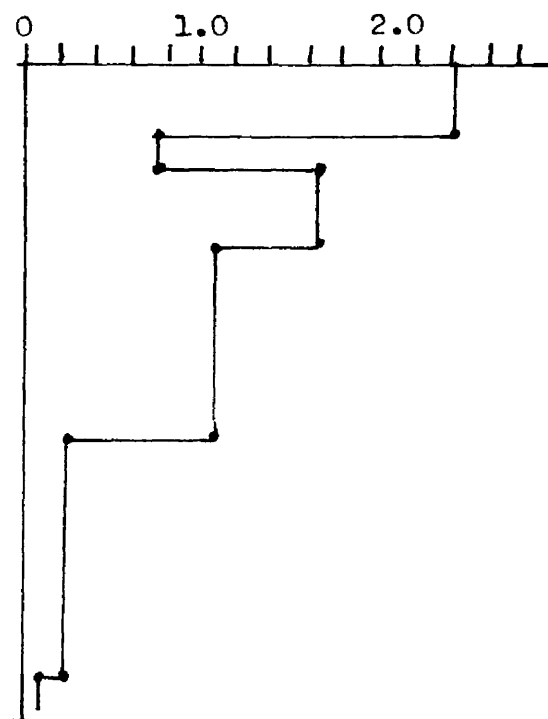
16A. "Free iron oxide" (Fe_2O_3), percent.



16C. pH measurements



16B. Organic matter, percent.



16D. Exchangeable hydrogen, m.e./100gm.

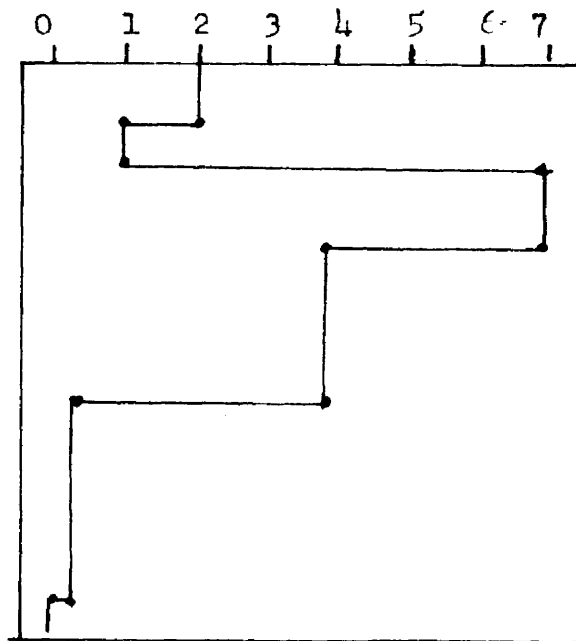
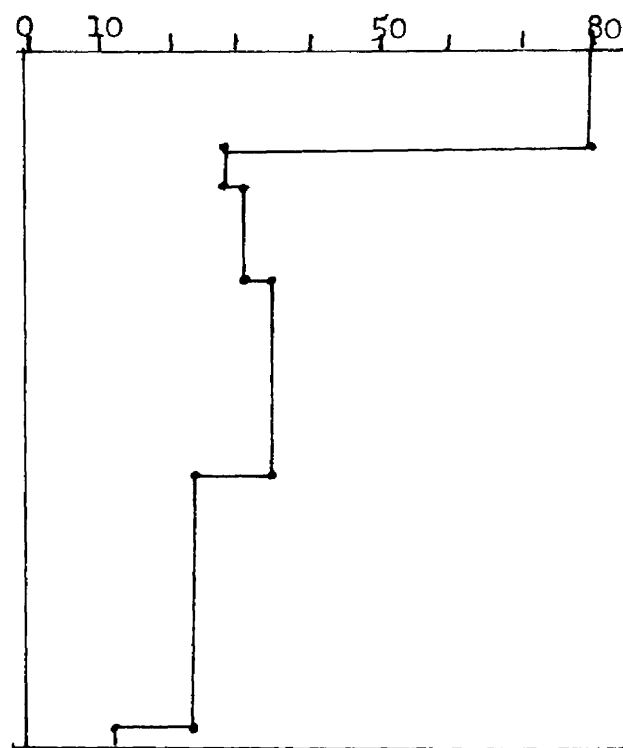
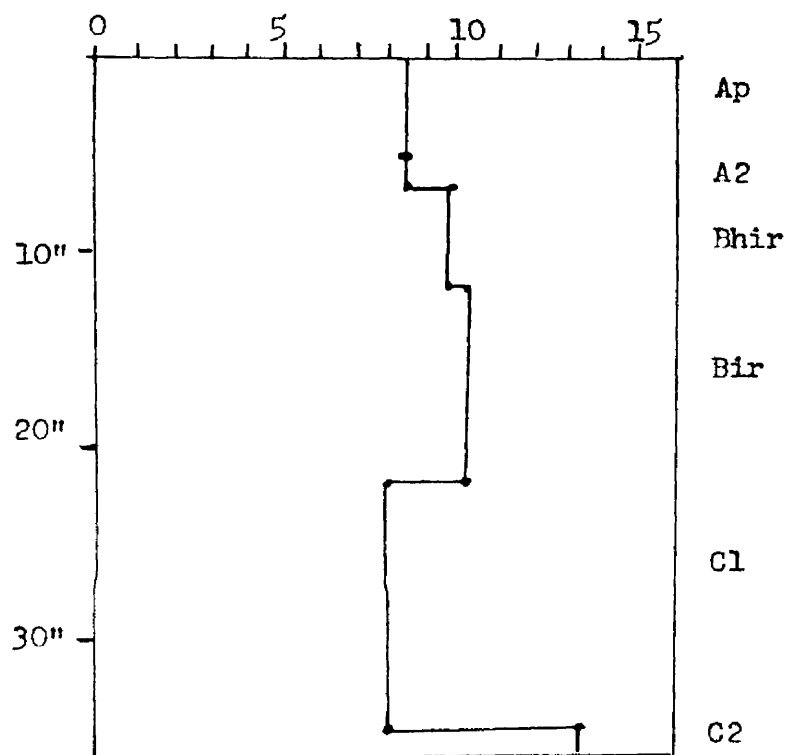


Figure 17. Wallace sand; "Free iron oxide/clay ratio, organic matter/clay ratio.

17A. "Free iron oxide" (Fe_2O_3),
gm./100gm. clay

17B. Organic matter,
gm./100gm. clay



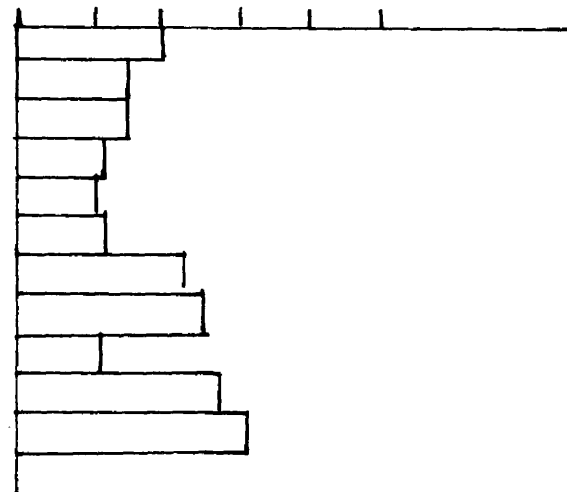
Mineralogical Properties of Soil Samples

The following graphs and tables show the mineralogical properties of selected horizons from the soil profiles studied. For a tabular presentation of this data, see the Appendix.

Figure 18. Montcalm loamy sand; medium sand quartz, fine sand quartz, medium sand plus fine sand quartz, medium sand/fine sand quartz.

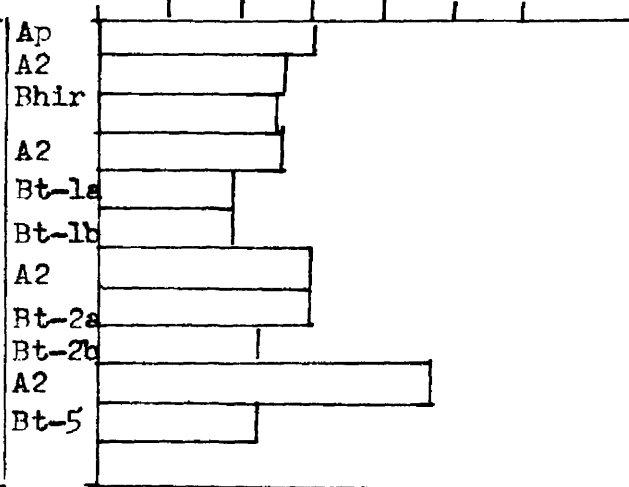
18A. Medium sand quartz, percent

0 10 20 30 40 50



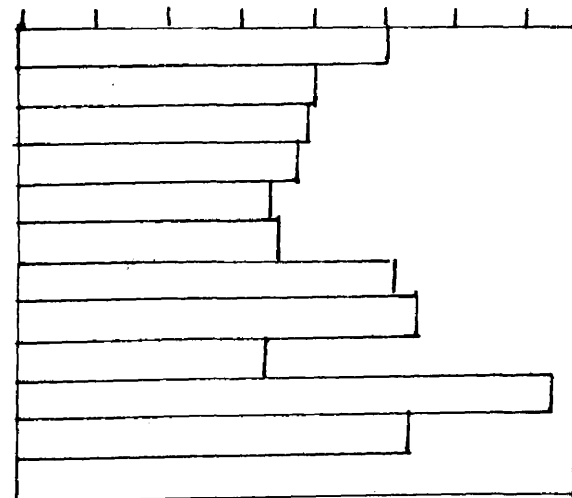
18B. Fine sand quartz, percent

0 10 20 30 40 50



18C. Medium sand plus fine sand quartz, percent

0 10 20 30 40 50 60 70



18D. Medium sand/fine sand quartz

0 .5 1.0 1.5

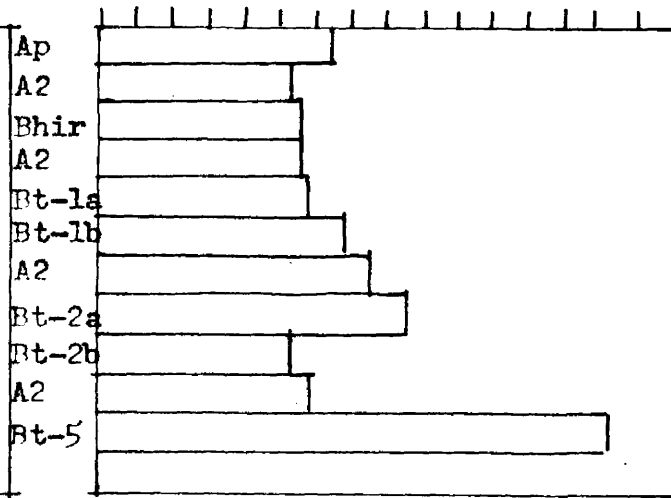
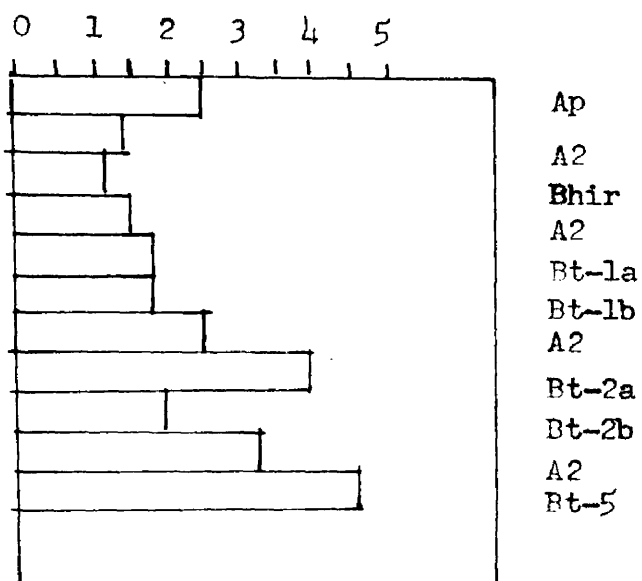
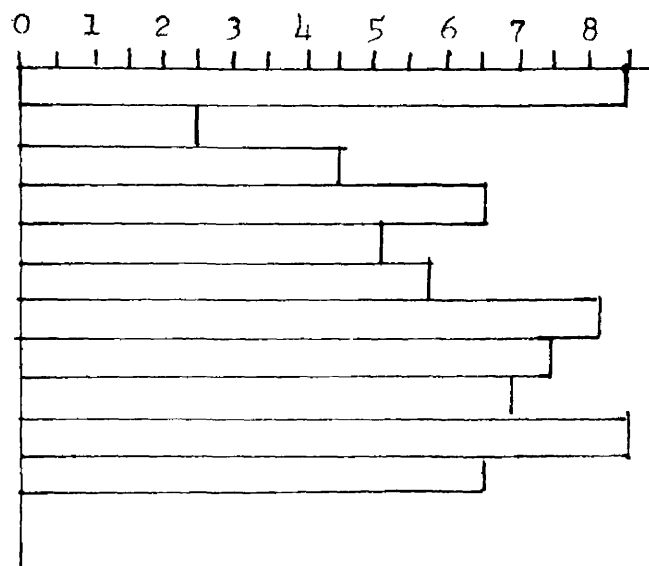


Figure 19. Montcalm loamy sand; medium sand K-feldspar, fine sand K-feldspar, medium sand plus fine sand K-feldspar, medium sand/fine sand K-feldspar.

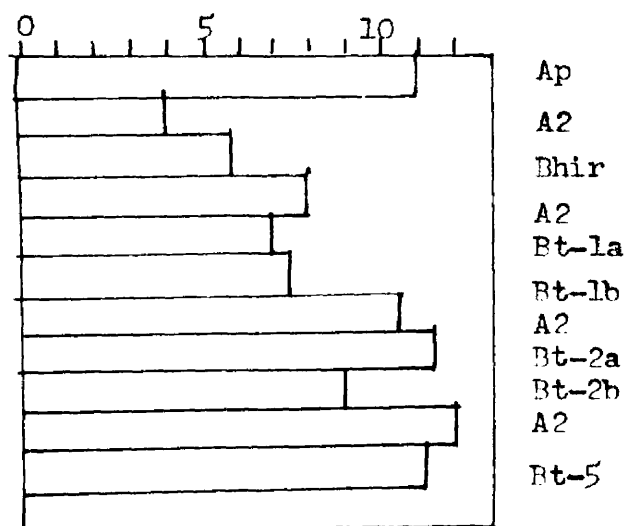
19A. Medium sand K-feldspar, percent



19B. Fine sand K-feldspar, percent



19C. Medium sand plus fine sand K-feldspar, percent



19D. Medium sand/fine sand K-feldspar

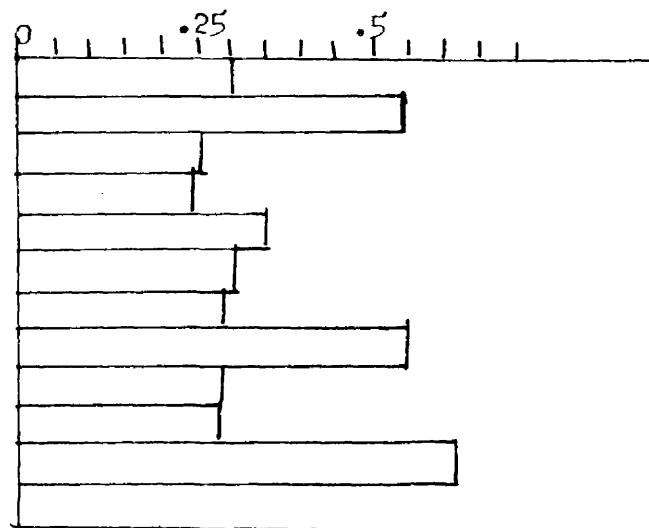
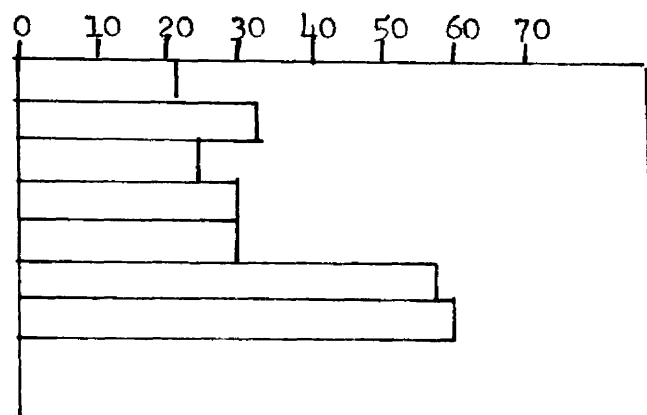
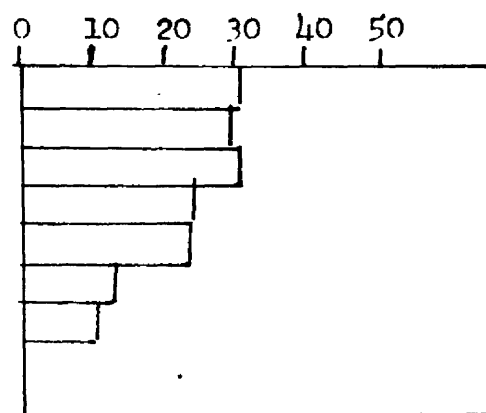


Figure 20. Montcalm fine sand; fine sand quartz, very fine sand quartz, fine plus very fine sand quartz, fine sand/very fine sand quartz.

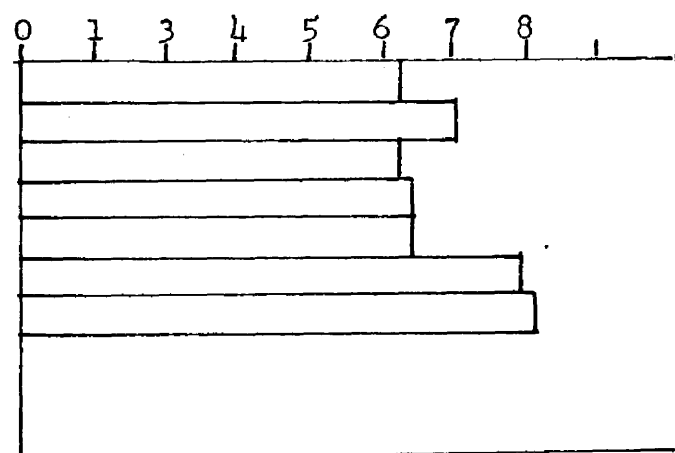
20A. Fine sand quartz, percent



20B. Very fine sand quartz, percent



20C. Fine sand plus very fine sand quartz, percent



20D. Fine sand/very fine sand quartz

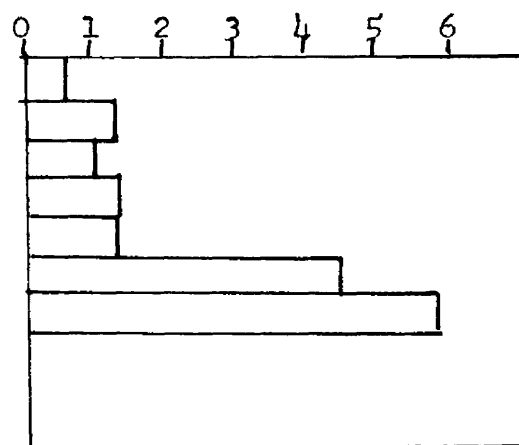
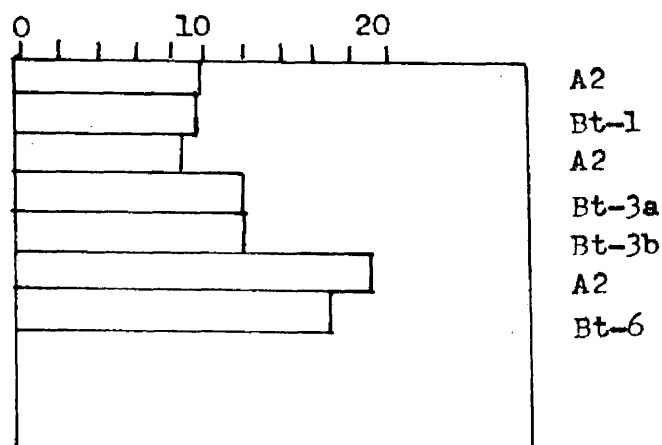
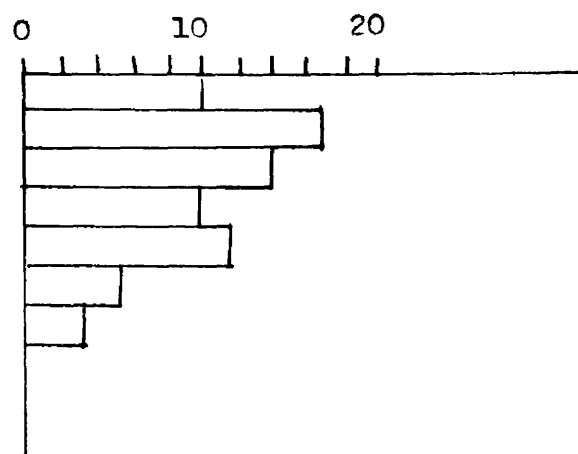


Figure 21. Montcalm fine sand; fine sand K-feldspar, very fine sand K-feldspar, fine sand plus very fine sand K-feldspar, fine sand/very fine sand K-feldspar.

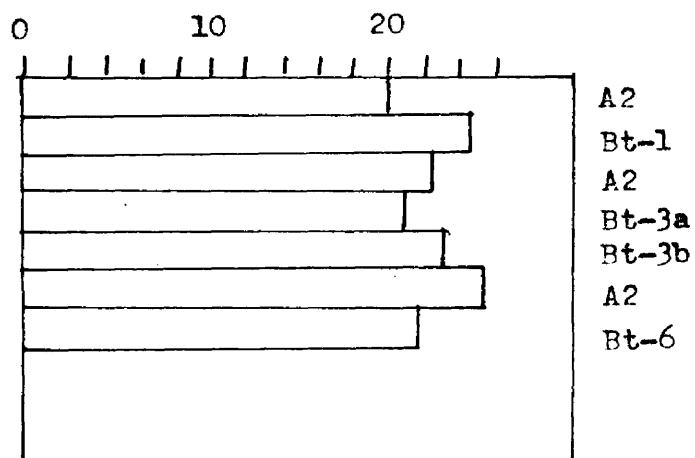
21A. Fine sand K-feldspar, percent



21B. Very fine sand K-feldspar, percent



21C. Fine sand plus very fine sand K-feldspar, percent



21D. Fine sand/very fine sand K-feldspar

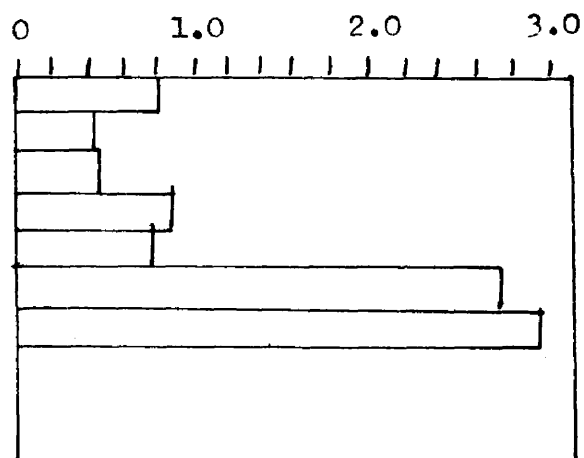
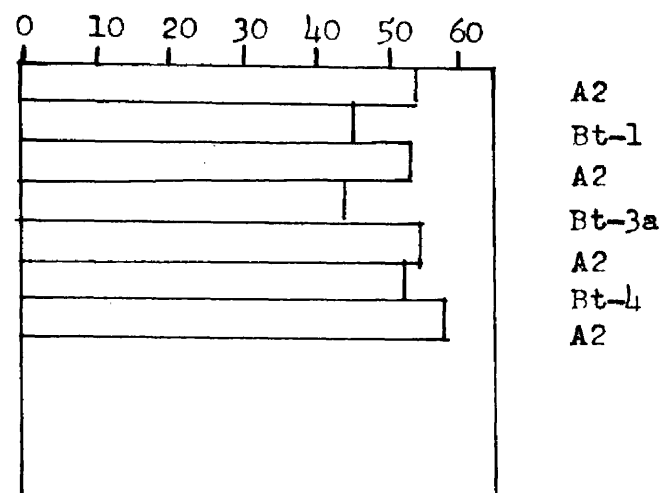
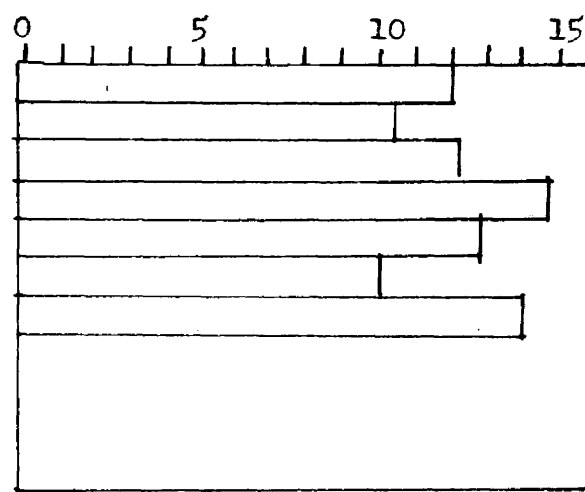


Figure 22. Coloma fine sand; fine sand quartz, very fine sand quartz, fine sand plus very fine sand quartz, fine sand/very fine sand quartz.

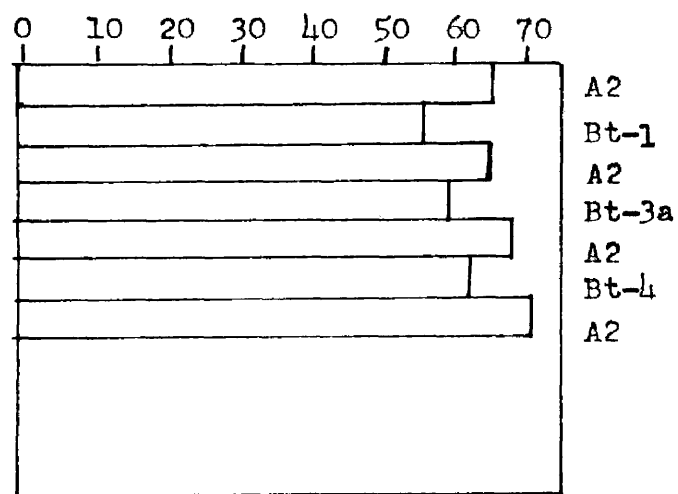
22A. Fine sand quartz, percent



22B. Very fine sand quartz, percent



22C. Fine sand quartz plus very fine sand quartz, percent



22D. Fine sand quartz/very fine sand quartz

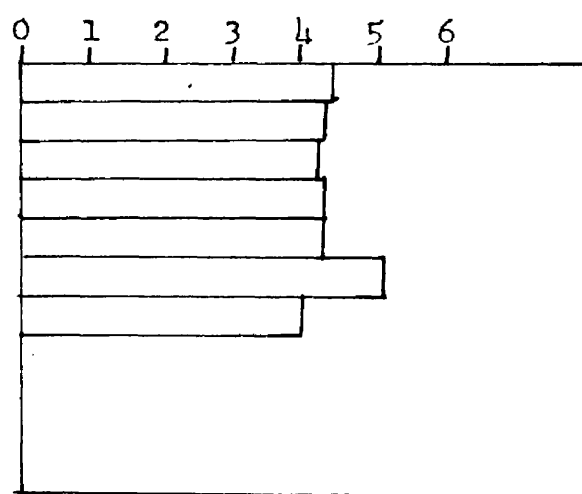
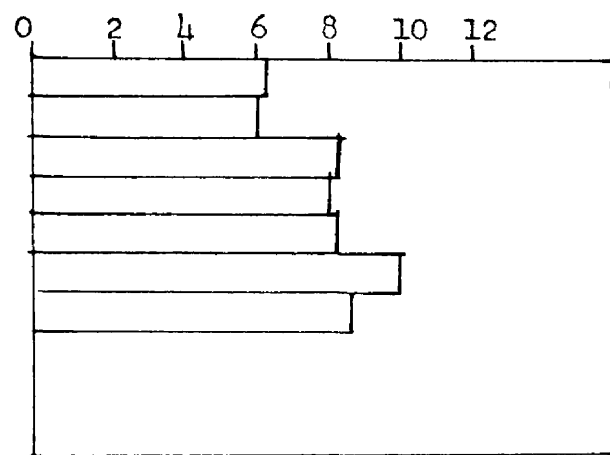
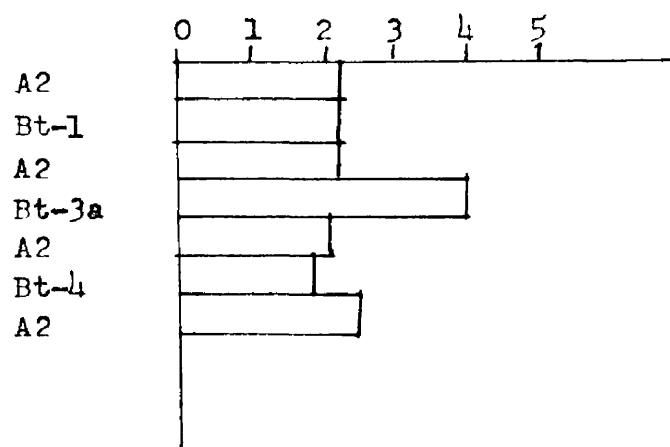


Figure 23. Coloma fine sand; fine sand K-feldspar, very fine sand K-feldspar, fine sand/very fine sand K-feldspar, fine sand plus very fine sand K-feldspar.

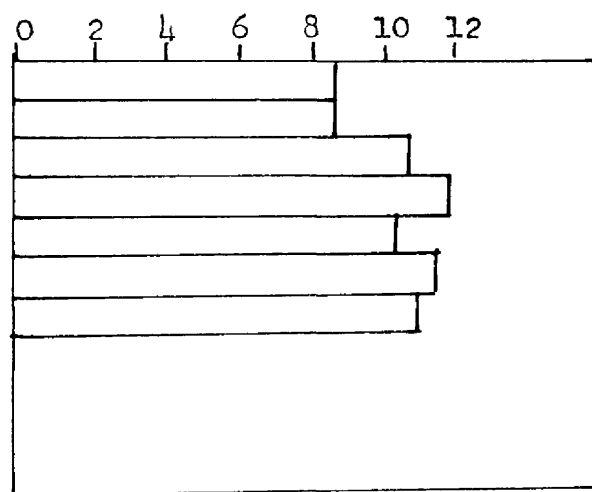
23A. Fine sand K-feldspar, percent



23B. Very fine sand K-feldspar, percent



23C. Fine sand plus very fine sand K-feldspar, percent



23D. Fine sand/very fine sand K-feldspar

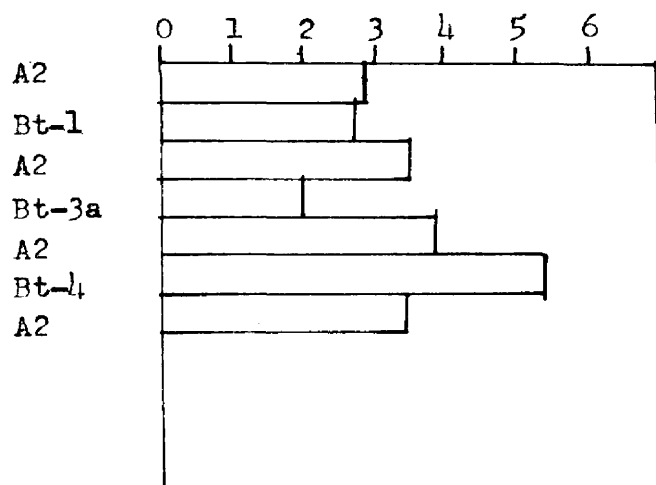
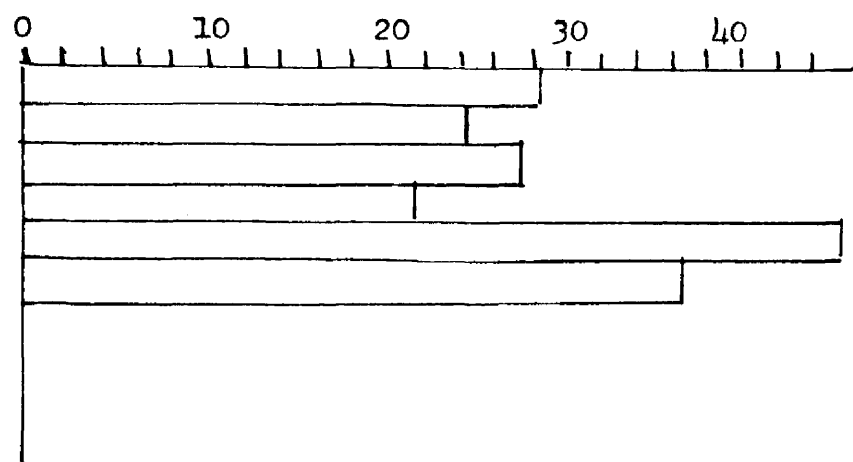
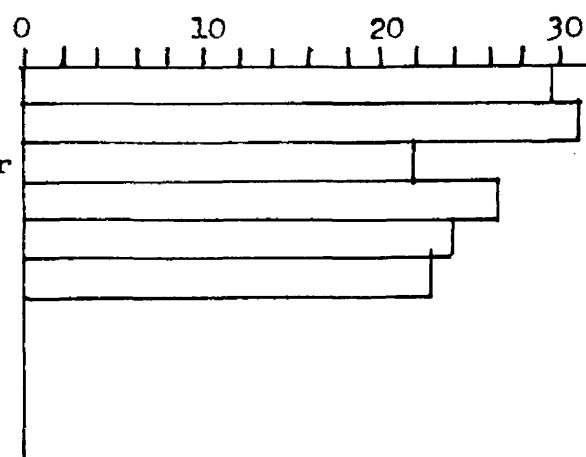


Figure 24. Wallace sand; medium sand quartz, fine sand quartz, medium plus fine sand quartz, medium/fine sand quartz.

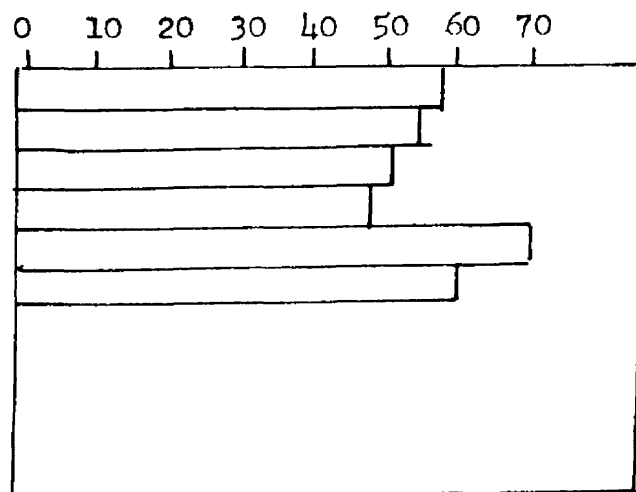
24A. Medium sand quartz, percent



24B. Fine sand quartz, percent



24C. Medium sand plus fine sand quartz, percent



24D. Medium sand/fine sand quartz

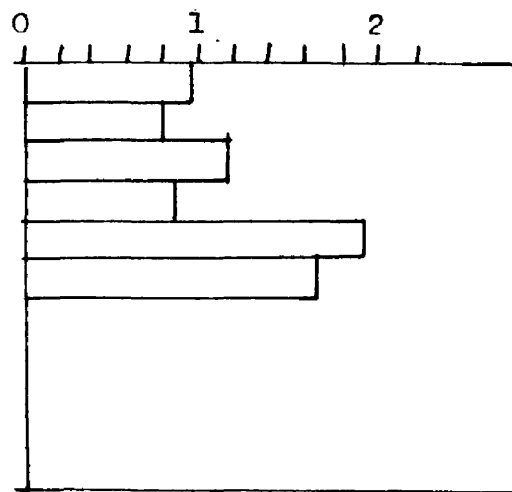
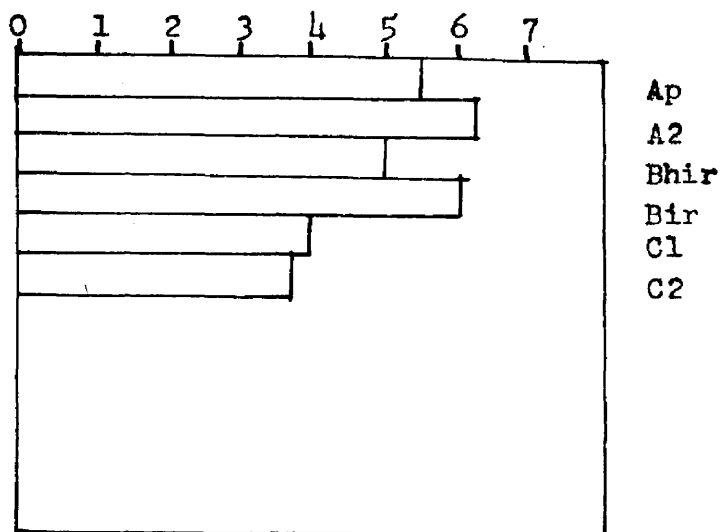
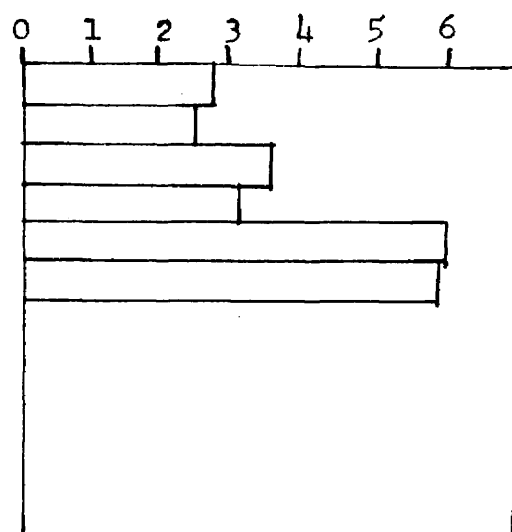


Figure 25. Wallace sand; fine sand K-feldspar, medium sand K-feldspar, medium sand plus fine sand K-feldspar, medium sand/fine sand K-feldspar.

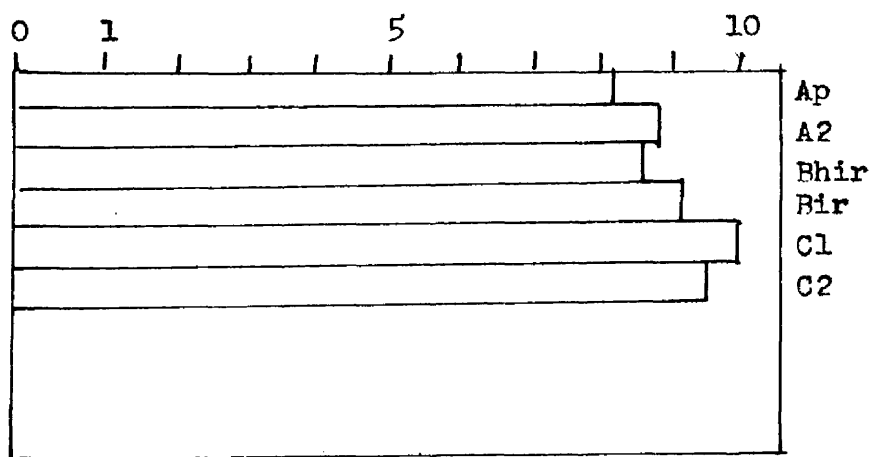
25A. Fine sand K-feldspar, percent



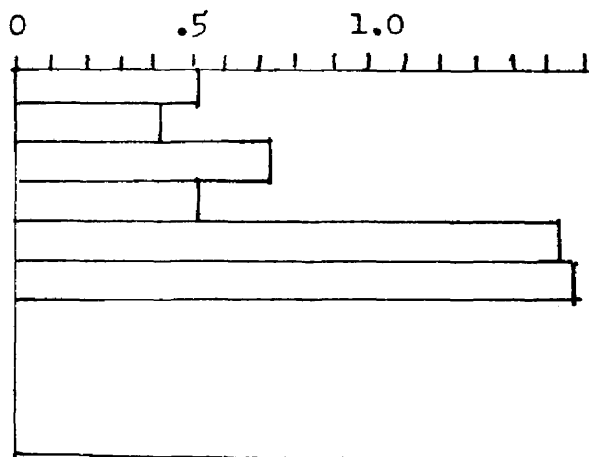
25B. Medium sand K-feldspar, percent



25C. Medium sand plus fine sand K-feldspar, percent



25D. Medium sand/fine sand K-feldspar



Quartz Analysis

Distribution of quartz in the dominant sand fractions was taken as an index of the uniformity of the parent material. The accuracy of determinations was $\pm$ 11.5 percent of quartz at the 5 percent level, and $\pm$ 5.7 percent at the 33 percent level using Fisher's 't' test in computing the significant difference. Pollack and Whiteside (1954) reported a 4.9 percent figure at the 5 percent level for quartz, while Phillippe and White (1950) reported a 2.19 percent figure at the 5 percent level for quartz. Coloma fine sand was the only profile of the four investigated which did not indicate evidence of some stratification when using the statistical quartz correlation, Table 1. The method of using quartz as a weathering index is not infallible, but is helpful in investigating the uniformity of a parent material. Other characteristics such as particle size distribution, feldspar content of dominant sand fractions, and clay mineral analysis should be examined before deciding the origin of specific horizons.

Feldspar Analysis

K-Feldspars (Orthoclase and Microcline) were the dominant feldspars present in all four soils. Cann and Whiteside (1952) reported orthoclase to be as resistant to weathering as quartz, while Ca-plagioclase was lost from soils due to weathering. As such, K-feldspar distribution in the sand

fraction may be used as an additional guide to the uniformity of parent material. This fact was used in correlating soil horizons in Table 8. In most cases quartz plus K-feldspar plus heavy minerals added up close to 100 percent of sand fraction going slightly above or below it at times. Variation might be due to a greater or smaller preferred orientation of quartz or feldspar in x-ray samples as compared with the respective standards.

X-ray Silicate Clay Mineral Analysis

Both kaolinite and illite occur in all horizons of soil profiles investigated. Montmorillonite occurs in the upper sequum of the Montcalm loamy sand (Podzol), throughout the Wallace sand (maximal Podzol) and is almost completely absent from Montcalm fine sand and Coloma sand which occur in the Central and Southern part of Michigan. The common occurrence of illite and kaolinite is in agreement with the results reported by Grim (1942), Bidwell and Page (1950), Alexander, et al. (1939), Winters and Simonson (1951). Chlorite was present in the Podzol soils studied. Chlorite is completely absent from the Gray-Brown Podzolic Coloma profile but present in the other profiles. Vermiculite is absent from the Wallace (Podzol) and occurs only in the calcareous stratifications of the Montcalm loamy sand (Podzol). Different origin of parent material may be the cause for the complete absence of vermiculite from the upper part of the Montcalm loamy sand profile. It can also be postulated that illite, and chlorite to a lesser

extent, weather to give montmorillonite in a Podzol profile as suggested by Jackson, et al. (1952). Illite may weather to form vermiculite and chlorite in both Podzol and Gray-Brown Podzolic soils as proposed by Walker (1949), Tamura and Swanson (1954). The relative intensity of an x-ray diffraction peak obtained from a clay mineral is a function of its degree of orientation in the sample irradiated. The same amounts of clay minerals in two different samples may give different peak intensities due to the difference in degree of orientation in the sample. No quantitative evaluation was attempted.

Clay Mineral Analysis by D. T. A.

In all four profiles analyzed, the presence of kaolinite was definitely established, thus corroborating x-ray analyses. The presence of expanding type of clay minerals was also demonstrated although no attempt was made to separate them. The presence of organic colloids is indicated by the strong exothermic peaks in the Montcalm loamy sand and Wallace sand Podzol profiles, (Figures 26, 27, 28). Figure 28 shows the influence of hydrogen-peroxide treatment on the clay fraction of Montcalm parent material. The exothermic peak characterizing organic matter presence in untreated clay fraction between 300 and 400° C was eliminated by hydrogen peroxide treatment. The exothermic peak in the Ap horizon of the Wallace sand profile between 700 and 800° C indicates strong absorption of organic colloid on the clay (Jordan, 1949). Neither the Bhir

and Bir horizons of the Wallace and Montcalm loamy sand nor the Bt horizons show the strong adsorption of organic matter on silicate clay. However, the organic peak between 300 and 400° is apparent in the Bhir and Bir horizons and some Bt horizons (Bt4a, Bt5). The shape and temperature of an exothermic peak may thus be used as an indication of the kind of organic matter, as well as its relationship to silicate clay minerals present.

No attempt was made to measure quantitatively all clay minerals present from the D.T.A. data. A sample of kaolin (Cornwall, England) was analyzed and comparing its peak height to those of soil clays, the Coloma fine sand and Montcalm fine sand on this basis contained approximately 10 percent kaolinite in A2 horizons and 20-25 percent kaolinite in the Bt horizons. Wallace sand horizons average between 5 and 10 percent kaolinite while Montcalm loamy sand contained between 5 and 20 percent kaolinite in its horizons.

Table 1.

Statistically significant differences in quartz contents
of sand fractions

Horizon	Horizons correlated (depth)	Horizon	(depth)	Fraction	Correlation
<u>Montcalm loamy sand</u>					
Bt-1b	(30-35")	A2	(35-39")	m.s. f.s.	iii ¹ ii
"	"	Bt-2b	(41-43")	m.s. f.s.	iii ii
A2	(35-39")	Bt-2a	(39-41")	m.s. f.s.	iii iii
Bt-2b	(41-43")	"	"	m.s. f.s.	ii i
Bt-2b	(41-43")	A2	(58-62")	m.s. f.s.	ii ii
A2	(58-62")	Bt-5	(62-69")	m.s. f.s.	ii i
<u>Wallace sand</u>					
Ap	(0-5")	Bhir	(12-22")	m.s. f.s.	iii ii
C1	(22-35")	"	"	m.s. f.s.	iii iii
"	"	C2	(35+)"	m.s. f.s.	iii ii
<u>Montcalm fine sand</u>					
Bt-1	(25")	Bt-3a	(49")	f.s. v.f.s.	iii ii
"	"	Bt-3b	(53")	f.s. v.f.s.	iii iii
A2	(47")	Bt-3a	(49")	f.s. v.f.s.	iii ii

Table 1. (continued)

Horizons correlated		Horizons correlated		Fraction	Correlation
Horizon	(depth)	Horizon	(depth)		
Bt-3b	(53")	Bt-3a	(49")	f.s.	111
				v.f.s.	11
"	"	A2	(60")	f.s.	11
				v.f.s.	111
Bt-6	(62")	"	"	f.s.	111
				v.f.s.	11
A2	(47")	"	"	f.s.	111
				v.f.s.	111
<u>Coloma fine sand</u>					
A2	(61")	Bt-1	(65")	f.s.	11
				v.f.s.	111
A2	(73")	"	"	f.s.	111
				v.f.s.	111
A2	"	Bt-3a	(76")	f.s.	111
				v.f.s.	111
A2	(95")	"	"	f.s.	11
				v.f.s.	111
"	"	Bt-4	(101")	f.s.	11
				v.f.s.	111
A2	(106")	"	"	f.s.	1/11
				v.f.s.	111
A2	(61")	A2	(73")	f.s.	11
				v.f.s.	111
A2	(106")	"	"	f.s.	11
				v.f.s.	111
Bt-1	(65")	Bt-3a	(76")	f.s.	111
				v.f.s.	111
Bt-4	(106")	"	"	f.s.	111
				v.f.s.	111

¹ 1 - significant difference at the 5 percent level.
 11 - " " " " 33 percent "
 111 - no significant difference at the 33 percent level.

Table 2.

Heavy mineral content of sand fractions

(Each value given is an average of two determinations)

Sample	Depth	Horizon	Percentage by weight*		Sample	Depth	Horizon	Percentage by weight	
			medium sand	fine sand				medium sand	fine sand
<u>Montcalm loamy sand</u>					<u>Montcalm fine sand*</u>				
M1	0-8"	Ap	0.3	0.5	K2	17"	A2	0.9	3.3
M2	8-10"	A2	0.2	0.4	K3	25"	Bt-1	1.0	2.7
M3	10-17"	Bhir	0.2	0.7	K7	47"	A2	0.8	2.1
M4	17-24"	A2	0.3	0.6	K8	49"	Bt-3a	0.9	2.5
M5	24-30"	Bt-1a	0.6	0.6	K9	53"	Bt- 3b	0.8	1.9
M6	30-35"	Bt-1b	0.6	0.7	K15	60"	A2	0.8	3.0
M7	35-39"	A2	0.3	0.8	K16	62"	Bt-6	0.8	4.8
M8	39-41"	Bt-2a	0.2	0.8					
M9	41-43"	Bt-2b	0.3	0.7					
M15	58-62"	A2	0.06	0.9					
M16	62-69"	Bt-5	0.3	5.8					
<u>Wallace sand</u>					<u>Coloma fine sand**</u>				
W1	0-5"	Ap	0.1	0.4	C6	61"	A2	2.0	5.4
W2	5-7"	A2	0.1	0.6	C7	65"	Bt-1	3.0	6.5
W3	7-12"	Bhir	0.3	0.7	C10	73"	A2	1.6	4.6
W4	12-22"	Bir	0.8	1.0	C11	76"	Bt-3a	1.7	4.6
W5	22-35"	C1	0.6	1.0	C13	95"	A2	1.6	3.5
W6	35+ "	C2	0.8	1.8	C14	101"	Bt-4	1.5	4.4
					C15	106"	A2	1.6	4.4

* At the 5 percent level a significant difference
 ≥ 0.5 for medium sand
 ≥ 1.7 for fine sand

**At the 5 percent level a significant difference
 ≥ 0.5 for fine sand
 ≥ 1.0 for very fine sand

Table 3.

X-ray determination of relative amounts of clay minerals expressed as areas under respective peaks on a Brown electronic recorder graph

Sample	Horizon	Depth (in-ches)	17.7A° mont- morill- onite*	10 A° illite* illite+vermiculite+montmorillonite +interst. illite+vermiculite** +interst. illite+montmorillonite	14 A° chlorite kaolinite*	7 A°
<u>Montcalm loamy sand</u>						
M1	Ap	0-8	12	3	-	3
M2	A2	8-10	21	5	2	7
M3	Bh	10-17	3	5	3	5
M4	A2	17-24	-	6	4	4
M5	Bt-1a	24-30	-	20	7	8
M6	Bt-1b	30-35	-	21	2	4
M7	A2	35-39	-	6	2	2
M8	Bt-2a	39-41	-	8	3	4
M9	Bt-2b	41-43	-	39	17	17
M13	Bt-4	52-58	-	22	17	17
M16	Bt-6	62-69	-	24	9	10
<u>Wallace sand</u>						
W1	Ap	0-5	24	5	10	4
W3	Bh	7-12	15	4	10	5
W4	Bhir	12-22	3	2	6	6
<u>Montcalm fine sand</u>						
K2	A2	17	2	8	3	6
K3	Bt-1	25	2	3	2	3
K7	A2	47	-	5	6	8
K8	Bt-3a	49	-	7	9	9
K9	Bt-3b	53	-	8	3	10
K15	A2	60	2	11	-	8
K16	Bt-6	62	2	6	2	5

-continued-

Table 3 (continued)

Sample	Horizon	Depth (in- ches)	17.7A° mont- morill- onite*	10 A° illite* illite+vermiculite+montmorillonite +interst. illite+vermiculite** +interst. illite+montmorillonite	14 A° chlorite ***	7 A° kaolinite*
Coloma fine sand						
C6	A2	63	-	14	-	7
C7	Bt-1	65	-	7	-	6
C10	A2	73	-	4	-	11
C11	Bt-3a	76	2	6	-	5
C13	A2	95	-	5	-	6
C14	Bt-4	101	-	7	-	6
C15	A2	106	-	7	-	8

*Glycerol treated

** 110 C + KCl

" "

*** 550 C.

Table 4.

Determination of clay minerals by differential thermal analysis* (expressed as amplitude of peaks between designated temperatures)

Sample	Horizon	Depth (in-ches)	Endothermic Peaks		Exothermic Peaks	
			100-200 C ***	500-600 C **	temperature	intensity
<u>Montcalm loamy sand****</u>						
M1	Ap	0-8		5	200-400	strong
M2	A2	8-10		12	"	weak
M3	Bhir	10-17		12	"	strong
M4	A2	17-24		18	"	v. weak
M5	Bt-1a	24-30		12	"	"
M6	Bt-1b	30-35		10	"	weak
M7	A2	35-39		10	"	"
M8	Bt-2a	39-41		16	"	v. weak
M9	Bt-2b	41-43		17	"	"
M13	Bt-4	52-58		14	"	strong
M16	Bt-5	62-69		21	"	"
<u>Wallace sand****</u>						
W1	Ap	0-5		5	600-800	v.strong
W3	Bhir	7-12		10	300-500	strong
W4	Bhir	12-22		5	200-400	strong
<u>Montcalm fine sand</u>						
K2	A2	17	7	10	none	none
K3	Bt-1	25	7	17	"	"
K7	A2	47	8	10	"	"
K8	Bt-3a	49	10	22	"	"
K16	Bt-6	62	9	21	"	"
<u>Coloma fine sand</u>						
C7	Bt-1	65	30	18	none	none
C11	Bt-3a	76	23	25	"	"
C13	A2	95	20	8	"	"
C14	Bt-4	101	16	20	"	"
C15	A2	106	27	9	"	"
Kaolin (Cornwall, England)				90		

* Lime free, (acid treated), Na-clay material

** Kaolinite type clay mineral

*** 2:1 expanding type clay minerals

**** No recording of 2:1 peaks due to strong displacement by organic matter presence.

Microscopic Examination of Natural Soil Aggregates

Montcalm loamy sand

In the Bhir horizon of the Podzol sequum, large, semi-rounded to subangular mineral grains and small white granular material dominated the fabric of the aggregates. The fine granular material acted as a matrix around larger fragments, occurring in between as well as on their surfaces. Few, small, brown clay material particles were observed in the fine matrix, around and on the surface of larger mineral grains. In the second A2 horizon, immediately below the Podzol sequum, no brown, clay-like material was observed.

The first textural B, as well as the rest of textural subsoil horizons underneath, showed a dense brown, clay-like material, acting as bridges between larger mineral fragments. Brown material was mostly concentrated in between grains, very little occurring on their surfaces. The A2 horizons, in between the textural Bs', had little if any of the brown clay-like material. Density of the brown material, by volume, varied between the various textural bands. Greatest density seemed to occur in the Bt-4a(52-58") horizon, being somewhat less in textural bands above or below it.

Montcalm fine sand and Coloma fine sand

Both profiles showed the same fabric features. Textural bands contained brown, clay-like material, acting as bridges between larger mineral fragments, with little if any on the

surface of the fragments. A2 horizons, in between the textural bands, showed a very spotty appearance of brown material, mostly as brown stains on mineral fragments, and no fine material bridges were evident anywhere.

Artificial Soil Column Experiments

Tables 5, 6, and 7 summarize the measurements made in the percolation experiments with artificial soil columns.

Table 5.

Volume and clay concentration of water or percolating suspensions flowing in and out (inflow and outflow) of 30 mesh quartz sand columns of different heights

Column	Volume of column c.c.	Height of column cm.	Volume c.c.		Clay concentration percent	
			Influent	Effluent	Influent	Effluent
1.	390	80	780	720	.028	.026*
2.	390	80	780	735	.014	.015*
3.	280	57	560	526	.014	.014*
4.	390	80	780	-	.0	.018

*Values corrected by subtraction of the amount of solids which came out with distilled water in column 4.

Table 6.

Volume and clay concentration of water or percolating suspensions flowing in and out (inflow and outflow) of artificial Coloma fine sand columns of different heights; also liquid and clay retained by those columns

Column	Height cm.	Weight gm.	Clay concentration percent	Volume		Liquid retained c.c.	Clay retained from sus- pension
				Influent	Effluent		
				c.c.			gm. %
1.	90	480	0	960	880	80	-
2.	90	480	.057	550*	450	100	.21 67
3.	47	240	.057	325	254	71	.11 62
4.	47	240	.057	500**	510	70	.12 42
5.	46	250	.057	630*	530	100	.18 51
6.	46	250	0	500	440	60	-
7.	46	250	.014	500	430	70	.007 10
8.	48	250	.057	440*	340	100	.15 59
9.	46	250	.029	485*	410	75	.07 52
10.	46	250	.043	250*	170	80	.08 78
11.	28	150	0	300	255	45	-
12.	29	150	.029	300	240	60	.04 47
13.	15	75	0	150	120	30	-
14.	15	75	.029	150	130	20	.03 61

*Percolation ceased after the indicated amount was added and came through.

**80 ml. of distilled water were added before indicated amount was leached through.

Table 7.

Clay concentrations in different layers of artificial Coloma fine sand columns after leaching with 2000 ml. of distilled water

Section height cm.	Total sand percent	Silt percent	Clay percent
Bottom = 0			
A. <u>Source material</u>			
	99.2	.4	.4
B. <u>Standard columns</u>			
0-10	-	-	I. 1.5 II. 1.0
10-20	-	-	1.2 .7
20-30	-	-	1.3 .9
30-40	-	-	1.8 .7
40-50	-	-	1.6 1.2
C. <u>Experimental columns</u>			
0-10	I. 99.2 II. 97.1 III. 96.9 IV. 98.9	I. .5 II. 1.5 III. 1.7 IV. .5	I. .3 II. 1.4 III. 1.4 IV. .6
10-20	99.1 98.9 98.0	.5 .6 1.3	.4 .5 .7
20-30	99.5 97.4 98.3	.4 2.2 1.0	.3 .4 .7
30-40	99.5 98.8 97.3	.2 .7 1.8	.3 .3 .9
40-50	98.7 99.0 98.6	.9 .4 1.0	.4 .6 .4
50-60	98.9 97.3 98.8	.6 .3 2.4	.5 .5 .3
60-70	98.7 98.7 98.8	.3 .8 1.0	.7 .5 .5
70-80	98.7 98.7 98.3	.8 1.0 1.0	.7 .7 .7
80-110	98.3		.6
Average			.7 .9 .7

Analyzing statistically the standard columns and using the fisher test ("t" test), a significant difference between the clay content of the fractions should be greater than .6 percent of clay. The differences in clay content of layers in the leached columns are no greater than in those moistened by capillarity.

Table 5 shows results obtained with quartz columns. The higher the concentration of the inflowing suspension, the higher the concentration of the outflowing liquid. Height of column had little effect on the effluents concentration. Apparently none of the suspensions lost clay in percolating through the quartz sand but all gained some sediment from the quartz as did distilled water. The only clay retained in quartz columns was therefore that suspended in the liquid retained by the columns.

Table 6 shows results obtained by leaching artificial soil columns of different heights with clay suspensions of different concentrations. The only increases in clay concentration on passing through the column were in the cases of distilled water. Intermediate concentrations of clay in the influents; 0.0142, 0.0285, and 0.0425 percent, gave very similar effluent concentrations; 0.0148, 0.016 and 0.0135 percent respectively. In some instances, when the clay concentration or volume of the influent is high i.e. 0.029, and soil column longer than 48 cm., percolation ceases after a while. Initial wetting of soil column 4 with distilled water, did not alter the concentration of clay in effluents, or the amount of clay retained.

Table 7 shows what effect a distilled water leaching has on the distribution of less than two micron clay in a uniform soil column. The fractionation and clay analyses of the two standard columns helped in obtaining a statistical significant figure, to be used in the study of results obtained from

the four leached columns. The difference in silt, sand or clay contents of the various fractions in the soil columns, can therefore be attributed to the initial differences in the filling of the columns.

Results obtained with oxalic acid leaching experiment were as follows:

a. Twenty-four hours after the first 50 ml. of oxalic acid were added, distinct brown color bands appeared in column 4 (uniform, non-limy material) at a depth of 87 centimeters; column 3 (limy stratum at 93-101 cm.) at a depth of 82 centimeters; and in column 2 (limy stratum at 17-24 cm.) at a depth of 84 centimeters. In column 1 (three limy strata), no bands were observed at that period.

b. After seventy two hours (3 days), a new brown band appeared in column 3 (limy stratum at 93-101 cm.) at a depth of 67 cms. and in column 4 at a depth of 62 cms. Column 2 (limy stratum at 17-24 cms), showed a series of three faint brown bands just above the limy layer. Column 1 (three limy strata) showed the formation of brown bands beneath the lower margin of each of the limy strata, forming an extension of these layers.

c. After ninety-six hours, column 1 showed a series of faint brown bands, between the second and third limy strata (51-65 cms.). Column 2 and 3 showed the formation of brown bands immediately below the calcareous layers.

d. After five days a series of brown bands were observed

directly above the upper limy stratum in column 1 (27-31 cms.) and column 3 (93-101 cms.).

e. After seven days the formation of a red band was evident in the upper part of the limy stratum of column 1, the one closest to the surface, and in the only limy layer of column 2.

f. Only the uniform non-limy column showed evidence of some clay in the effluent, while the rest of the columns gave clear effluents.

g. All but two of the color bands formed were dark yellowish brown (10YR4/4, moist). The two bands formed in the calcareous layers were red (10R5/8, moist).

h. Columns 2, 3 and 4 showed strong leaching effects in their upper part with yellow (10YR7/6, moist) color. Areas above limy layers showed accumulation of material with darker colors; yellowish brown (10YR 5/4, moist).

i. Color bands formed above limy material in stratified columns or in uniform non-limy column were much more distinct and contrasting than those formed in between limy layers.

j. No oxalate ion was detected in any of the four column leachates.

GENERAL DISCUSSION AND INTERPRETATION OF RESULTS

Physical and Chemical Properties of Textural Horizons

Textural horizons, whether close to the surface or deep are an integral part of the soil profile. Whether petro-pedo-genetic or pedo-genetic, their properties may be markedly influenced by the processes taking place in the soil profile. Textural horizons may differ from soil to soil. One common feature to all is that they are horizons containing more clay than the adjoining layers. In Michigan the large majority of soils are relatively young. The materials were deposited mainly during the Cary and Mankato sub-stages of the Wisconsin glacial period. Inherent properties of parent materials strongly influence soil properties and profile development. Multiple textural horizons are found in materials of sand to sandy loam textures. The textural horizons that are due to original stratification of parent material may differ from those formed in originally uniform parent materials. Those differences may not necessarily be observed in the field but should be detectable with the aid of physical and chemical analyses in the laboratory. The following is a summary of physical and chemical properties of the multiple textural horizons that were analysed in this study:

- a. Textural layers contain two to seven times the amount of clay that is present in intervening sandier horizons.
- b. Largely due to their much higher clay content, textural

layers have total specific surface areas two to twelve times higher than specific surface areas of the intervening horizons. The amount of specific surface is a function of the amount of clay as well as the type of clay minerals and the amount of organic matter found in the bands.

- c. Textural layers are horizons of concentration and/or accumulation of organic matter and "free iron". This "free iron" accumulation may be partly or wholly due to the higher clay content i.e. iron in the lattice of clay minerals that is released during chemical analysis.
- d. Textural layers are horizons of high exchange capacity and exchangeable hydrogen, (in absence of free lime). The high exchange capacity is due to higher colloidal content and determined by the amount and type of clay mineral as well as organic colloid present.
- e. Textural layers have lower pH values and higher percent base saturation than horizons in between (in absence of free lime).
- f. Exchange capacity and specific surface per gram of clay reflect the dominant influence of the type of clay mineral present in the textural layers. Vermiculite, montmorillonite and colloidal organic matter are the greatest contributors, followed by illite, chlorite and kaolinite.
- g. The "free iron"/clay ratio is lower in textural layers than in horizons in between. The "free iron"/clay ratio

in textural layers is similar to or lower than that found in the Podzol B of the Montcalm and Wallace profiles. The range in total chemical analyses of clay minerals as reported by Grim (1955) are as follows:

	Fe_2O_3	
Montmorillonite	Tr.	- 6.35
Vermiculite	2.78	- 10.94
Chlorite	0.82	- 8.70
Illite	0.76	- 18.88
Kaolinite	0.27	- 2.00

Since all of these clay minerals are present in the soils analyzed it is possible that the "free-iron" found in the textural bands can be partially or wholly attributed to the clay minerals present in them.

- h. Organic matter/clay ratios are lower in non-limy textural horizons than in the adjoining horizons. They are much lower than those of the Podzol B.
- i. The heavy mineral distribution in the soil profile shows no preferential concentration in either textural bands or adjoining horizons (with exception of the lowest textural horizon in the Montcalm loamy sand profile).
- j. The Podzol sequa studied i.e. Montcalm and Wallace profiles contain montmorillonite, illite, kaolinite and chlorite near the surface, while deeper in the profile illite, vermiculite, and kaolinite or chlorite predominate. In the Gray-Brown Podzolic soil, i.e. Coloma fine sand, illite, vermiculite, and kaolinite predominate with rare appearances of montmorillonite.

- k. Quartz studies were undertaken to evaluate uniformity of the parent material. Parent materials were all high in quartz. Large variations in ratios of fine sand and medium or very fine sand quartz fractions from different horizons indicate some lithologic variations in parent materials.
- l. Feldspar distribution shows no distinct pattern when comparing textural horizons with horizons in between. Orthoclase and microcline were the dominant feldspars in all soil profiles.

Horizon Nomenclature and Classification

Field observations of soil horizons form the basis for any further genetic interpretations. Field characteristics such as relative position in the profile, color, texture, structure and lime presence, are the criteria used in arriving at a possible mode of formation of soil horizons. Any useful soil classification scheme must be based in part on properties observable in the field. The elimination of a genetic bias from soil classification will cause soils people working in the field to become artists rather than scientists. When we draw a line around a mapping unit in the field, we assume the whole area classified to be similar enough in characteristics to be included in the group of characters observed in the holes bored. This in turn relies on the assumption that soil forming factors in the classified area are similar enough to cause a similar combination of soil properties. We are

therefore mapping areas on a genetic basis manifested in field characteristics. If we leave out the genesis factor from the classification scheme, we in fact remove one of the bases of our field mapping. The question as to what is more important, "process" or "characteristic" can only be answered by asserting that they are inseparable.

Cohen and Nagel (1934), in their discussion of the "scientific method", assert that the process of classifying things really involves, or is a part of, the formation of hypotheses as to the nature of things. Further, the most important thing in the choice of a basis for a natural classification is to pick that property in the objects studied which will be the significant clue to their nature.

With this in mind we now turn to the horizon designation of the soil profile studied. Each designation consists of both pedogenic and petrogenic part. Designations such as A2, Bh, Bhir, and Bt refer to characteristics of the horizons that indicate the dominant soil formation processes taking place, and as such are a pedogenic designation. In cases where it was established that some horizons were formed from significantly different parent material than others, a petrogenic designation in the form of a Roman numeral was assigned to a specific parent material grouping. They are numbered in the order in which they are found from the surface downward. The choice of criteria for such separations are critical. The following is a list of the criteria chosen:

1. Percentage of material larger than 2 mm. (on basis of bag-sample).
2. Particle size distribution, the emphasis being on the dominant sand fractions.
3. Clay mineral analyses of the clay fractions. These are given little weight because of the possible origin and mobility of this fraction during soil formation.
4. Quartz content of dominant sand fractions and their sums.
5. Ratio of amounts of quartz in dominant sand fractions.
6. Ratio of K-feldspar content of dominant sand fractions.
7. Heavy mineral content of dominant sand fractions.

The small numerals (i) assigned to each horizon in Table 8 are based on each of the above criterion, separately. Finally, these are evaluated collectively with a large Roman numeral in each horizon. It should be emphasized here that this tabulation is primarily designed to point out the possible petrogenic relationships of the various textural layers.

Pedogenic designations preceded by the same Roman numeral indicate their probable origin from similar parent materials in that profile, i.e. petrogenically uniform. It is possible for an original stratification of the parent material to be modified by soil processes and thus become partly pedogenic and partly petrogenic. This is another reason that both pedogenic and petrogenic designations are necessary.

Table 8.

Probable pedogenetic and petrogenetic layers in soil profiles

Pedo- genetic (in- horizon ches)	Depth	Texture		Mineralogical Composition					Petro- genetic layers	
		Mater- ial	Mechani- cal	Clay mineral Analysis	Percent- age Quartz ²	m.s.K-feldspar				Heavy mineral Analysis ³
						f.s.quartz	f.s.K-feldspar	f.s.K-feldspar		
>2mm. Analysis										
<u>Montcalm loamy sand</u>										
Ap	0-8	1	1	1	1	1	1	1	I	
A2	8-10	1	1	1	1	1	1	1	I	
Bhir	10-17	1	1	1	1	1	1	1	I	
A2	17-24	1	1	1	1	1	1	1	I	
Bt-1a	24-30	1	1	1	1	1	1	1	I	
Bt-1b	30-35	1	1	1	1	1	1	1	I	
A2	35-39	1	1	1	1	1	1	1	II	
Bt-2a	39-41	1	1	1	1	1	1	1	III	
Bt-2b	41-43	1	1	1	1	1	1	1	IV	
A2	58-62	1	1	1	1	1	1	1	V	
Bt-5	62-69	1	1	1	1	1	1	1	VI	
<u>Wallace sand</u>										
Ap	0-5	1	1	1	1	1	1	1	I	
A2	5-7	1	1	1	1	1	1	1	I	
Bhir	7-12	1	1	1	1	1	1	1	I	
Bir	12-22	1	1	1	1	1	1	1	I	
Cl	22-35	1	1	1	1	1	1	1	II	
C2	35+	1	1	1	1	1	1	1	III	

--continued--

Table 8. (continued)

Probable pedogenetic and petrogenetic layers in soil profiles

Petro- genetic horizon	Depth (in- ches)	Texture Mechani- cal Analysis	Mineralogical Composition					Petro- gene- tic layers	
			Clay mineral analysis	Percent- age quartz ²	f.s. quartz				Heavy mineral ³
					v.f.s.	K-feldspar	v.f.s.		
<u>Montcalm fine sand</u>									
A2	17	i	i	i	i	i	i	I	
Bt-1	25	i	i ⁴	i	i	i	i	I	
A2	47	i	i ⁴	i	i	i	i	I	
Bt-3a	49	i	i ⁴	i	i	i	i	I	
Bt-3b	53	i	i ⁴	i	i	i	i	I	
A2	60	ii	i ⁴	i	ii	ii	i	II	
Bt-6	62	ii	i ⁴	i	ii	ii	ii	III	
<u>Coloma fine sand</u>									
A2	63	i	i ⁴	i	i	i	i	I	
Bt-1	65	i	i ⁴	i	i	i	ii	II	
A2	73	i	i ⁴	i	i	i	i	I	
Bt-3a	76	i (or ii)	i ⁴	i (or ii)	i (or ii)	i (or ii)	i	I or II	
A2	95	i	i ⁴	i	i	i	iii	IV	
Bt-4	101	i (or iii)	i ⁴	i (or iii)	i (or iii)	i (or iii)	i	I or V	
A2	106	i	i	i (or ii)	i	i	i	I	

¹Particle size distribution in non-clay fractions.²Dominant sand fractions; used in statistical correlation of horizons. See also Table 1.³Percentages in dominant sand fractions.⁴D.T.A. analysis indicated a two-fold kaolinite concentration which may justify designating these horizons as "ii". X-ray analyses do not show such a preferential concentration of kaolinite in the Bt horizons.

Soil Profile Development with Emphasis on the Origin of Textural Bands

Properties of textural subsoil horizons were reviewed in the preceding sections. Table 8 showed how specific physical, chemical and mineralogical analyses were used as criteria to differentiate the probable pedogenetic and petro-genetic origin of these textural layers. Two kinds of genetic textural layers may be postulated:

- a. Pedo-petrogenetic; those formed due to the interaction of an original stratification of the parent material and modifications caused by the genesis of the soil profile.
- b. Pedogenetic; those formed primarily due to genetic changes in the soil profile.

The following is an attempt to explain the mode of origin of the two kinds of textural layers in light of the results obtained in the laboratory.

Pedo-petrogenetic textural bands

Barshad (1955) mentions the following criteria for testing the uniformity of parent-materials:

- a. Total mineralogical analysis, with particular attention to the heavy mineral fraction.
- b. Nature of particle size distribution of the resistant minerals (heavy or light) of the non-clay fraction.
- c. Nature of ratio of two resistant minerals in any one of the non-clay fractions.
- d. Particle size distribution of the whole non-clay fraction.

- e. Nature of clay distribution with depth.
- f. Nature of changes in chemical composition of non-clay fraction.

Most of these criteria were used to some extent in the construction of Table 8. Some of the criteria indicated different parent materials, while others were less specific. The "independability" of a property is important in the final evaluation i.e. Roman numeral assignment to the various horizons. The greater the number of criteria pointing towards a petrogenetic difference, the more positive a person can be that such a difference exists.

Glacial drift materials, more often than not, do show some kind of stratification. At least two kinds of independent stratifications were found in soil profiles under investigation (Table 8); (a) textural stratification due to different particle size distribution of the non-clay fraction, (b) mineralogical stratification due to differences in heavy mineral content, quartz and K-feldspar and possible differential clay mineral type distribution. The two types of discontinuities do occur simultaneously in some of the soil profiles investigated e.g. Montcalm fine sand, Bt-6 horizon.

Micropedological observations of the textural bands below 35 inches, in the Montcalm loamy sand soil, showed the presence of a brown clay-like material, acting as bridges between mineral grains, very little occurring on their surfaces. This material may have moved into these layers and deposited along

channels of movement or particularly where suspension drop-lets left clay on drying of the soil.

The Wallace sand (maximal Podzol) profile shows a discontinuity in the particle size distribution of the sand fractions below 22 inches. On that basis, C1 and C2 horizons may be regarded as petrogenetically different from the rest of that profile.

No free lime was found in the Montcalm and Coloma fine sand profiles. D. T. A. analyses of the same two profiles showed the kaolinite type clay minerals to be twice as high in the textural layers as compared to the intervening sandier horizons. This can be attributed to any of the following causes, separately or combined: (a) Differential accumulation of kaolinite in textural layers. Bloomfield (1954) found ash and aspen leaves to deflocculate kaolin much more than montmorillonite. This preferential dispersion may account for higher mobility of kaolin with respect to other clay minerals. (b) Original discontinuity in the distribution of kinds of clay minerals in the soil profile i.e. petrogenic feature.

Mechanical and mineralogical analyses indicate a possible difference in original parent material of the two lowest

horizons in the Montcalm fine sand e.g. A2Bt-5 and to a lesser extent in the Bt-1, Bt-3a and Bt-4 horizons of the Coloma fine sand profile.

The influence the textural and mineralogical petrogenic differences have on the potential initiation of a textural band can be evaluated in the light of the following available information:

- a. Under the prevailing climatic conditions, quartz and K-feldspar, constituting 90 percent or more of the non-clay fraction of soils under investigation, contribute little if any to the formation of clay in place.
- b. The presence of Ca-feldspar, the least resistant of the feldspars under prevailing climatic conditions, was not demonstrated in the x-ray analysis of dominant sand fractions.
- c. Neither Na nor K-feldspar show any preferential differences in textural bands compared to intervening layers.
- d. Silt content of Coloma fine sand is very low i.e. rarely rises much above 2 percent. Little potential sieving action on clay moving in suspension can be postulated therefore. In the Montcalm fine sand profile, the silt is somewhat higher in the overlying A₂ than the Bt horizons in all cases.
- e. The same kinds of clay minerals are found in both textural bands and intervening sandier layers. However,

the kaolinite type clay minerals increase in percentage in the textural bands in the Montcalm and Coloma fine sand profiles.

- f. In lime free textural horizons, no preferential concentration or reduction of heavy minerals is apparent. With its easily weathered ferromagnesium minerals, this fraction could have contributed to the formation of clay or iron-oxides in place.

The textural and mineralogical discontinuities may be used solely as indicators to the possible existence of depositional bands in the parent material. As such, it does not completely account for their formation. Pedogenesis may play a major role in the formation of textural bands, regardless of the inherent mineralogical properties and discontinuities in the parent material. It is for this reason that they often obscure original differences in the parent material.

The role of pedogenesis in textural band formation

Textural bands of the soil profiles investigated showed a higher concentration of clay (less than two microns), "free iron oxide" and colloidal organic matter. The increased content of the three components can be attributed to: (a) individual movement and accumulation of the three components. (b) An iron-organic matter complex moving independently of the clay. (c) "Free iron oxide" derived wholly from lattice of clay minerals and as such its concentration is a direct function of the clay content, while the colloidal organic matter moved

independently. (d) The movement and accumulation of a clay mineral-iron-organic matter complex as a unit. (e) The weathering in situ of silt size particles, releasing both silicate clay minerals as well as free iron oxide. A combination of all five possibilities seems to fit the situation on hand, the reasons for such an assertion to be pointed out now.

Analysis of clay fraction (less than two micron) from Montcalm loamy sand C horizon (72 inches), showed the clay fraction to contain 2.5 percent "free iron oxide" as Fe_2O_3 . If all the free iron oxide was derived from the clay only, Bt-1a horizon in the Montcalm loamy sand with 20 percent clay should contain 0.5 percent "free iron oxide". As results indicated (Appendix Table 10), the "free iron oxide" content of that horizon was 1.1 percent. There was more "free iron oxide" than could be accounted for if it was only derived from the clay itself. The following calculations also indicate that in the Montcalm and Coloma fine sand profiles the textural horizons contain more "free iron oxide" than can be obtained from the total disintegration of clay minerals present. These calculations are based upon the assumptions that there is 6 percent of total Fe_2O_3 in the clay mineral fractions of these soils and that all of this is soluble as "free iron oxides". Grim's (1955) citations data of clay mineral analysis cited previously indicate that this would be a reasonable figure based on the four clay minerals present. Actually the chemical composition of the clay minerals is quite variable and the proportions of each present are not known.

Horizon	Clay %	Calculated "Free iron oxide" of soil from clay Percent Fe_2O_3	"Free iron oxide" in soil Percent Fe_2O_3
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Montcalm fine sand

A2	3.6	0.22	0.4
Bt-1	8.0	0.48	0.6
A2	2.4	0.15	0.3
Bt-3a	9.3	0.56	0.7
Bt-3b	7.2	0.43	0.6
A2	0.9	0.05	0.2
Bt-6	6.3	0.38	0.5

Coloma fine sand

A2	2.7	0.2	0.5
Bt-2	9.9	0.6	0.9
A2	2.6	0.15	0.5
B5-3a	10.0	0.6	0.9
A2	2.4	0.15	0.4
Bt-4	8.4	0.5	0.8
A2	2.2	0.13	0.4

However, even assuming a complete breakdown of the clay minerals during iron analysis and a fairly high figure for the total iron content of the clay minerals present, the clay content does not account for all the "free iron oxide" present in the textural bands. The D.T.A. analyses do not show the presence of free iron oxide in the textural bands of the Montcalm loamy sand or the Podzol B horizons of the Wallace sand. Mineralogical analyses also show that the "iron rich" types of clay minerals i.e. illite, vermiculite and chlorite (when present) are concentrated in the sandier layers in between the textural bands, in the Montcalm and Coloma fine sand profiles. This being the case, "free iron oxide"/clay ratios should be higher in these sandy layers. This is borne out by the results

obtained (Figures 11C and 14C). A person could justly surmise therefore that only a part of the "free iron oxide" found in the textural bands was derived from the clay minerals themselves, but the rest has not been identified for certain as known crystalline forms of "free iron oxide".

If part of the "free iron oxide" in the textural bands is assumed as "independent" of the iron in the original clay minerals present, its movement and deposition in the soil may be due to: (a) independent movement of amorphous oxides in suspension or in solution, (b) movement in an organic matter-iron complex form, or (c) movement in a clay-iron complex.

A sandy soil "skeleton" can be assumed to have a net negative charge. The iron oxide, having a net positive charge, under acidic conditions must be "protected" or the pores must be large enough, in order for it to move through an oppositely charged medium. Organic matter decomposition products can react with iron oxide to form a complex with a net negative charge, depending on the ratios of the two components as shown by Deb (1950 and Delong and Schnitzer (1955 a,b). This complex in turn could move through a negatively charged soil medium.

Iron ions can be adsorbed on the surface of clay minerals and preferentially oriented clay and iron oxides have been cited to explain the pleochroism of some silicate clays (personal communication from Dr. Stephens, England). Therefore, movement might occur as a silicate-iron oxide complex.

Experiments with pure quartz columns in the laboratory showed

the ability of a less than two micron clay from a differentiated Coloma subsoil sample to move unhampered through them. On the other hand, the same complex, moving in suspension (of the same concentration) through a bulk sample of the same Coloma subsoil material, was partially prevented from moving through it, as manifested by the reduction in concentration in the effluent (see Tables 5 and 6).

A simultaneous movement of two negative constituents such as clay minerals and organic-iron complex, is possible without mutual interference. The accumulation of both of these components of the soil suspension can be brought about in the following manners: (a) Deposition of both out of soil suspension due to the lack of water to flush them further, sedimentation, or by withdrawal of water by evapo-transpiration. The alternate wetting and drying of the soil body by rainfall could cause such an accumulation at the "forward progress margin" of the wetting front, as might occur in these soils during certain periods. (b) Free lime presence, causing the flocculation of both clay minerals or clay complexes and/or the organic-iron complex. Due to the absence of free lime in the Montcalm and Coloma fine sand profiles, this mechanism seems somewhat doubtful there, although the parent materials of those profiles probably contained some lime. However, in the Bt-5 textural band of the Montcalm loamy sand, this may be the major factor. (c) Mutual flocculation of free iron oxide and clay, as suggested by Folks and Riecken (1956).

There exists the possibility of the organic-iron and/or other colloidal complexes reversing their electrical charge with varying conditions in the soil profile. This might be brought about by the adsorption of additional iron from the soil matrix to the organic or clay complexes moving through it, or withdrawal by adsorption of one of the components in the percolating fluid. Once the organic-iron ratio reaches a critical point i.e. 100 percent saturation of the organic matter exchange capacity with iron, the complex will become positive, according to Delong and Schnitzer (1955a). This change in electric sign will cause the flocculation of the organic complex itself in the negative matrix, as well as some of the clay minerals coming in contact with it. If this were the main or only mechanism by which the clay is deposited, increased free iron oxide/clay ratios would be expected in the textural bands. This is the case in the A2, Bt-1a and Bt-1b layers of the Montcalm loamy sand. The reverse is evident in the Bt-5 layer of the same profile, where petrogenetic differences and free lime complicate the picture. Also, in the Montcalm and Coloma fine sand profiles, the sandier intervening layers have a higher free iron oxide/clay ratio than the adjoining textural bands, if all the "free iron oxides" are attributed to the clay fraction of the soil. As such, the iron oxide acting as a flocculating agent is not the only factor in the movement and accumulation of clay in textural bands. (d) The beginning of deposition in fine pores of the original materials due to textural or

structural conditions originally present in the soil. Such a physical barrier may start a sieving action on any colloidal material moving through the soil. These concentrations may also become absorption media for other components in the soil solution which in turn may be "caught" and deposited.

Comparing the organic matter/clay ratios of the textural horizons to those found in the Wallace or Montcalm Podzol sequa, we find them to be many times lower in the textural bands. The organic matter/clay ratios are higher in the sandier intervening layers than in the textural bands themselves, except in the Bt-2 horizon of the Montcalm loamy sand, while "free iron oxide"/organic matter ratios are very similar in both types of layers.

Microscopic studies of non-limy textural bands in the Montcalm loamy sand, Montcalm and Coloma fine sand profiles showed the brown clay-like material to concentrate in between mineral grains, acting as bridges between them, very little occurring on the grain surfaces. This may be taken as indication that deposition out of suspension took place, perhaps by evapo-transpiration of the moisture in between the mineral grains. Physical translocation of clay in soils is caused by the movement of water. In order for that to happen, clay must be dispersed and brought into suspension. According to Barshad (1955) conditions favoring dispersion are a high state of hydration, low electrolyte content, pH far from isoelectric points and the absence of oppositely charged colloids in the

same system. A reverse in any of these conditions will cause clay flocculation out of suspension or no movement at all. Organic matter may help clay move by chelating the positive iron and aluminum oxides. According to Barshad, clay migration is a seasonal affair, alternating with periods of flocculation. He too advocates the idea of clay and iron moving independently or simultaneously, depending on interaction in the three component system of silicate clay-iron oxide-organic matter. As mentioned previously, a less than two micron colloidal fraction containing such a system was observed to move through and be partially retained by natural soil material columns in the laboratory (Table 5).

The build-up of clay concentration may take place at the surface of a layer containing free lime and cause a textural band to form there. With the removal of the free lime by solution, clay will be able to migrate further. No clay was observed to migrate through the columns containing free lime layers in the laboratory but clay did move out of columns containing no limy layers. These columns were leached with both distilled water and dilute oxalic acid solution. In the case of oxalic acid leaching, brown color bands were evident immediately below the limy bands after 2000 ml. (160 surface inches or about the equivalent of 5 years mean annual rainfall) of solution were poured through. Allowing for runoff and evaporation-transpiration losses, this would be the equivalent of many more years of leaching under natural conditions.

In the non-limy column, a rapid formation of color bands was evident as the oxalic acid permeated the soil column. This may be an illustration of the possible importance of organic acids in the movement and accumulation of (colloidal material) in soils. It also corroborates work done by Folks and Riecken (1956), demonstrating a possible mechanism of band formation. The fact that no oxalate ion was detected in the effluent of any of the soil columns, may be due to the interaction of the organic anion or acid with soil constituents fixed in the columns, e.g. iron or aluminum oxides. The importance of soil organic matter as a source for organic acids, phenols and tannins has been demonstrated. These compounds were derived from the leachates of various leaves and were shown by Bloomfield (1953 a,b) and Delong and Schnitzer (1955 a,b) to have a complexing action on iron compounds derived from soil materials.

By way of summary, from the data available, both physical and chemical mechanisms are involved in the textural band formation in soils under investigation. The ability of a "differentiated complex" of iron oxide-silicate clay-colloidal matter to move through columns containing natural soil material may be one of the possible mechanisms. The individual movement of silicate clay and iron-organic matter complex simultaneously or at different seasons can also be postulated. The deposition of the individual complexes or a combination of them may be caused by a chemical interaction between them, physical factors

such as alternate wetting and drying of the soil (evapo-transpiration), the activity of a third agency on one or both of the mobile constituents i.e. free lime flocculating clay, organic-iron complex or both. As results show, a combination of the above mentioned factors is needed to explain physical, chemical and micropedological observations.

CONCLUSIONS

Coarse textured soils in Northern Michigan often show textural horizons below a Podzol sequum. Field observations revealed that these textural layers are more reddish in color as well as finer textured than the sandier horizons immediately above or below them. These textural layers vary in thickness from 1/8 to 8 inches and from one to many in a particular profile. They cut across geologic strata at different angles and are often discontinuous (Figure 5). In addition to these non-limy, brown, strong brown, or strong yellowish brown textural bands, some calcareous layers which do not often follow surface configuration and do not cut across geologic strata are found in some profiles.

Physical, chemical and mineralogical studies in the laboratory showed that the non-limy, more reddish textural horizons contain a higher concentration of silicate clay minerals, "free iron oxide" and organic matter than the adjoining layers. They may or may not be of the same parent material as the horizons immediately above and below them. They are wholly or in part the result of pedogenetic processes acting on the original stratification of the parent material.

With time, soil formation processes bring about an alteration of any geologic strata. Lime is leached out, clay and/or iron oxide and organic matter may move independently or as a complex in or out of it. Weathering in place may cause further accumulation of silicate clay. They then are in part pedogenetic

in origin i.e. pedo-petrogenetic. Pedogenetic textural bands are due primarily to soil formation processes. Translocation of silicate clay minerals and colloidal organic matter may take place independently or as a complex, at different periods or simultaneously. In the soils examined, some of the iron oxide in textural bands may be attributed to the clay material itself, while some is possibly in the form of "free iron oxide".

As evident from the uniform distribution of clay minerals in some non-stratified soil columns and artificial soil column experiments in the laboratory, bulk movement in coarse textured soils is a major factor in the translocation of clay independently or as a complex with iron and colloidal organic matter. Free lime, and the alternate wetting and drying of the soil, may bring about the deposition of clay out of soil suspension, with the eventual formation of a textural horizon. Once a fine material accumulation is initiated, larger quantities of water will be held by that horizon. With increased moisture, some weathering in situ might take place resulting in a further increase in silicate clay mineral content. This does not eliminate the possible interaction between iron oxide, clay and organic matter to initiate a textural horizon.

The dynamics of soil formation very often obscure the importance of parent material in soil characteristics observed in the field. A seemingly pedogenic textural band may turn out to be of partially petrogenic origin after detailed mineralogical studies have been conducted in the laboratory.

Both petrogenic and pedogenic aspects of soil formation are a part of the genetic history of the soil profile, and as such, must be considered in any natural soil classification system.

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APPENDIX

X-ray and Differential Thermal Analysis of Clay from
Montcalm loamy sand and Wallace sand profiles

Figures 26, 27 and 28 serve as an illustration of the type of x-ray diffractions as well as thermal curves obtained from soil clay samples. Clays were obtained from lime free (acid treated) sodium saturated soils. ^{Figure 28} ~~The same~~ ~~figure~~ shows the manner in which areas under respective ~~diffraction~~ peaks were calculated.

2. Areas under the diffraction peaks

MONTCALM LOAMY SAND.

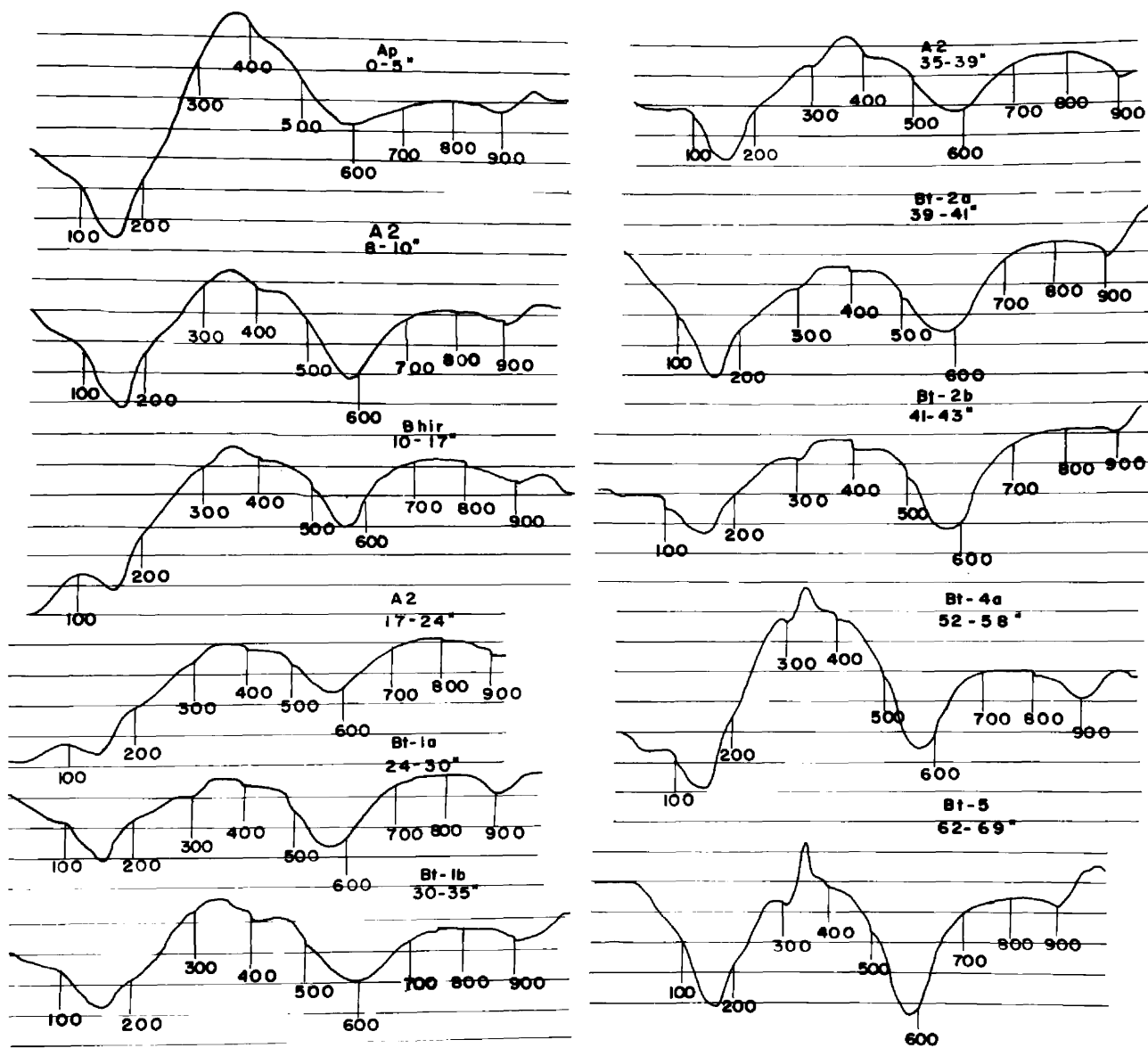


Fig. 26 D.T.A. ANALYSIS
CLAY FRACTION

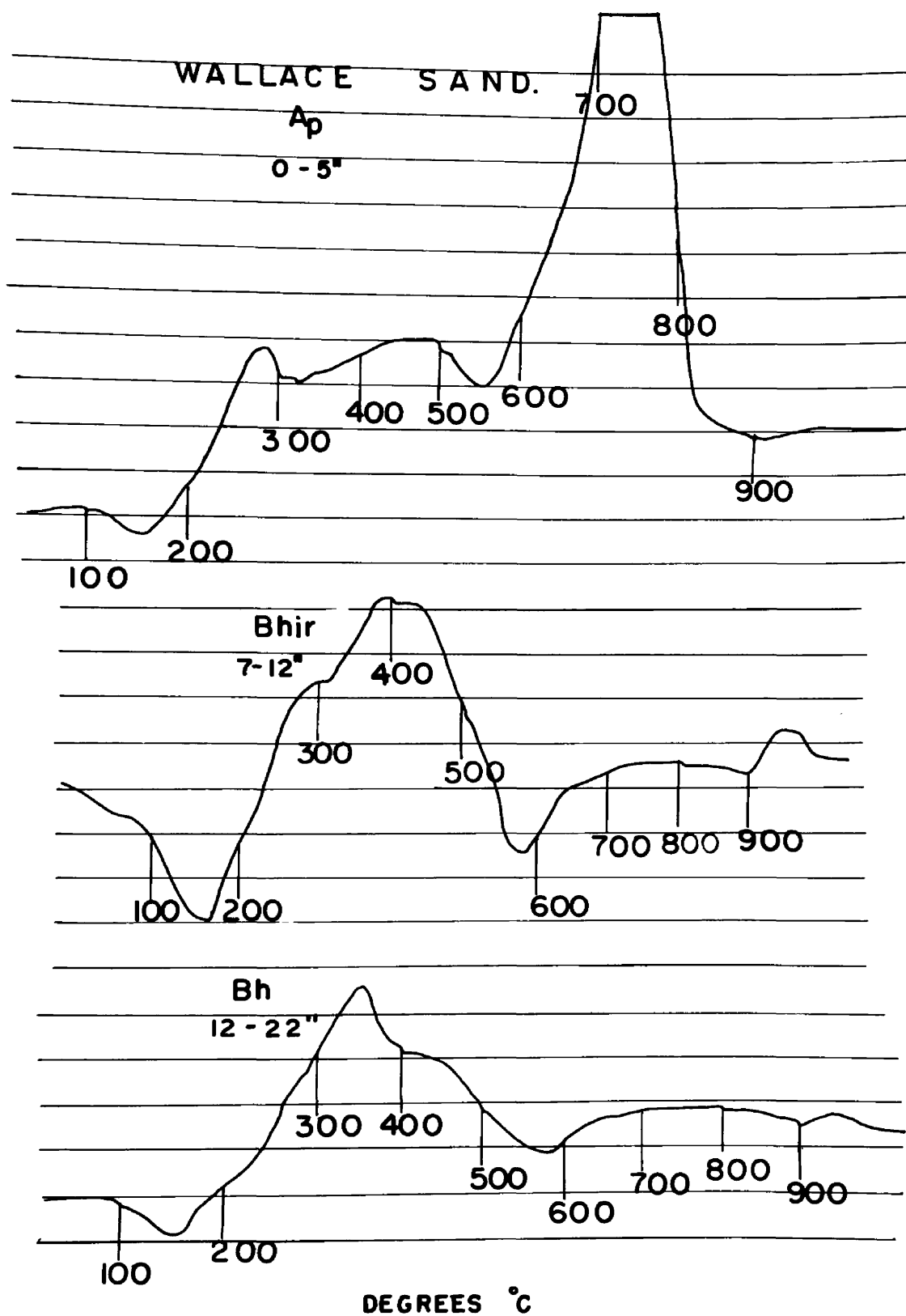


Fig. 27 D.T.A. ANALYSIS
CLAY FRACTION

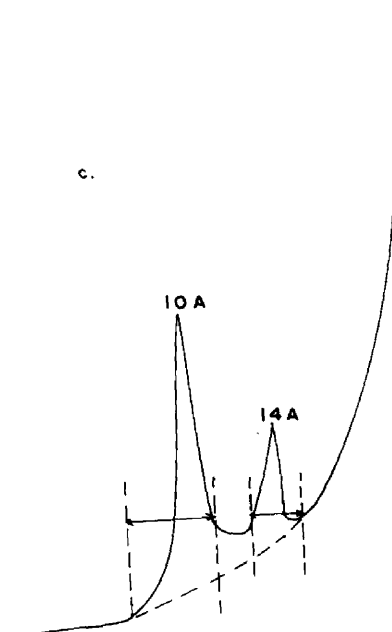
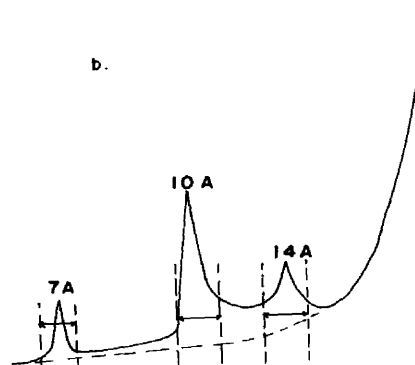
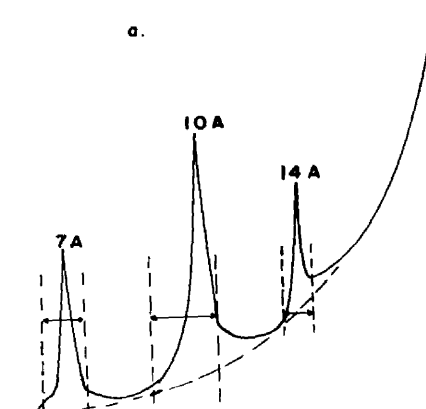
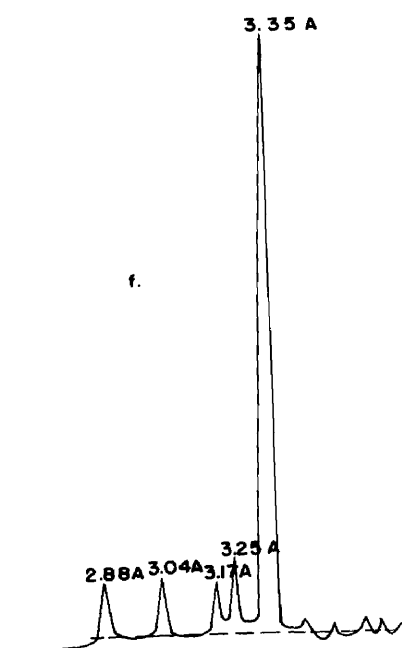
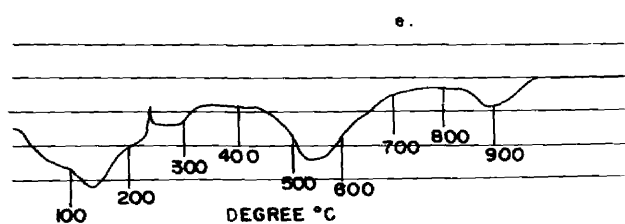
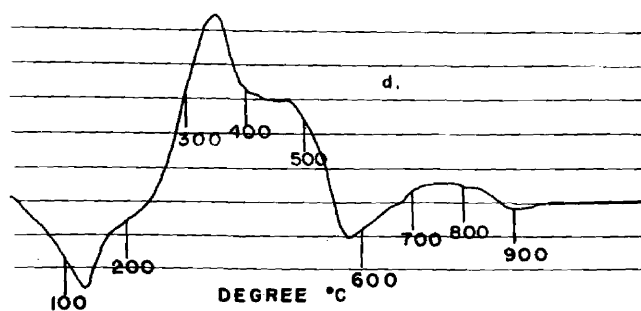


Fig. 28 MONTCALM L.S. PARENT-MATERIAL
 a. x-ray, glycerol
 b. " " , KCl, 110°C
 c. " " " , 550°C
 d. D.T.A.,
 e. " , organic matter "free"
 f. x-ray, ground to 300 mesh bulk sample
 a.-e. Na-Clay, lime-free.

Computations of Quartz and Feldspar Percentages From X-ray Data

Standard samples gave the following peak heights, using a scale factor of 8 (in scale divisions) :

	<u>A°</u>	<u>E. Wurman</u>	<u>H. Bailey (1956)</u>
Quartz	3.35	280	176
K-feldspar, ave.	3.25	-	60
Na-feldspar (oligoclase)	3.20	-	119

From the ratio of quartz peaks, a figure for the feldspar minerals was established:

$$\text{K-feldspar, ave. (Wurman)} = \frac{280}{176} \times 60 = 95$$

$$\text{Na-feldspar (Wurman)} = \frac{280}{176} \times 119 = 190$$

When a mixture of feldspars is being irradiated, the 3.25 A° peak is totally due to the K-feldspar i.e. orthoclase and microcline, while the 3.2 A peak is mainly due to Na-feldspar e.g. oligoclase, but is reinforced to some extent by the K-feldspar.

From H. Bailey's data: 100 percent K-feldspar would give 21.0 divisions peak height at 3.20 A° (S.F. = 8). In the tables that follow, the percentage feldspar is reported as corrected values, assuming:

$$3.25 \text{ A}^\circ \text{ peak} = \text{All K-feldspar (microcline, orthoclase)}$$

$$3.20 \text{ A}^\circ \text{ peak} = \text{Na-plagioclase (oligoclase)} - (21 \times \% \text{ K-feldspar calculated from 3.25 A peak})$$

$$\begin{array}{lcl} \text{Percentage quartz} & = & \frac{(3.35 \text{ A}^\circ \text{ peak height})}{280} \times 100 \\ \text{in sample} & & \end{array}$$

$$\begin{array}{lcl} \text{Percentage K-feldspar} & = & \frac{(3.25 \text{ A}^\circ \text{ peak height})}{95} \times 100 \\ \text{in sample} & & \end{array}$$

$$\begin{array}{lcl} \text{Percentage Na-feldspar} & = & \frac{(3.2 \text{ A}^\circ \text{ peak height} - 21 \times \frac{3.25 \text{ A peak height}}{95})}{190} \times 100 \\ \text{in sample} & & \end{array}$$

Table 9.

Physical properties of Montcalm loamy sand profile

Sample	Horizon	Depth	Mechanical Analyses (percent)							Total Sp. Sur- face M ² /gm.		
			Total	V.C.S.		C.S.	M.S.		F.S.		V.F.S.	Silt Clay
			2mm. sands (1)	mm.	mm.	mm.	mm.	mm.	mm.		mm.	
M1	Ap	0-8"	3.2	85.0	0.6	18.1	23.9	38.6	3.8	10.8	4.2	7.2
M2	A2	8-10	1.4	71.0	1.1	13.4	16.5	33.1	6.9	25.0	4.0	3.7
M3	Bhir	10-17	1.7	66.4	0.9	12.2	15.1	31.1	7.1	25.5	8.1	8.9
M4	A2	17-24	2.2	65.6	1.0	10.0	14.0	31.3	8.5	29.7	5.4	4.1
M5	Bt-1a	24-30	1.8	54.3	0.9	9.2	12.6	24.0	7.6	25.7	20.0	34.3
M6	Bt-1b	30-35"	3.1	59.4	1.0	10.1	14.0	25.2	9.1	23.6	17.0	31.2
M7	A2	35-39	5.9	94.9	2.6	30.9	25.5	35.5	0.9	-	-	4.0
M8	Bt-2a	39-41	0.5	82.2	0.8	15.8	27.2	35.9	2.5	3.7	13.1	29.1
M9	Bt-2b	41-43	2.8	62.0	1.2	10.1	13.7	31.4	5.6	20.9	17.1	45.8
M15	A2	58-62	0.0	98.3	0.0	5.7	35.0	56.8	9.8	0.5	1.2	0.9
M16	Bt-5	62-69	3.0	89.7	1.2	21.1	36.0	30.3	1.1	1.7	8.6	27.0

(1) On basis of bag-sample

Table 10.

Chemical Properties of Montcalm loamy sand profile

Sample	Horizon	Depth	Total Carbon %	pH	Exch. H m.e./100 gm.	Exch. Cap. m.e./100gm.	Base Saturation %	"Free iron" (Fe ₂ O ₃) %
M1	Ap	0-8"	0.65	6.4	1.5	4.0	62.8	0.5
M2	A2	8-10"	0.38	6.6	1.3	2.7	51.5	0.4
M3	Bh1r	10-17"	0.65	6.2	2.2	3.7	39.0	0.7
M4	A2	17-24"	0.28	6.2	0.9	1.2	24.5	0.3
M5	Bt-1a	24-30"	0.31	5.6	4.4	6.2	29.0	1.1
M6	Bt-1b	30-35"	0.38	6.6	-	-	-	-
M7	A2	35-39"	0.21	6.9	0.3	0.5	34.0	0.3
M8	Bt-2a	39-41"	0.28	6.8	0.9	5.9	84.1	0.6
M9	Bt-2b	41-43"	0.28	6.4	1.4	8.7	83.9	0.9
M15	A2	58-62"	0.12	8.0	-	0.5	100.0	0.2
			0.09*					
M16	Bt-5	62-69"	0.15	7.6	-	5.5	100.0	0.9
			0.07*					
C	Clay		0.48					2.5
*Inorganic carbon								

Table 11.

Physical properties of Wallace sand profile

Sample	Horizon	Depth	Mechanical analyses (percent)							Total			
			Total 2mm. (1)	V.C.S.		C.S.	M.S.		F.S.	V.F.S.	Silt	Clay	face M ² /gm.
				2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05					
W1	Ap	0-5"	3.9	89.5	0.9	17.0	32.1	36.4	3.1	7.3	3.1	4.3	
W2	A2	5-7"	2.9	91.0	1.3	21.2	27.4	39.3	1.8	6.2	2.8	4.3	
W3	Bhr	7-12"	9.2	89.2	2.1	22.0	30.2	32.1	2.8	5.1	5.7	11.7	
W4	B1r	12-22	6.7	92.1	2.8	26.6	25.2	35.8	1.7	4.8	3.1	11.8	
W5	C1	22-35	0.0	98.1	0.0	14.9	52.1	31.1	0.0	0.9	1.0	-	
W6	C2	35+	4.4	98.3	0.0	27.8	42.0	28.6	0.0	0.7	0.9	-	

(1) On the basis of bag-sample.

Table 12
Chemical properties of Wallace sand profile

Sample	Horizon	Depth	Total carbon %	pH	Exch. H. m.e./100gm.	Exch. Cap. m.e./100gm.	Base Saturation %	"Free iron" (Fe ₂ O ₃) %
W1	Ap	0-5"	1.25	6.5	2.1	4.6	54.5	-
W2	A2	5-7"	0.45	6.1	1.0	1.6	37.5	0.2
W3	Bhir	7-12"	0.99	5.3	7.0	6.9	0	0.6
W4	B1r	12-22"	0.63	5.5	3.9	5.0	22.0	0.3
W5	C1	22-35"	0.13	6.4	0.4	1.2	65.0	0.1
W6	C2	35+ "	0.07	6.4	0.2	0.8	75.0	0.1

Table 13.

Physical properties of Montcalm fine sand profile

Sample	Horizon	Depth	Total sands	Mechanical Analyses (percent)							Total Sp. Sur- face M ² /gm.
				V.C.S.	C.S.	M.S.	F.S.	V.S.F.	Silt	Clay	
				2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05			
K2	A2	17"	79.3	0	0	0	31.6	47.7	17.1	3.6	7.1
K3	Bt-1	25"	78.5	0	0	0	32.9	45.6	13.5	8.0	16.9
K7	A2	47"	78.3	0	0	0	34.1	44.2	19.3	2.4	5.1
K8	Bt-3a	49"	74.6	0	0	0	40.8	33.8	16.1	9.3	19.8
K9	Bt-3b	53"	80.9	0	0	0	43.6	37.3	11.9	7.2	16.1
K15	A2	60"	95.5	0	0	0	75.2	20.3	3.6	0.9	1.8
K16	Bt-6	62"	92.1	0	0	1.7	75.4	15.0	1.6	6.3	9.3

Table 14.

Chemical properties of Montcalm fine sand profile

Sample	Horizon	Depth	Total carbon %	pH	Exch. H. m.e./100gm.	Exch. Cap. m.e./100gm.	Base Saturation %	"Free iron" (Fe ₂ O ₃) %
K2	A2	17"	0.12	6.6	0.3	1.6	81.1	0.4
K3	Bt-1	25"	0.12	6.7	1.6	3.9	60.0	0.6
K7	A2	47"	0.05	7.4	0.0	0.9	100.0	0.3
K8	Bt-3a	49"	0.13	6.2	2.2	3.7	39.0	0.7
K9	Bt-3b	53"	0.09	6.6	1.8	2.3	21.0	0.6
K15	A2	60"	0.04	7.2	0.0	0.3	100.0	0.2
K16	Bt-6	62"	0.06	6.7	1.2	1.6	25.0	0.5

Table 15.

Physical properties of Coloma fine sand profile

Sample	Horizon	Depth	Mechanical Analyses (percent)								Total Sp.Sur- face M ² /gm.	
			V.C.S.		C.S.		MS.		F.S.			V.F.S.
			mm.		mm.		mm.		mm.			
			mm.		mm.		mm.					
Total sands			2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	Silt Clay				
C6	A2	63"	95.4	0	3.1	6.5	67.0	18.8	1.9	2.7	4.5	
C7	Bt-1	65"	88.8	0	1.7	6.0	64.9	16.2	1.3	9.9	27.2	
C8	A2	73"	96.1	0	1.1	4.3	70.8	19.9	1.3	2.6	6.8	
C11	Bt-3a	76"	89.1	0	0.6	2.7	61.7	24.1	0.9	10.0	24.6	
C13	A2	95"	96.5	0	1.1	6.5	69.8	19.1	1.1	2.4	5.2	
C14	Bt-4	101"	90.3	0	0.5	2.7	71.6	15.5	1.3	8.4	20.3	
C15	A2	106"	96.5	0	0.9	6.0	68.0	21.6	1.3	2.2	4.9	

Table 16.

Chemical properties of Coloma Fine sand profile

Sample	Horizon	Depth	Total carbon %	pH	Exch. H. m.e./100gm.	Exch. Cap. m.e./100gm.	Base Saturation %	"Free iron" (Fe ₂ O ₃) %
C6	A2	63"	0.10	7.5	0.0	0.7	100.0	0.5
C7	Bt-1	65"	0.11	6.5	2.4	3.2	41.0	0.9
C10	A2	73"	0.06	5.5	0.1	0.7	79.4	0.5
C11	Bt-3a	76"	0.11	5.5	1.0	3.7	71.6	0.9
C13	A2	95"	0.04	6.2	0.3	0.5	30.0	0.4
C14	Bt-4	101"	0.11	5.5	1.2	3.1	60.0	0.8
C15	A2	106"	-	6.0	0.3	0.5	30.0	0.4
Clay A2-B6			0.56					
								7.7

Table 17.

Percentages of quartz (by x-ray diffraction) in sand fractions, percentages of quartz sand fractions in soil horizons, with sums and ratios of quartz sand fractions

Sample	Horizon	Depth	(Percent)					
			Quartz in Sand Fractions		M.S. Quartz	F.S. Quartz	M.S. Quartz + F.S. Quartz	M.S. Quartz F.S. Quartz
			M.S.	F.S.				
<u>Montcalm loamy sand</u>								
M1	Ap	0-8"	83.5	79.5	19.9	30.7	50.6	0.65
M2	A2	8-10"	88.0	80.0	14.5	26.5	41.0	0.55
M3	Bh1r	10-17"	94.4	80.7	14.3	25.1	39.4	0.57
M4	A2	17-24"	85.8	80.7	12.0	25.3	37.3	0.47
M5	Bt-1a	24-30"	85.0	77.1	10.7	18.5	29.2	0.58
M6	Bt-1b	30-35"	90.0	77.1	12.6	18.5	31.1	0.68
M7	A2	35-39"	89.3	84.2	22.7	29.9	52.6	0.76
M8	Bt-2a	39-41"	93.5	82.9	25.5	29.8	55.3	0.86
M9	Bt-2b	41-43"	86.5	71.4	11.8	22.4	34.2	0.53
M15	A2	58-62"	79.3	82.1	27.8	46.7	74.5	0.59
M16	Bt-5	62-69"	87.8	73.5	31.6	22.3	53.9	1.42
<u>Wallace sand</u>								
W1	Ap	0-5"	88.6	81.5	28.5	29.6	58.1	0.96
W2	A2	5-7"	89.3	78.5	24.4	30.8	55.2	0.79
W3	Bh1r	7-12"	91.4	75.0	27.6	24.1	51.7	1.14
W4	B1r	12-22"	86.4	73.6	21.8	26.4	48.2	0.83
W5	C1	22-35"	87.9	78.5	45.7	24.2	69.9	1.89
W6	C2	35+"	87.9	80.0	36.9	22.9	59.8	1.61

Table 17. (continued)

Sample	Horizon	Depth	(Percent)					
			Quartz in Sand Fractions		F.S. + V.F.S.		F.S. + V.F.S.	
			F.S.	V.F.S.	Quartz	Quartz	Quartz	$\frac{\text{F.S. Quartz}}{\text{V.F.S. Quartz}}$
<u>Montcalm fine sand</u>								
K2	A2	17"	68.3	64.3	21.6	30.7	52.3	0.70
K3	Bt-1	25"	72.1	60.0	33.7	27.3	61.0	1.23
K7	A2	47"	73.5	62.9	25.0	27.8	52.8	0.90
K8	Bt-3a	49"	75.0	70.8	30.6	23.9	54.5	1.28
K9	Bt-3b	53"	70.0	62.9	30.5	23.5	54.0	1.30
K15	A2	60"	76.4	60.7	57.5	12.7	70.2	4.50
K16	Bt-6	62"	80.7	70.7	60.9	10.6	71.5	5.73
<u>Coloma fine sand</u>								
C6	A2	61"	80.0	64.3	53.5	12.1	65.6	4.42
C7	Bt-1	65"	70.0	64.3	45.5	10.4	55.9	4.37
C10	A2	73"	74.3	61.5	52.5	12.3	65.0	4.28
C11	Bt-3a	76"	71.5	61.5	44.1	14.8	58.9	2.98
C13	A2	95"	78.6	66.5	54.8	12.8	67.6	4.27
C14	Bt-4	101"	72.9	66.5	52.2	10.3	62.5	5.07
C15	A2	106"	84.2	65.7	57.2	14.2	71.4	4.02

Table 18.

Percentages of K-feldspars and Na-feldspars (by x-ray diffraction) in sand fractions, percentages of K-feldspars and Na-feldspars sand fractions in soil horizons and ratios of K-feldspars sand fractions

Sample	Horizon	Depth	Medium sand			Fine sand			M. S.		F. S.		M.S./ F.S.
			K- feldspar %	Na- feldspar %	Total %	K- feldspar %	Na- feldspar %	Total %	K- feldspar %	Na- feldspar %	Total %		
<u>Montcalm loamy sand</u>													
M1	Ap	0-8"	11.0	-	11.0	22.0	-	22.0	2.5	8.5	0.29		
M2	A2	8-10"	8.4	-	8.4	7.8	2.0	9.8	1.4	2.6	0.54		
M3	Bh1r	10-17"	7.8	-	7.8	14.7	-	14.7	1.2	4.6	0.26		
M4	A2	17-24"	11.5	-	11.5	20.9	-	20.9	1.6	6.5	0.25		
M5	Bt-1a	24-30"	14.2	-	14.2	21.5	-	21.5	1.8	5.2	0.35		
M6	Bt-1b	30-35"	12.6	1.8	14.4	23.0	-	23.0	1.8	5.8	0.31		
M7	A2	35-39"	9.4	-	9.4	23.0	-	23.0	2.4	8.2	0.29		
M8	Bt-2a	39-41"	15.2	-	15.2	20.9	-	20.9	4.1	7.5	0.55		
M9	Bt-2b	41-43"	14.7	2.3	17.0	22.0	-	22.0	2.0	6.9	0.29		
M15	A2	58-62"	9.4	1.5	10.9	15.2	-	15.2	3.3	8.6	0.28		
M16	Bt-5	62-69"	13.1	-	13.1	21.5	8.0	29.5	4.7	6.5	0.72		
<u>Wallace sand</u>													
W1	Ap	0-5"	8.9	-	8.9	14.7	-	14.7	2.8	5.4	0.54		
W2	A2	5-7"	9.4	-	9.4	15.7	-	15.7	2.6	6.2	0.42		
W3	Bh1r	7-12"	12.0	-	12.0	15.7	-	15.7	3.6	5.0	0.72		
W4	B1r	12-22"	12.6	-	12.6	16.8	-	16.8	3.2	6.0	0.53		
W5	C1	22-35"	11.5	-	11.5	12.6	-	12.6	6.0	3.9	1.54		
W6	C2	35+ "	14.1	-	14.1	13.1	-	13.1	5.9	3.7	1.59		
												126.	

Table 18. (continued)

Sample	Horizon	Depth	Fine sand		Very fine sand			F. S.		V.F.S.		F.S./ V.F.S. Ratio
			K- feldspar %	N- feldspar %	Total %	K- feldspar %	Na- feldspar %	Total %	K- feldspar %	K- feldspar %		
<u>Montcalm fine sand</u>												
K2	A2	17"	31.4	-	31.4	24.6	2.3	26.9	9.9	9.9	9.9	1.0
K3	Bt-1	25"	29.4	-	29.4	36.6	1.8	38.4	9.7	16.7	16.7	0.58
K7	A2	47"	25.1	1.2	26.3	31.4	2.4	33.8	8.6	13.9	13.9	0.62
K8	B5-3a	49"	27.2	-	27.2	29.3	2.3	31.6	11.1	9.9	9.9	1.12
K9	Bt-3b	53"	25.7	-	25.7	31.9	1.6	33.5	11.2	11.9	11.9	0.94
K15	A2	60"	25.7	1.3	27.0	27.7	1.2	28.9	19.3	5.6	5.6	3.40
K16	Bt-6	62"	22.5	1.3	23.8	29.3	1.2	30.5	17.0	4.6	4.6	3.70
<u>Coloma fine sand</u>												
C6	A2	61"	9.4	4.0	13.4	11.5	3.6	15.1	6.3	2.2	2.2	2.86
C7	Bt-1	65"	9.4	3.0	12.4	13.6	3.2	16.8	6.1	2.2	2.2	2.77
C10	A2	73"	12.0	3.3	15.3	12.0	5.8	17.8	8.4	2.4	2.4	3.50
C11	Bt-3a	76"	13.1	4.0	17.1	16.7	3.0	19.7	8.1	4.0	4.0	2.02
C13	A2	95"	12.0	3.8	15.8	11.5	3.6	15.1	8.4	2.2	2.2	3.82
C14	Bt-4	101"	13.6	4.4	18.0	11.5	4.1	15.6	9.7	1.8	1.8	5.40
C15	A2	106"	12.6	3.9	16.5	11.5	5.1	16.6	8.6	2.5	2.5	3.44