UTILIZING THE MORPHOLOGY OF SELECTED OKLAHOMA SOILS FOR THE INTERPRETATION OF SOME ENGINEERING QUALITIES

By

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CHAPTER I

INTRODUCTION

Major soil series of Oklahoma lack accurate shrink-swell characterization data for engineering interpretation. This soil quality influences tillage management, excavation, construction and maintenance of many soils involved in engineering projects.

Particle size distribution and clay mineralogy influence shrink-swell more than any other properties. Five soils were chosen which retain textural family classifications ranging through coarse loamy, fine loamy, fine clayey and fine silty with mixed mineralogy. Thus, the coefficient of linear extensibility should vary with textural families and clay mineralogy. These soils were chosen with respect to the central concept of each series. The selections anticipate a general application of information to other closely related soils.

Very little recorded data exist pertaining to COLE values of many key soils. Land use interpretations and classification of vertic subgroups require more data than presently available for such purposes. Thus exist the premises for this study.

CHAPTER II

REVIEW OF LITERATURE

Soil Forming Factors

The pedons employed for this study originate from two resource regions of Oklahoma (Figure 1). The Reddish Prairie and the Rolling Red Plains occupy an area from north and south central Oklahoma through western Oklahoma. Mixed grasses dominate soils developed in Permian Redbed formations under a warm, temperate, subhumid climate.

Climate

The pedons studied occur in two adjacent climatic areas of Oklahoma. An indistinct boundary exists between the two based on gradual climatic change (15). In the eastern Reddish Prairie the average annual precipitation reaches 35" per year and decreases to 28" average annual rainfall at its boundary with the Rolling Red Plains. The Western Rolling Red Plains experiences average annual precipitation as low as 22" per year. The prevailing wind in both areas is southerly and both experience long dry summer periods accompanied by hot dry winds from the south. The growing season ranges from 190 days in the north to 225 days in the south (11).

The climatic change influences other soil forming factors. The vegetation of the Rolling Red Plains is sparser, more adaptive to dryer climates and the topography shows more evidence of physical

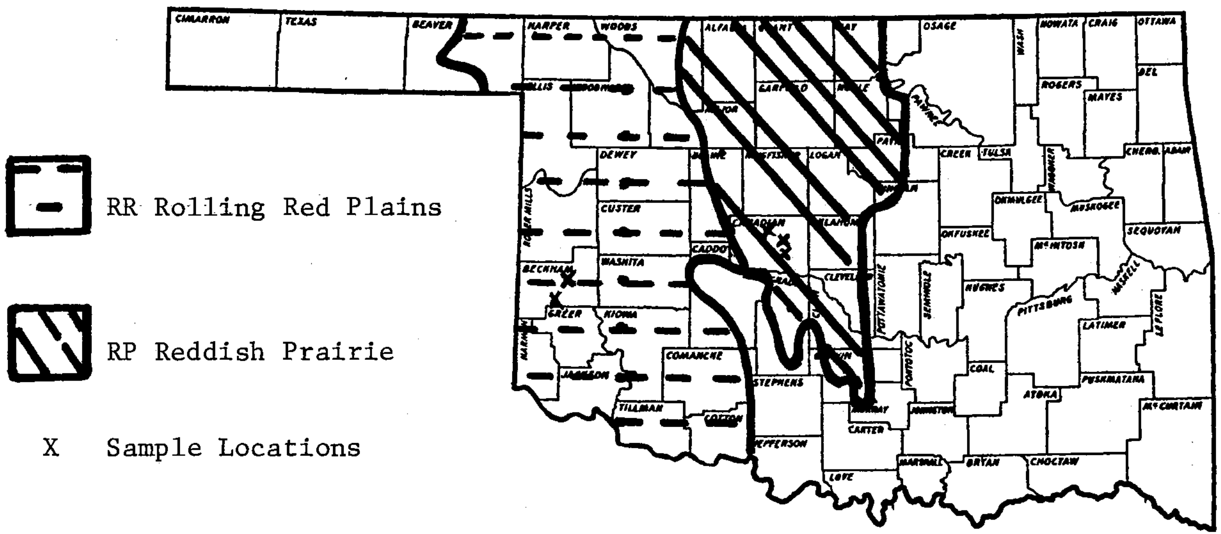

Figure 1. The Rolling Red Plains and Reddish Prairie Resource Areas of Oklahoma.

weathering. Lower rainfall, results in shallower water penetration than in the Reddish Prairie producing concentrations of calcium carbonates in the soil (25).

Parent Material

Pedons occurring in the Reddish Prairie and Rolling Red Plains developed in materials of Permian and post-Permian geologic periods (15). Permian formations extend westward in north-south bands from central Oklahoma to the Oklahoma Texas border (21). Clay beds and shales dominate the stratified Permian formations giving rise to vast areas of clayey soils. The clay mineralogy of these soils is generally mixed with a high percentage of 2:1 clays (26). The combination of clayey soils with high proportions of 2:1 minerals has a high potential for engineering problems.

Post-Permian materials (pleistocene) overlay vast areas adjacent to major western Oklahoma rivers. These deposits involve younger, coarser, less weathered soils than the surrounding Permian exposures resulting in different management and engineering problems (29).

Vegetation

Grasses climax the vegetation of Oklahoma prairies (8, 25). Original climax grass species combined with the other soil forming factors to evolve the classical dark fertile soils of the prairies (31). Climax grass species reflect the clayey drought-prone evolution of the prairie soils (35). In central Oklahoma tall grasses climaxed the vegetation on loamy soils and midgrasses dominated vegetation on finer soils. In the drier western areas tall grasses dominate loams and sands while short grasses dominate finer textured soils.

Scrub oak dominates the coarser Pleistocene deposits along the rivers. The deep, coarse, duny material near major western rivers, vegetated by trees, produce lighter colored forest type soils (29).

Relief

General relief patterns change gradually, but often distinctly, from central to western Oklahoma. Topographic differences result from gradual climatic change and sparser vegetation density toward the west. Subdued changes of relief characterize the Reddish Prairie landscape. Broad interstream divides and wide shallow valleys form a smooth to rolling topography with convex slopes (15, 28). The smooth broad surfaces combined with slowly permeable clays produce poor drainage and enhance the formation of deep profiles with well developed B2t horizons.

Relief frequently acquires a less subdued attitude in the Rolling Red Plains. A dryer climate and sparser vegetation result in a higher degree of physical weathering. Steep gradients and the changing course of rivers in this dry environment have caused the evolution of a scared rough topography. Rivers flow through the area in narrower valleys than to the east. These rivers supply coarse materials for larger areas of undulating and duny sand deposits. The relatively short time of existence of these materials combined with a drier climate and sparse vegetation result in the genesis of less well developed soils (15, 29).

Time

Evolution of soil individuals gradually occurs as dynamic forces of soil formation act through time (31, 35, 37). Chemical, physical, and biological processes produce results over a long period of time. Pedological observations and measurements merely express changes that have occurred through the life of a soil.

Soil individuals pass through stages of development; youth, maturity, and old age. Thorp and Smith (35) suggest the formation of minimal, medial and maximal subgroups based on increasing textural differences between A and B horizons. Young soils exhibit no textural change between A and B horizons while old soils exhibit far more clay in the B horizons than in A horizons.

Soil pedons of this study fall into the mature age brackets. Three pedons formed in permian parent material and exhibit well developed B horizons but have not yet begun to deteriorate into old age. Two pedons developed in sandy pleistocene deposits of western Oklahoma and exhibit development of the B horizon but still retain characteristics of the parent material.

Previous Work

Some soil properties are of special interest to engineers because they affect the construction and maintenance of roads, building foundations, waterstorage facilities, erosion control, drainage systems, and sewage disposal systems. The most important soil properties are permeability to water, Atterburg limits, soil drainage, shrink-swell characteristics, texture, and reaction. Topography depth to water table, and depth to bedrock are also important (22).

Atterburg limits are of major importance to engineering interpretations for soils. They indicate the desirability and stability of a soil for various engineering purposes.

As moisture evaporates soil volume decreases in direct proportion to moisture loss until the shrinkage limit is reached. After reaching the shrinkage limit soil volume remains the same with moisture loss. The volume of dry soil divided by the loss of moisture gives the shrinkage ratio. In general the lower the shrinkage limit and the higher the shrinkage ratio the greater the clay content will be.

Volume change is the change in volume from the field moisture equivalent to the shrinkage limit, expressed as a percentage of the dry volume. Soil Moisture content reaches the field moisture equivalent when moisture fills all pores in sands and cohesive soils approach saturation (1, 24).

Liquid limit and plastic limit indicate the effect of water on soil consistence. Soil changes from a semisolid to a plastic state as percent moisture increases from a dry state, plastic limit. Further moisture increase eventually changes the soil from a plastic state to a liquid state, the liquid limit. The plastic index indicates the moisture content range within which a soil is plastic and is the numerical difference between the liquid limit and the plastic limit (7, 24).

Shrink-swell properties generate volume changes, referred to as extensibility, within a profile. The measurement of this soil quality is called linear extensibility. Many researchers have conducted field experiments attempting to determine linear extensibility under natural soil conditions (16, 19, 36). However, due to lack of moisture standards these measurements have limited use in soil characterization. Engineering procedures call for the unnatural disruption of soil aggregates and destruction of soil fabric (16, 17). Now, however, recent developments of saran resin allow preservation of natural soil organization (4, 14).

General predictions for shrink-swell potential of mapping units are made using the coefficient of linear extensibility (COLE) (36). COLE employs the bulk density of natural soil clods desorbed to 1/3 bar and oven dry. Once determined, the bulk densities are used to calculate COLE and linear extensibility (4, 16).

Bulk density, COLE and L.E. measurements are effected by exchangeable ions, composition of the soil solution, particle size distribution, particle arrangement, mineralogy, and water retention properties (34). Bulk density is a direct result of particle size and arrangement in soils. Kaolinite in a sand matrix tends to form a laminated structure and montmorillonite tends to form a sponge-like structure (23). Flat pieces of clay orient parallel to one another with attractive forces between negatively charged surfaces and intervening exchangeable cations (34).

The type of clay present directly affects COLE and L.E. The 2:1 clays swell appreciably but 1:1 clays do not exhibit such a pronounced effect. The structure of 2:1 clays results in weaker bonds between units allowing movement of water into the structure. The absorption of water into a 2:1 structure is the main mechanism of soil shrink-swell (4, 34). The resulting swelling pressure and COLE are influenced by mineralogy of the clay fraction.

CHAPTER III

METHODS AND MATERIALS

Chemical Analyses

Chemical analyses of the study pedons employed standard Soil Conservation Service Procedures as outlined below.

Soil reaction measurements employed a glass-electrode meter to determine the hydrogen ion activity of a 1:1 mixture of soil with distilled water and a 1:1 mixture of soil with 1.0 N potassium chloride (30).

Organic matter determinations followed grinding of the sample to pass a 60 mesh sieve. Sample digestion occurred after the addition of ten ml of 0.4 N potassium dichromate, 15 ml of concentrated sulfuric acid, and heating of the sample solution to 161^{o}C. After cooling and the addition of 100 mls distilled water the sample was titrated with 0.2N ferrous ammonium sulfate solution (30).

The percent calcium carbonate was determined by the acid-neutralization method (3). Fifty ml of standardized 0.5 N Hcl added to the sample reacted with carbonates when boiled gently for five minutes. After filtration through retentive paper, several washings with distilled water removed excess acids. The HCL filtrate was then titrated to end point using phenolphalein as an indicator and 0.25N NaOH.

Physical Analyses

Determination of percent sand, silt and clay followed sufficient processing of air dry samples to pass a 2 mm screen. Particle size distribution utilized the pipette method outlined in Methods of Soil Analyses: Part I (2). The sample was passed through a sieve column collecting the very coarse, coarse, medium fine and very fine sand fractions.

Atterburg limit measurements required the use of standard ASTM procedures for liquid limit, shrinkage limit, plastic limit and plastic index (1).

Bulk density was determined using clods coated with saran resin before transfer to the laboratory and again in the laboratory for protection during measurement. The next step employed a tension table for moisture equilibration of the clod before removal to a tension plate. A 1/3 bar atmosphere was maintained on the tension plate until the clod equilibrated. Weight in air and volume displacement in water were measured before oven drying to constant weight. After oven drying to constant weight the clods were again weighed in air and the volume displacement measured (4, 16, 30). The weights in air were then adjusted for the weight of saran resin and wires. The bulk densities moist and dry were then calculated using the following formulas:

$$Dbe = \frac{WCod}{VCe} \qquad Dbod = \frac{WCod}{VCod}$$

where: Dbe = bulk density of the equilibrated clod, WCod = weight of the clod oven dry, VCe = volume of the clod equilibrated, Dbod = bulk density of the clod oven dry and VCod = volume of the clod oven dry.

The % water by weight and % water by volume at 1/3 bar tension may be calculated as follows:

$$WWE = \frac{WCe-WCod}{WCod} \times 100 \qquad VWe = \frac{WCe-VCod}{VCod}$$

where: WWE = the percent water by weight, WCe = weight of the clod equilibrated and VWe = the % water by volume.

COLE values were calculated using the bulk density figures.

$$COLE = \sqrt[3]{\frac{Dbod}{Dbe}} - 1$$

It is assumed that dimensional changes per unit of length along the axis are equal. The COLE values are then multiplied by horizon thickness to obtain the vertical linear extensibility. The sum of the vertical linear extensiblity for each horizon yields the cumulative vertical linear extensibility.

Mineralogical Analyses

Clay samples for x-ray diffraction received three 50 ml washings of either 1.0 N $CaCl_2$ or 1N KCl. After saturation, three washings with distilled water removed excess salts and dispersed the sample. Aliquots of the calcium saturated samples received glycerol solvation by the Jackson method for diagnostic vermiculite and montmorillonite peaks (18).

Cation exchange capacity was determined on the fine and coarse clay fraction of selected profile horizons. Ca saturated samples were washed 3 times with 1N NaCl and the supernate saved. The supernate was buffered with 10 ml of NH_4Cl-NH_4OH buffer and 10 drops of Eriochrome Black T indicator was added. The supernate was then titrated to a bright blue end point with EDTA.

CHAPTER IV

RESULTS AND DISCUSSION

Description of the Sampled Pedons

The important soils, Nobscot, Grandfield, Bethany, Kirkland, and Norge, were chosen for this investigation. They extend over large areas of old alluvial deposits of the Rolling Red Plains and eroded uplands of the Reddish Prairie. Sites for the Nobscot and Grandfield pedons were located in Beckham County and sites for the Bethany, Kirkland and Norge pedons were located in Canadian County. Collection of bulk and block samples followed the detailed description of each pedon. After air drying in the laboratory the samples remained stored until used.

Nobscot Fine Sandy Loam

The sampling site occurs on undulating to humocky or hilly, wind modified, upland formed from reddish alluvial sand. Soil development occurs under the influence of midgrasses and scrub oak and the site is currently used as pasture. It is a well drained soil with moderately rapid permeability and very slow runoff. Pedon Location is 600 feet E. and 90 feet N. of the SW corner of Sec. 35, T9N, R23W, Beckham County. About six miles south and two and a quarter miles east of Sayer, Oklahoma.

Horizon	Depth	Description
A1	0 to 5"	Brown (7.5YR 5/2) fine sand; dark brown (7.5YR 4/2) moist; weak fine granular; soft, very friable, nonsticky, non plastic; gradual wavy boundary.
A2	5 to 23"	Pink (7.5YR 7/4) fine sand, light brown (7.5YR 6/4) moist; structureless; loose; nonsticky; nonplastic, clear wavy boundary.
B21t	23 to 36"	Red (2.5YR 4/6) sandy loam, dark red (2.5YR 3/6) moist; weak coarse prismatic; hard, friable, slightly sticky, slightly plastic; few bands about ¼" thick of dark reddish brown (2.5YR 3/4) heavy sandy loam; few pores filled with clean sand grains; few root channels, sand grains coated and bridged with clay; gradual smooth boundary.
B22t	36 to 53"	Red (2.5YR 5/6) light sandy loam; red (2.5YR 4/6) moist; weak coarse prismatic; hard, very friable; nonsticky, nonplastic; thin bands of dark red (2.5YR 3/6) sandy loam about 1/8" thick and spaced 4 to 6 inches apart; bridged and coated sand grains; gradual smooth boundary.
B23t	53 to 71"	Reddish yellow (5YR 6/6) loamy sand, yellowish red (5YR 5/6) moist; weak coarse prismatic; hard, very friable; red (2.5YR 4/6, 3/6 m) sandy loam bands 1/8" to 1" thick and spaced 2 to 5 inches apart; about 5% splotches and streaks of clean sand grains; diffuse smooth boundary.
B3	71 to 80"	Reddish yellow (5YR 6/6) fine sand, yellowish red (5YR 5/6) moist; structureless; few thin bands of red (2.5YR 4/6, 3/6) sandy loam; about 5 percent splotches and streaks of clean sand grains.

Grandfield Fine Sandy Loam

The site occurs on nearly level to gently sloping uplands formed in old alluvial and aeolian sediments. Soil development occurs under the influence of tall to midgrasses and the site is currently an old abandoned gravel pit. This is a well drained, moderate to moderately rapid permeable soil with very slow runoff. It is a moderately extensive soil of west Texas and Oklahoma. Pedon location is 1650 feet S. and 823 feet W. of the NE Corner of Sec. 28, T11N, R22W, Beckham County. About six miles west and one half mile south of Elk City, Oklahoma.

Horizon	Depth	Descriptions
Ap	0 to 8"	Reddish brown (5YR 5/4) fine sandy loam, dark reddish brown (5YR 3/4) moist; weak very fine granular; soft, very friable, slightly sticky, slightly plastic; few pebbles, mostly less than 3/4 inch in size; abrupt smooth boundary.
B1	8 to 12"	Reddish brown (5YR 4/3) sandy clay loam, dark reddish brown (5YR 3/3) moist; weak fine and medium subangular blocky; hard, very friable; slightly sticky, slightly plastic, few pebbles, mostly less than ¼ inch in size; clear smooth boundary.
B21t	12 to 20"	Reddish brown (2.5YR 4/4) heavy sandy clay loam, dark reddish brown (2.5YR 3/4) moist; moderate medium and coarse prismatic; parting to moderate medium subangular blocky; very hard, friable, sticky, plastic; nearly continuous clay films on prism faces, few pebbles, mostly ¼ to 1 inch in size; clear smooth boundary.
B22t	20 to 31"	Red (2.5YR 4/6) sandy clay loam, dark red (2.5YR 3/6) moist; moderate medium and coarse prismatic; parting to moderate medium subangular blocky;

Horizon	Depth	Descriptions
B22t (con't)	20 to 31"	very hard, friable, sticky and plastic; nearly continuous clay films on prism faces, few pebbles, 2mm to 1 inch in size; clear smooth boundary.
B23t	31 to 45"	Red (2.5YR 5/6) sandy clay loam, red (2.5YR 4/6) moist; moderate medium and coarse prismatic; parting to moderate medium subangular blocky; very hard, friable, sticky and plastic; nearly continuous clay films on prism faces, few pebbles, mostly less than 3/4 inch in size; upper 3 inches contains many pebbles, mostly less than 3/4 inch in size but a few up to 2 inches; clear smooth boundary.
B24t	45 to 51"	Red (2.5YR 5/6) light sandy clay loam, red (2.5YR 4/6) moist; moderate, medium and coarse prismatic structure parting to moderate medium subangular blocky; hard, friable, slightly sticky and plastic; few pebbles, mostly less than 3/4 inch in size; thin discontinuous clay films on ped faces; clear smooth boundary.
B31	51 to 64"	Reddish yellow (5YR 6/6) sandy loam, yellowish red (5YR 5/6) moist; weak medium subangular blocky; hard, friable; about 40 percent of horizon is red (2.5YR 4/6) sandy clay loam bands 1 to 2 inches thick and spaced 3 to 5 inches apart; few pebbles less than ¼ inch in size; gradual smooth boundary.
B32	64 to 80"	Reddish yellow (5YR 6/8) loamy sand, yellowish red (5YR 5/8) moist; structureless, loose; many bands of red (2.5YR 5/6) sandy loam mostly less than 1 inch in thickness and spaced 1 to 3 inches apart; bands are irregular and form a net pattern.

Bethany Silt Loam

The sampling site occurs on nearly level to very gently sloping upland formed in weathered shale and claybeds capped with loess. Soil development occurs under the influence of tall grasses and the site is currently used as pasture. It is a well drained soil with slow permeability and slow runoff. Pedon location is 150 feet N. of SW Corner Sec. 4 T12N, R8W, Canadian County. About four and one half miles west of El Reno, Oklahoma.

Horizon	Depth	Descriptions
A11	0 to 6"	Very dark grayish brown (10YR 3/2) silt loam, very dark brown (10YR 2/2) moist; moderate medium granular; hard, friable; many fine roots; clear smooth; (4-6").
A12	6 to 12"	Very dark grayish brown (10YR 3/2) silt loam, very dark brown (10YR 2/2) moist; moderate medium granular; hard, friable; many fine roots and pores; clear smooth boundary.
B1t	12 to 18"	Dark grayish brown (10YR 4/2) silty clay loam, very dark grayish-brown (10YR 3/2) moist; weak, fine subangular blocky; firm; clear smooth boundary; many fine roots.
B21t	18 to 38"	Dark grayish brown (10YR 4/2) silty clay, very dark grayish brown (10YR 3/2) moist; strong, medium blocky; thick clay film on all ped faces; very hard, very firm; common fine roots; sticky when wet; horizontal pressure faces; gradual smooth boundary.
B22t	38 to 54"	Brown (10YR 5/3) silty clay, dark brown (10YR 4/3) moist; weak, coarse blocky; few fine roots; 3 to 5 percent fine lime concretions; few, fine, faint mottles (5YR 5/8) dry; very hard, very firm; clay films on ped faces; gradual smooth boundary.

Horizon	Depth	Descriptions
B23t	54 to 71"	Grayish brown (10YR 5/2) silty clay loam, dark grayish brown (10YR 4/2) moist; moderate coarse blocky; mottles (10YR 5/8 d, 5/6 m); many coarse distinct 30 to 40 percent mottling; fine vertical lime streaks; few crystals (gypsum); gradual smooth boundary.
B3	71 to 80"	Yellowish red (5YR 5/6) silty clay loam, yellowish red (5YR 4/6) moist; weak medium blocky; very hard, very firm; patchy clay films on vertical ped faces; many fine lime concretions 10 to 15 percent; a few black fine root channels.

Kirkland Silt Loam

The site occurs on nearly level to very gently sloping uplands weathered from Permian shale and clay beds. Soil development occurs under the influence of tall grasses and the site is currently part of an extremely large city park area. It is a well drained soil with very slow permeability and slow to medium runoff. Pedon location is 200 feet S. and 350 feet W. of NE Corner Sec. 13, T12N, R8W, Canadian County, Oklahoma. About one mile west and one and one half miles south of El Reno, Oklahoma.

Horizon	Depth	Descriptions
Ap	0 to 9"	Dark grayish brown (10YR 4/2) silt loam, very dark grayish brown (10YR 3/2) moist; weak fine granular; friable, slightly sticky, slightly plastic, many roots; clear smooth boundary.
A1	9 to 13"	Dark grayish brown (10YR 4/2) silt loam, very dark grayish brown (10YR 3/2) moist; weak fine granular; friable, slightly sticky, slightly plastic; common roots, abrupt smooth boundary.

Horizon	Depth	Descriptions
B21t	13 to 30:	Dark grayish brown (10YR 4/2) silty clay; Very dark grayish brown (10YR 3/2) moist; moderate medium blocky; firm, sticky, very plastic; shiny ped faces, few roots; clear smooth boundary.
B22tca	30 to 45"	Dark grayish brown (10YR 4/2) silty clay, very dark grayish brown (10YR 3/2) moist; moderate blocky; firm, sticky, very plastic; shiny ped faces, about 5 percent $CaCO_3$ in soft powdery masses, few fine $CaCO_3$ concretions, few masses of $CaSO_4$, few roots, gradual smooth boundary.
B31ca	45 to 54"	Grayish brown (10YR 5/2) silty clay loam, dark grayish brown (10YR 4/2) moist, weak fine and medium subangular blocky; firm, sticky, very plastic; about 2 percent soft masses of $CaCO_3$ and $CaSO_4$, few roots; gradual smooth boundary.
B32ca	54 to 72"	Grayish brown (10YR 5/2) silty clay, dark grayish brown (10YR 4/2) moist, weak fine and medium subangular blocky; firm, sticky, very plastic; few vertical streaks up to ¼ inch wide of 10YR 2/2, about 5 percent soft masses and threads of $CaCO_3$ and $CaSO_4$, few fine shot-like Fe-Mn concretions.

Norge Silt Loam

The site occurs on nearly level to gently sloping upland of old alluvial origin. Soil Development occurs under the influence of tall grasses and the site is currently part of an extremely large city park area. It is a well drained soil with slow permeability and slow runoff. Pedon location is 2800 feet S. and 2300 feet W. of the NE Corner Sec. 13, T12N, R8W, Canadian County. About one mile west and one mile and one half south of El Reno, Oklahoma.

Horizon	Depth	Descriptions
A1	0 to 8"	Dark reddish gray (5YR 4/2) silt loam, dark reddish brown (5YR 3/2) moist; weak fine granular; friable, slightly sticky, slightly plastic, common roots, gradual smooth boundary.
A12	8 to 17"	Reddish brown (5YR 4/3) silt loam, dark reddish brown (5YR 3/3) moist; moderate fine and medium granular; friable, slightly sticky, slightly plastic; common roots, gradual smooth boundary.
B1	17 to 25"	Reddish brown (5YR 4/4) silty clay loam, dark reddish brown (5YR 3/4) moist; moderate fine and medium subangular blocky; friable, sticky, plastic; common roots, few pebbles, mostly less than 3/4 inch in size, gradual smooth boundary.
B21t	25 to 42"	Dark reddish brown (5YR 3/4) moist; dark reddish brown (2.5YR 3/4) crushed, silty clay loam; moderate medium prismatic parting to moderate medium blocky; firm, sticky, very plastic; continuous clay films on all ped surfaces, common roots, few pebbles; gradual smooth boundary.
B22t	42 to 53"	Red (2.5YR 4/6) silty clay loam, dark red (2.5YR 3/6) moist; moderate medium prismatic parting to moderate medium blocky; firm, sticky, very plastic; few pebbles less than 3/4 inch in size, few Fe-Mn stains and streaks on ped faces, few fine Fe-Mn shot-like concretions, continuous clay films on ped faces that are dark reddish brown (5YR 3/4), few roots; clear smooth boundary.
B23tca	53 to 75"	Red (2.5YR 5/6) silty clay loam, red (2.5YR 4/6) moist; moderate medium prismatic parting to moderate coarse blocky; firm, sticky, very plastic; about 5 percent $CaCO_3$ concretions, mostly less than ½ inch in size, few pebbles, few Fe-Mn shot-like concretions, few roots.

Physical Properties

Particle Size Distribution

The particle-size-depth distribution curve of the Nobscot, Figure 2, exhibits maximum clay accumulation in the B21t with dwindling amounts of clay further down in the profile. The clay increase of the B21t, the presence of an A2 horizon and the ratio of fine to coarse clay are sufficient evidence to indicate formation of a rudimentary argillic horizon (Table 1). After initial clay increase, the B horizon rapidly decreases in percent clay and exhibits skeletal sand grains throughout. The coarse texture of the profile is indicative of high infiltration and permeability rates which increase weathering, clay movement, and argillic horizon formation.

The particle-size depth distribution curve of the Grandfield pedon, Figure 3, exhibits maximum clay accumulation in the B21t and decreases there after. The clay increase of the B21t, the presence of a B1 horizon, lamellae in the lower horizons, and the ratio of fine to coarse clay, Table 1, are evidence of a developing argillic horizon. The high sand content of the B horizon and the presence of pebble lines in the profile indicate deposition in rapid moving water precluding the absence of clay and giving further evidence of a developing argillic horizon. The rapid permeability and infiltration rates lead to increased weathering resulting in the downward movement of clay with moisture.

An intensive clay accumulation within the Norge profile is shown in Figure 4. Clay accumulation exceeds a 1.2 increase within the first 20 cm of the B horizon and reaches its maximum within the B22t horizon. The maximum is accompanied by an increased ratio of fine to coarse clay

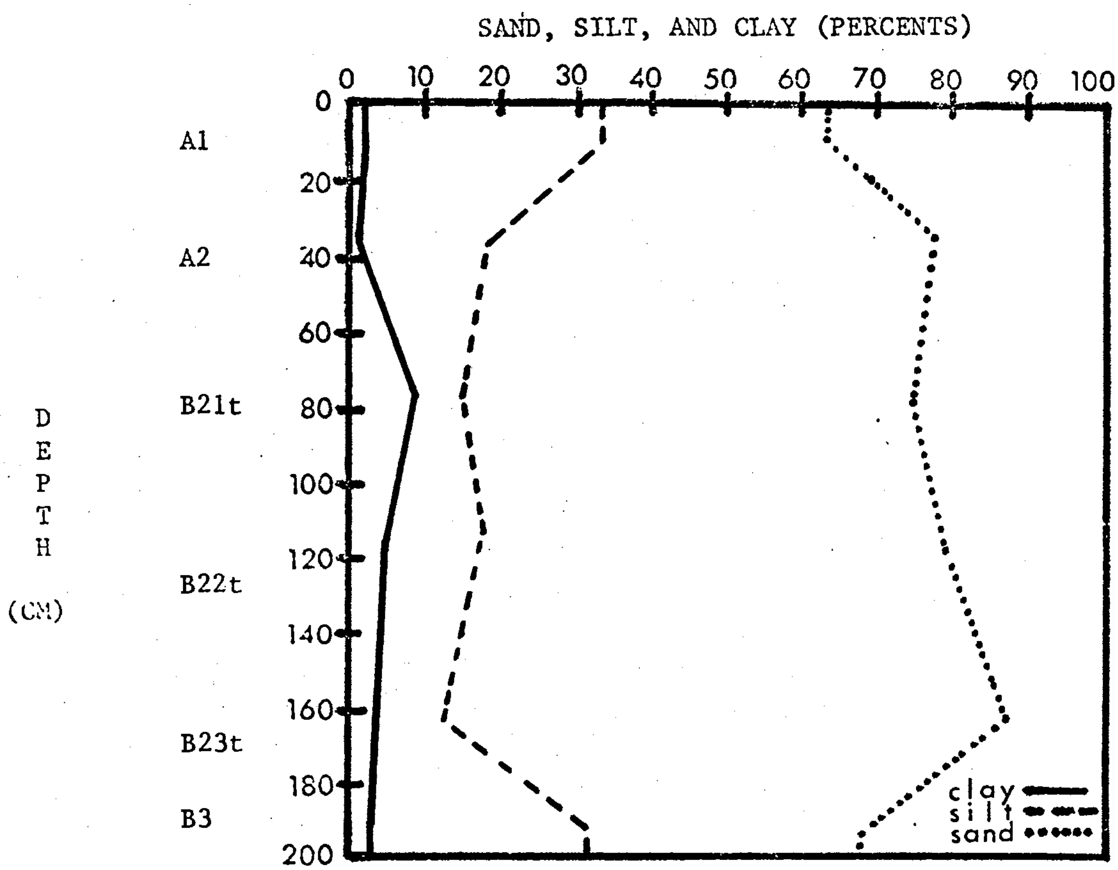

Figure 2. Particle Size-Depth Distribution Curve of the Nobscot Pedon.

TABLE I

PARTICLE-SIZE DISTRIBUTION OF THE GRANDFIELD AND NOBSCOT SOILS

Horizon	Depth Centimeters	Thickness Centimeters	%>2mm	Very Coarse Sand 2-1 mm	Coarse Sand 1-.5 mm	Medium Sand .5-.25 mm	Fine Sand .25-.1 mm	Very Fine Sand .1-.05 mm	Coarse Silt .05-.02	Medium Silt .02-.005	Fine Silt .005-.002	Clay 0.002	Ratio Fine/Coarse Clay
						Grandfield							
AP	00-20	20	4.7	10.0	24.6	24.0	10.6	16.3	0.9	1.3	1.9	10.3	2.96
B1	20-31	10	6.0	20.3	19.3	28.6	11.1	2.9	1.1	3.7	1.4	11.6	
B21t	31-51	20	3.4	23.9	9.1	17.9	6.2	4.7	0.4	4.9	4.7	28.2	
B22t	51-79	28	2.3	3.9	14.1	15.4	11.1	4.3	25.4	4.9	5.9	15.1	4.52
B23t	79-114	36	5.0	7.5	28.0	13.8	10.2	2.5	18.5	2.0	1.4	16.1	7.13
B24t	114-130	15	0.9	2.8	21.8	23.6	13.5	3.2	16.6	1.3	1.3	15.9	11.27
B31	130-163	33	1.0	3.5	22.8	21.5	18.1	4.5	15.4	1.1	0.1	12.9	6.28
						Nobscot							
A1	00-13	13	0.0	0.1	10.0	24.3	15.3	13.9	32.7	0.2	0.2	3.4	16.89
A2	13-58	46	0.0	0.3	21.2	26.4	22.3	8.8	16.1	1.8	0.9	2.1	
B21t	58-91	33	0.0	6.5	8.0	33.0	21.9	6.5	14.5	0.8	0.7	8.1	6.98
B22t	91-135	43	0.0	15.0	2.8	33.9	19.0	5.6	15.2	1.1	1.9	5.4	
B23t	135-180	46	0.0	14.8	8.5	34.3	21.6	4.7	10.7	0.5	0.4	4.4	
B3	180-203	23	0.0	0.1	3.0	35.4	21.7	4.4	31.2	0.8	0.2	3.2	4.56

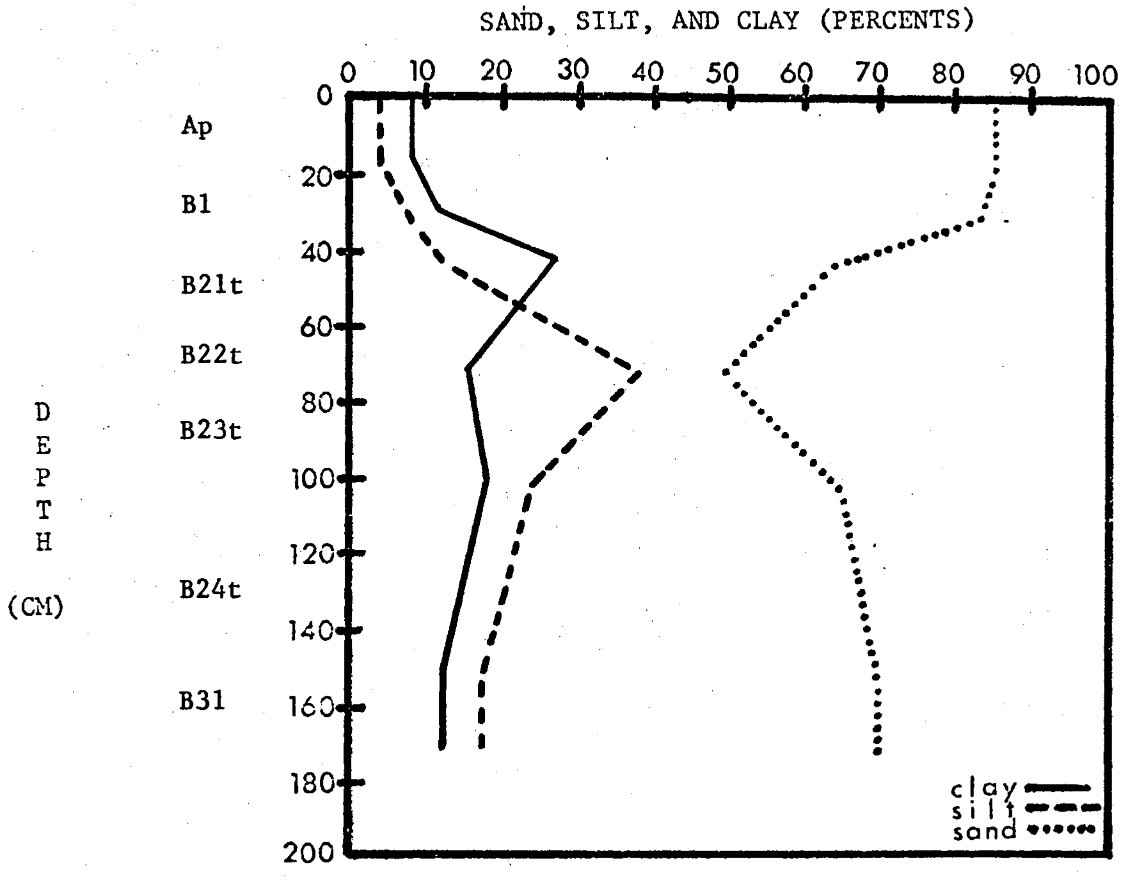

Figure 3. Particle Size-Depth Distribution Curve for the Grandfield Pedon.

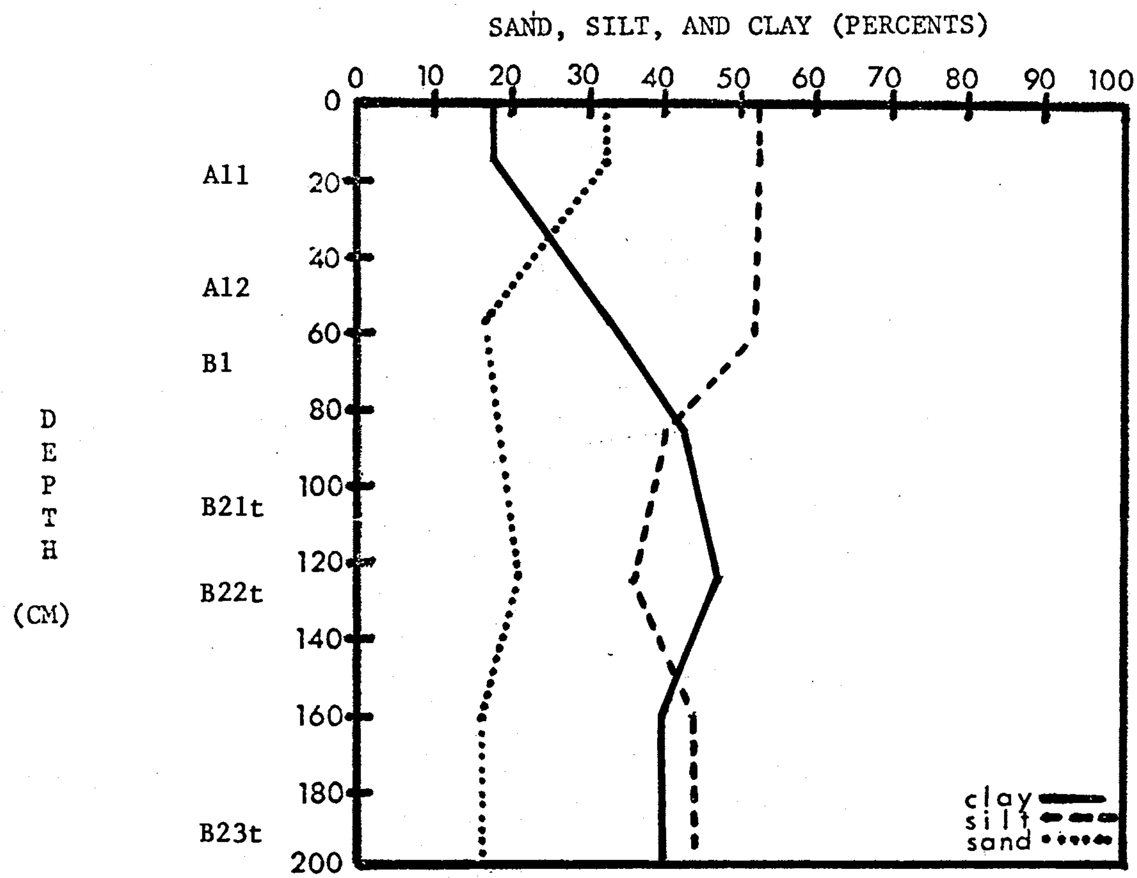

Figure 4. Particle Size-Depth Distribution Curve for the Norge Pedon.

(Table II). These data lend credence to the field observation of an argillic horizon. The field description notes a firm, sticky, very plastic consistence and blocky structure in the B2t horizon along with continuous clay films on ped faces. The profile possesses clay contents and morphological characteristics indicative of a strongly developed argillic horizon.

The particle-size-distribution curve for the Bethany profile (Figure 5) exhibits high clay accumulation within the B horizon. Clay content continually increases with depth in the profile accompanied by an increased ratio of fine to coarse clay in the B2 horizon (Table II). These data support the recognition of an argillic horizon from the field description. The field description acknowledges a very hard, very firm, sticky consistence and blocky structure with clay films on ped faces in the B2 horizons. Also present are a B1 horizon and pressure faces in the B21t horizon indicating extended profile development with accumulations of 2:1 clays. Overall the profile exhibits high clay contents and morphological characteristics indicative of a well developed argillic horizon.

Clay accumulation within the Kirkland profile is shown in Figure 6. Clay accumulation exceeds a 1.2 increase within the first 20 cm of the B horizon and reaches its maximum within the B22t horizon. The maximum is accompanied by an increased ratio of fine to coarse clay (Table II). These data verify the field observation of an argillic horizon. The field description recognizes a firm, sticky, very plastic consistence and blocky structure. The profile also retains an abrupt transition between A and B horizons and pressure faces in the B2 horizons indicating extensive profile development with a high

TABLE II

PARTICLE-SIZE DISTRIBUTION OF THE BETHANY, KIRKLAND AND NORGE SOILS

Horizon	Depth Centimeters	Thickness Centimeters	%>2 mm	Very Coarse Sand 2-1 mm	Coarse Sand 1-.5mm	Medium Sand .5-.25 mm	Fine Sand .25-.1 mm	Very Fine Sand .1-.05 mm	Coarse Silt .05-.02 mm	Medium Silt .02-.005 mm	Fine Silt .005-.002 mm	Clay 0.002 mm	Ratio Fine/ Coarse Clay
							Bethany						
A11	00-15	15	0.0	0.0	0.1	0.1	1.6	19.1	42.2	16.4	3.1	17.4	3.48
A12	15-31	15	0.0	0.0	0.1	0.3	1.8	16.0	40.7	14.9	2.9	23.3	
B1	31-46	15	0.0	0.0	0.1	0.3	1.8	16.3	35.7	16.4	4.0	25.4	
B21t	46-97	51	0.0	0.1	0.3	0.6	2.2	11.2	24.9	19.2	10.5	31.0	4.75
B22tca	97-137	41	0.0	0.2	0.3	1.0	1.9	9.7	30.1	16.7	5.5	34.6	3.93
B23t	137-180	43	0.0	0.1	0.2	0.7	3.8	15.7	27.6	12.0	3.5	36.5	
B3	180-203	23	0.0	0.2	0.3	0.8	3.3	17.3	26.6	10.3	2.8	38.5	3.04
							Kirkland						
Ap	00-23	23	0.0	0.2	0.3	0.7	1.4	15.4	45.5	16.8	3.2	16.5	2.85
A1	23-33	10	0.0	0.1	0.2	0.3	0.8	10.9	41.7	20.4	4.7	20.8	
B21t	33-76	43	0.0	0.0	0.0	3.0	0.8	4.5	26.9	20.7	6.2	37.8	
B22tca	76-114	38	0.0	0.0	0.0	2.6	2.1	3.4	23.1	22.7	6.4	39.8	3.64
B31	114-137	23	0.3	0.2	0.2	0.4	0.6	4.9	34.4	18.3	6.1	34.9	
B32	137-183	46	1.0	0.1	0.4	0.7	1.2	7.6	25.0	18.7	22.1	24.2	
							Norge						
A11	00-20	20	0.1	6.8	0.2	1.2	2.2	20.9	34.9	14.1	2.4	17.3	2.31
A12	20-43	23	0.0	0.1	0.3	1.0	2.3	19.4	37.0	12.1	2.4	25.5	
B1	43-64	20	0.1	0.1	0.4	1.1	1.6	13.2	32.2	14.2	4.0	33.2	4.23
B21t	64-107	43	0.0	0.1	0.5	1.1	1.9	14.3	22.6	14.6	2.7	42.1	
B22t	107-135	38	0.5	0.4	0.6	1.2	2.4	15.6	21.0	10.5	3.7	44.7	3.46
B23t	135-191	56	0.3	0.2	0.8	1.3	1.0	12.5	26.1	12.6	4.9	40.8	2.11

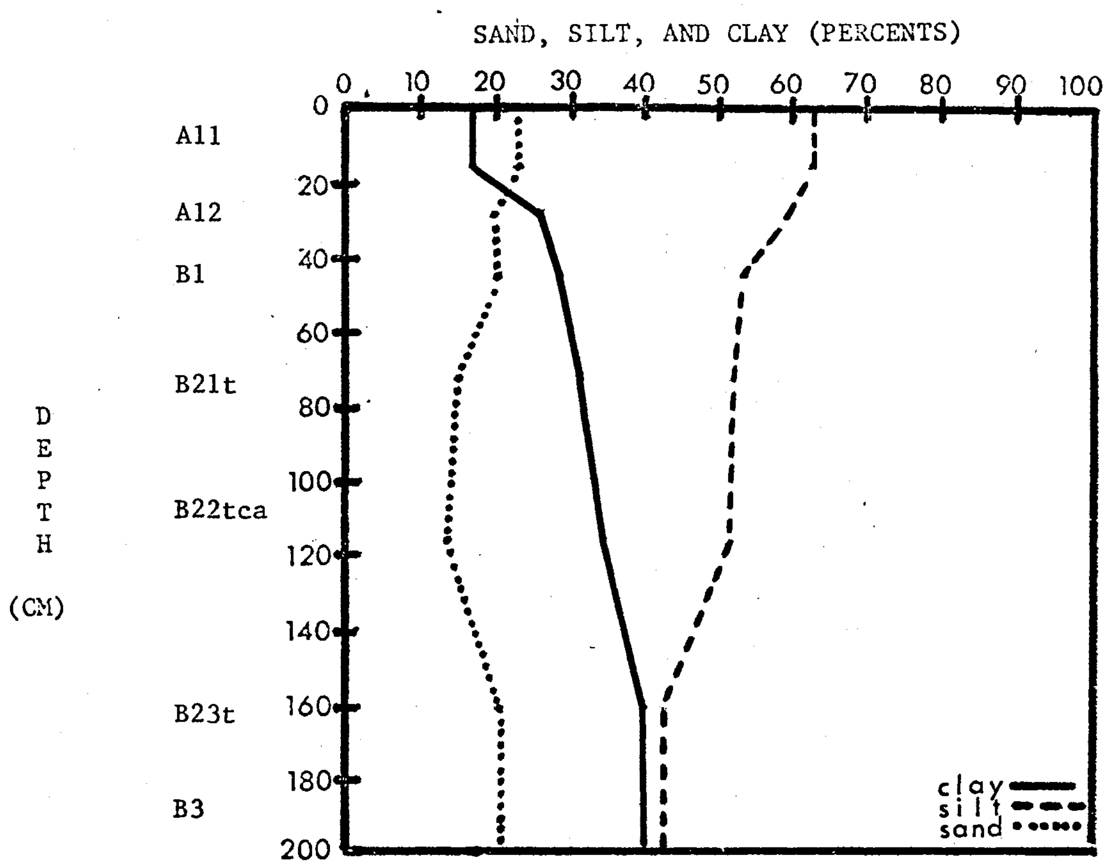

Figure 5. Particle Size-Depth Distribution Curve for the Bethany Pedon.

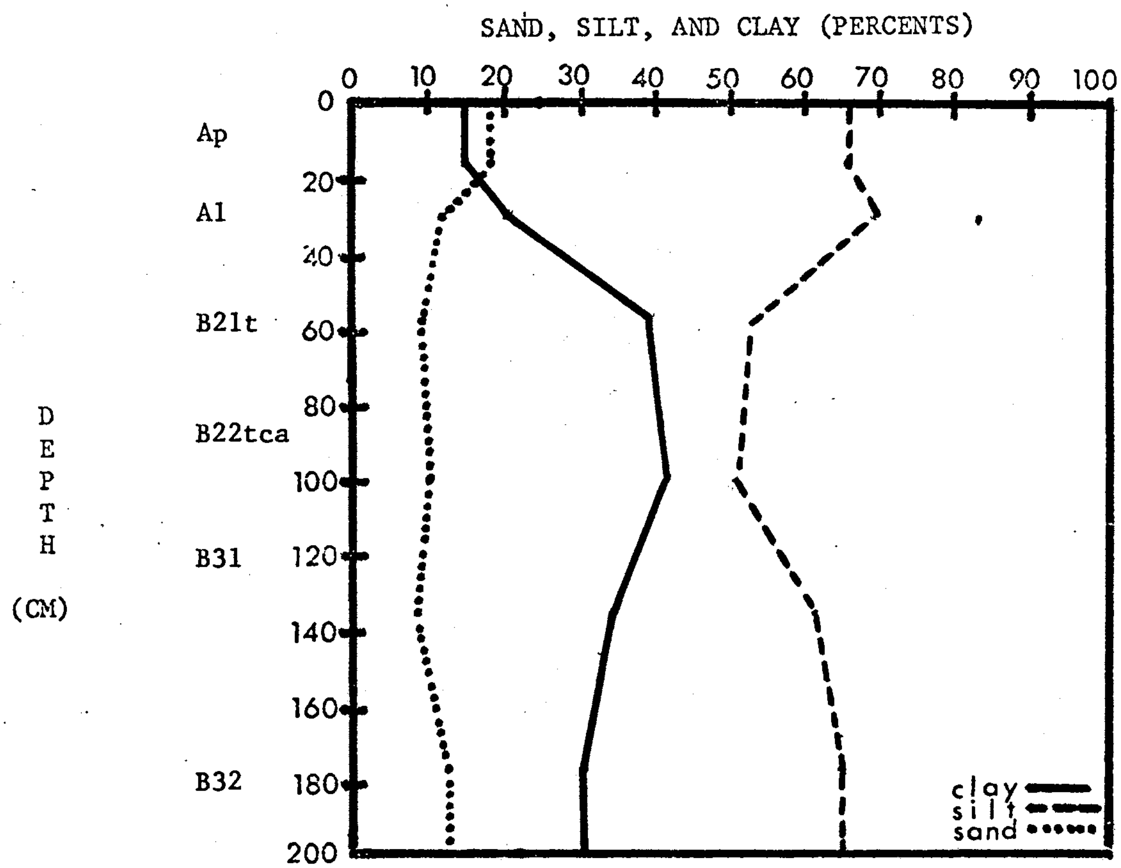

Figure 6. Particle Size-Depth Distribution Curve for the Kirkland Pedon.

concentration of 2:1 clays. The profile possesses high clay contents and morphological characteristics pointing to a well developed argillic horizon.

Bulk Density

Soil bulk densities indicate the presence of certain morphological properties and genetic processes. Due to the coarse nature and decreased intra ped void spaces of the fine earth fraction in loamy soil the Nobscot and Grandfield pedons have high bulk densities (Table III). The dry bulk densities range up to 1.83 g/cm^2 but indicate nothing other than the influence of texture.

The Bethany, Kirkland and Norge soils are finer and thus expected to have lower bulk densities unless altered by some morphological property. All three soils possess horizons with dry bulk densities in excess of 1.80 gm/cm^3 and clay percentages greater than 35% in those same horizons (Table IV). These horizons also include structures of medium to coarse size indicating the prevalent action of shrinking and swelling. Shrinking and swelling action in fine soils results in a compaction effect thus increasing dry bulk densities.

COLE

COLE values of the Nobscot and Grandfield generally fall short of any significant value, except in the B21t horizon of the Nobscot (Table III). Pedon clay fractions are insufficient to dominately influence physical properties (Table I).

COLE values of the Bethany, Kirkland and Norge are significantly higher. Values exceed 0.03 indicating the presence of substantial

TABLE III

BULK DENSITY AND EXTENSIBILITY OF THE GRANDFIELD AND NOBSCOT PEDONS

Horizon	Depth Centimeters	% Water by Weight Equilibrated	% Water by Volume Equilibrated	Bulk Density Equilibrated	Bulk Density Oven Dry	Linear Extensibility		
						COLE	Vertical Centimeters	Cumulative Verticle
				Grandfield				
Ap	0-20	-	-	-	-	-	-	1.47
B1	20-31	-	-	-	-	-	-	1.47
B21t	31-51	19	30	1.59	1.83	0.019	0.39	1.47
B22t	51-79	15	26	1.64	1.78	0.022	0.62	1.08
B23t	79-114	12	21	1.72	1.83	0.013	0.46	0.46
B24t	114-130	-	-	-	-	-	-	-
B31t	130-163	-	-	-	-	-	-	-
				Nobscot				
A1	00-13	-	-	-	-	-	-	3.75
A2	13-58	-	-	-	-	-	-	3.75
B21t	58-91	13	21	1.56	1.65	0.050	1.65	3.75
B22t	91-135	11	17	1.52	1.62	0.027	1.17	2.13
B23t	135-180	8	13	1.59	1.65	0.021	.98	.96
B3	180-203	-	-	-	-	-	-	-

TABLE IV

BULK DENSITY AND EXTENSIBILITY OF THE BETHANY, KIRKLAND AND NORGE PEDONS

Horizon	Depth Centimeters	% Water by Weight Equilibrated	% Weight by Volume Equilibrated	Bulk Density Equilibrated	Bulk Density Oven Dry	COLE	Linear Extensibility Vertical Centimeters	Linear Extensibility Cumulative Verticle
				Bethany				
A11	00-15	23.3	30.3	1.30	1.38	0.020	0.31	11.19
A12	15-31	29.0	36.3	1.25	1.37	0.030	0.46	10.88
B1	31-46	28.2	36.1	1.28	1.39	0.028	0.43	10.42
B21t	46-97	25.0	35.0	1.43	1.88	0.095	4.83	9.99
B22tca	97-137	23.8	37.0	1.52	1.81	0.060	2.44	5.16
B23t	137-180	20.2	30.7	1.54	1.76	0.063	2.72	1.72
				Kirkland				
Ap	00-23	26.8	35.4	1.32	1.38	0.016	0.37	12.41
A1	23-33	26.8	36.8	1.37	1.47	0.024	0.24	12.04
B21t	33-76	26.9	39.4	1.46	1.90	0.090	3.89	11.80
B22tca	76-114	25.8	37.7	1.46	1.82	0.076	2.90	7.91
B31	114-137	31.2	44.3	1.42	1.79	0.081	1.85	5.01
B32	137-183	28.3	42.0	1.49	1.81	0.069	3.16	3.16
				Norge				
A11	00-20	25.6	27.5	1.22	1.28	0.014	0.28	9.22
A12	20-43	26.3	32.2	1.23	1.34	0.029	0.66	8.94
B1	43-64	24.6	32.9	1.34	1.55	0.050	1.02	8.28
B21t	64-107	24.6	36.6	1.49	1.81	0.066	2.85	7.26
B22t	107-135	24.1	37.2	1.65	1.95	0.058	1.62	4.41
B23t	135-191	22.2	36.4	1.64	1.90	0.050	2.79	2.79

amounts of smectite (Table IV). The Bethany profile has COLE values up to 0.075 and a cumulative linear extensibility of 11.19 cm. The Kirkland profile has COLE values up to 0.090 and a cumulative linear extensibility of 12.41 cm. The Norge profile has COLE values up to 0.066 and a cumulative linear extensibility of 9.22 cm (Table IV). The shrink-swell of these three profiles is a significant indication of severe limitations for many engineering projects.

Chemical Properties

Organic Matter

Organic matter content has a recognized effect on soil physical properties. High organic matter percentages decreases the bulk density (Table IV) and reduce Atterburg limits (Table IX). This is especially evident in the A horizon of the Kirkland. The effects of organic matter on physical properties of the Nobscot and Grandfield are minor due to low organic matter percentages (Table V) and the coarse texture of the soil.

The effects of organic matter on the physical properties of the Norge, Kirkland, and Bethany are much greater. These three pedons occurred on virgin or nearly virgin sites. Thus organic matter content of the A horizons is exceptionally high and bulk densities are much less than in lower horizons (Table VI). The Atterburg limits are also noticeably repressed but large amounts of organic matter present make the A horizons unstable for engineering purposes that involve compaction and filling. Furthermore the COLE values of these horizons with more than 1.5% organic matter are noticeably depressed. This is due to the loss of some clay by translocation and most importantly the flocculating

TABLE V

ORGANIC MATTER AND CALCIUM CARBONATE EQUIVALENT

Horizon	Depth Centimeters	% Organic Matter	Calcium Carbonate Equivalent
		Grandfield	
Ap	00-20	1.63	0.8
B1	20-31	1.30	2.2
B21t	31.51	1.53	3.1
B22t	51-79	0.62	1.8
B23t	79-114	0.26	2.3
B24t	114-130	0.25	2.3
B31	130-163	0.20	1.8
		Nobscot	
A1	00-13	1.54	0.0
A2	13-58	0.47	0.0
B21t	58-91	0.68	0.0
B22t	91-135	0.44	0.0
B23t	135-180	0.43	0.0
B3	180-203	0.22	0.0

TABLE VI

ORGANIC MATTER AND CALCIUM CARBONATE EQUIVALENT

Horizon	Depth Centimeters	% Organic Matter	Calcium Carbonate Equivalent
		Bethany	
A11	00-15	4.13	3.3
A12	15-31	2.28	3.3
B1	31-46	1.78	3.0
B21t	46-97	1.01	4.7
B22tca	97-137	0.70	17.2
B23t	137-180	0.53	7.4
B3	180-203	0.18	5.0
		Kirkland	
Ap	00-23	1.88	2.4
A1	23-33	1.58	5.4
B21t	33-76	1.38	7.4
B22t	76-114	1.07	16.3
B31	114-137	0.78	10.9
B32	137-183	0.72	6.7
		Norge	
A11	00-20	3.42	2.1
A12	20-43	2.15	3.2
B1	43-64	1.59	4.6
B21t	64-107	1.08	4.6
B22t	107-135	0.41	3.2
B23t	135-191	0.55	6.2

effect of organic matter on clay particles.

Total Carbonates

The total soil carbonates are a measure of translocation within a pedon. The Nobscot pedon produced no significantly measurable amounts of carbonates. Total carbonates in the Grandfield are very low in the A horizon and the increase in the B horizons are a sign of some translocation occurring in the profile (Table V).

The Norge pedon has some translocation of carbonates downward in the profile though no large concentrations have developed (Table VI). However, translocation, and argillic development have occurred. Due to it geologically young age, less weathering and translocation have occurred than in older pedons of this study.

The Kirkland pedon has heavy concentrations of carbonates in its B horizons indicating active translocation and soil development over a long period of time (Table VI). Carbonate concentrations exceed 15 percent in the B22t horizon qualifying it as a calcic horizon. The high concentration may have depressed linear extensibility to some degree.

The Bethany also has heavy concentrations of carbonates in the B horizons indicating active translocation and soil development over a long period of time (Table VI). Carbonate concentrations exceed 15 percent in the B22t horizons qualifying it as a calcic horizon. The calcium carbonate concentrations of the lower horizons may have depressed natural shrinking and swelling tendencies.

Mineralogical Properties

X-ray Diffraction

X-ray diffraction patterns for A and B horizons of the Bethany pedon are given in Figure 7. A low 15.2A^{o} peak in the coarse clay calcium saturated sample of the A horizon indicates the presence of montmorillonite, vermiculite, and chlorite, however, montmorillonite does not produce much peak when the sample is glycerol solvated. Mica (illite) produces a peak at 10.04A^{o} which is intensified by the collapse of vermiculite and montmorillonite after potassium saturation and heat treatment. Chlorite and vermiculite produce second order peaks at about 7.15A^{o} and illite produces second order peak at 5.00A^{o}. Well crystallized quartz identifies itself with a peak at 3.35A^{o}.

Calcium saturation of the fine clay produces a broad peak at 16.05A^{o} and glycerol solvation produces even higher intensity at the lower angles indicating the presence of low angle scatter due to interstratified and interlayered montmorillonite. Some mica is also present as identified by the flat peak at 10.16A^{o} in the calcium saturated sample and quartz expresses itself at 3.35A^{o}.

The B horizon shows more intense peaks for montmorillonite than does the A horizon. The coarse clay fraction predicts interstratified vermiculite and montmorillonite from the lower angle diffraction of the calcium saturated sample, however, glycerol solvation depresses the broad peak and potassium saturation along with heat treatment identify the presence of chlorite and vermiculite at 10.20A^{o}. Second order chlorites and vermiculite are found at 7.13A^{o} and second order mica at 5.00A^{o}. Strong, well crystallized quartz patterns are found at 3.35A^{o}.

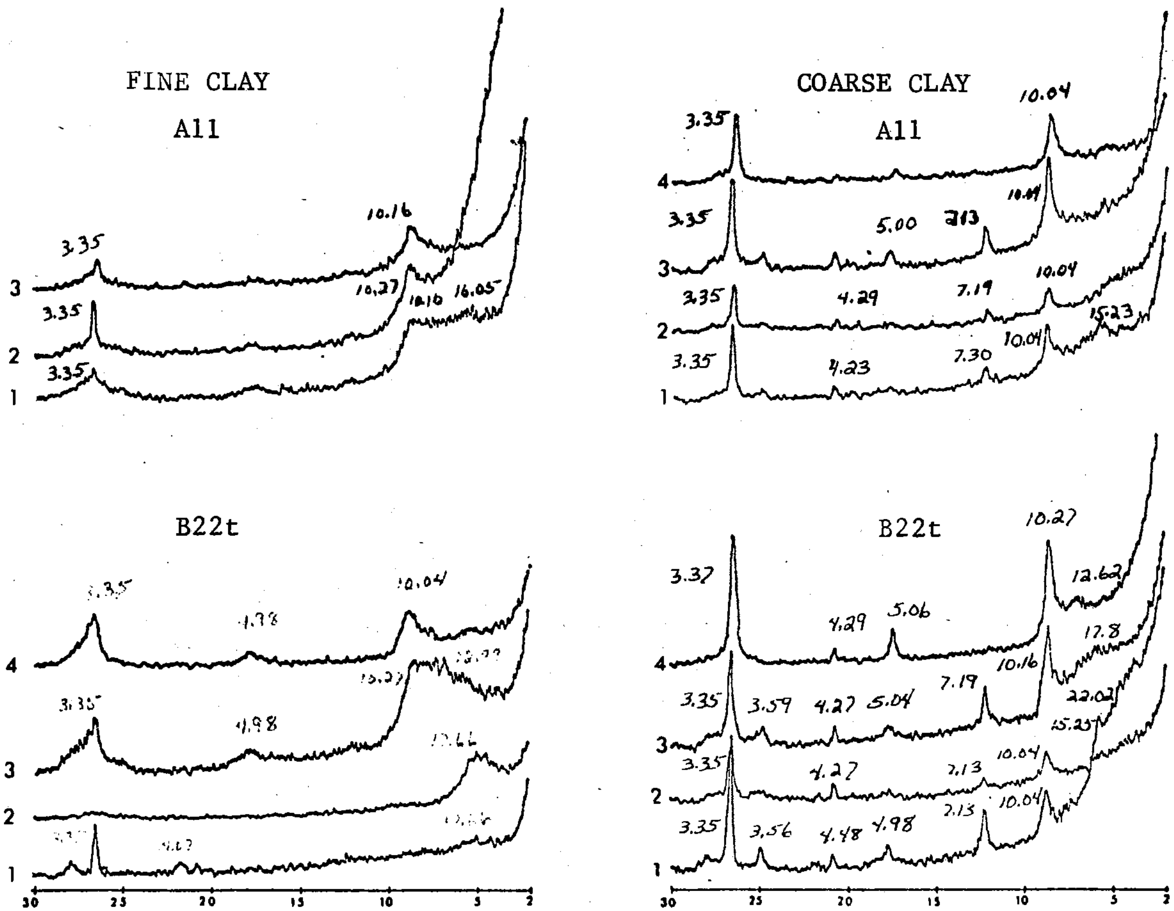

Figure 7. X-ray Diffractograms for the Bethany Pedon; (1) Mg-Saturated, (2) Glycerol Solvated, (3) K-Saturated and, (4) Heated to 500°C. Measurements in Angstroms.

The fine clay of the B horizon produces a broad peak at 17.66A° indicating the presence of poorly crystallized montmorillonite. Potassium saturation produces one broad peak between 10.27A° and 12.99A° again indicating the presence of poorly crystallized montmorillonite. This is confirmed by the presence of a sharp peak at 10.04A° after heat treatment. Some third order chlorite on second order mica presents itself at 4.98A° and a quartz peak is found at 3.35A°.

X-ray diffraction patterns for the A and B horizons of the Kirkland soil are given in Figure 8. The coarse clay fraction of the A horizon exhibits some activity between 14A° and 15A° and a more intense diffraction between 17A° and 18A° in the glycerol solvated sample indicating the presence of poorly crystallized montmorillonite. Potassium saturation intensifies the mica peak at 10.04A° due to the constriction of vermiculite. Second order vermiculite and chlorite are expressed at 7.13A° in the potassium saturated sample and well crystallized quartz produces intense peaks at 3.35A°.

The fine clay fraction produces broader lower peaks due to poorly crystallized soil minerals. Montmorillonite, vermiculite and chlorite produce some diffraction in the calcium saturated sample and poorly crystallized montmorillonite faintly expresses itself under glycerol solvation. Micaceous materials produce low peaks at 10.04A° and quartz produces a peak 3.35A°.

The B horizon shows more intense peaks than does the A horizon. Calcium saturated coarse clay indicates montmorillonite, vermiculite, and chlorite at 15.77A° and low angle scatter due to interlayered and interstratified montmorillonite. Micaceous materials produce a peak at 10.04A° in the calcium saturated and glycerol solvated samples.

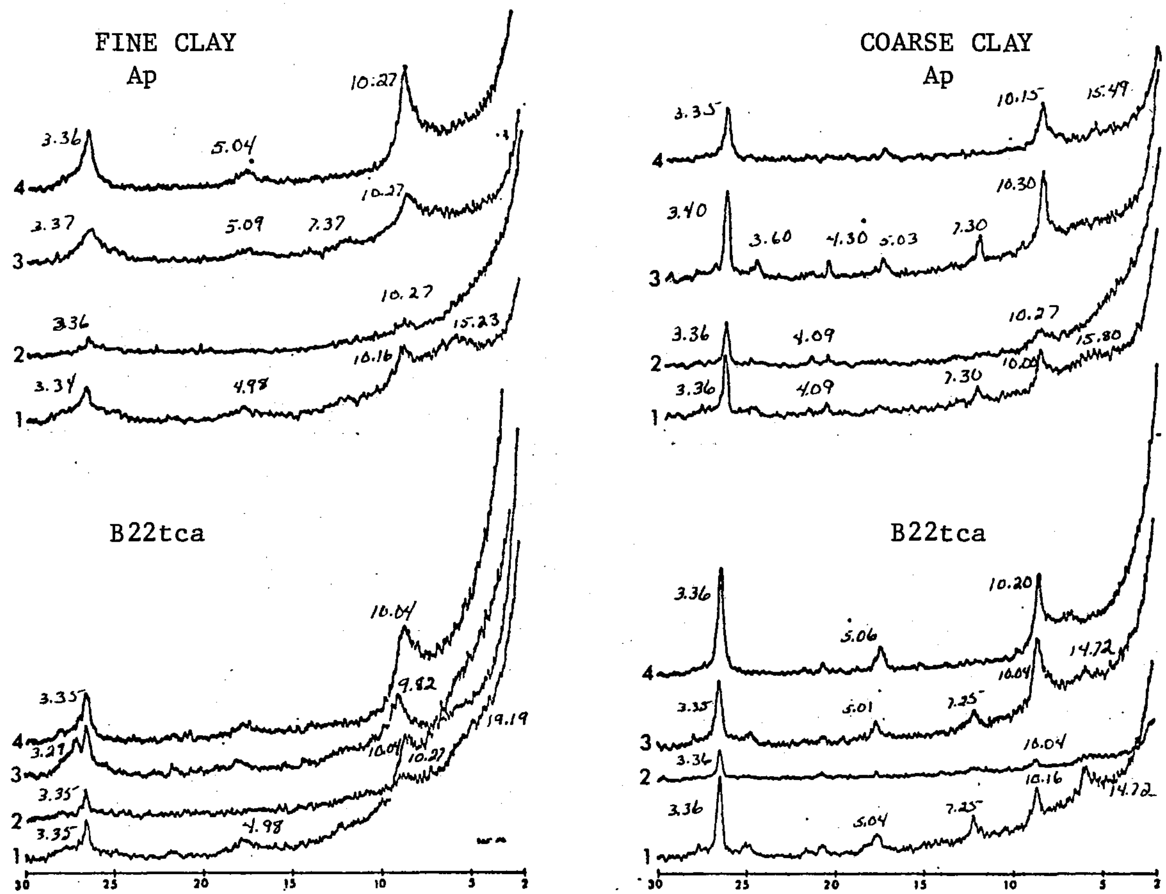

Figure 8. X-ray Diffractograms for the Kirkland Pedon; (1) Mg-Saturated, (2) Glycerol Solvated, (3) K-Saturated and, (4) Heated to 500°C. Measurements in Angstroms.

Both potassium saturation and heat treatment intensify this peak by collapsing vermiculite and montmorillonite. Second order chlorite produces a peak at 7.13A^{o} and well crystallized quartz produces a peak at 3.35A^{o}.

The calcium saturated fine clay fraction produces a very intense peak at approximately 16.35A^{o} and an even more intense peak at approximately 15.77A^{o} for the potassium saturated sample. These samples indicate the presence of considerable 2:1 montmorillonite, vermiculite and chlorite. Glycerol solvation produces a fairly intense peak of interlayered montmorillonite and illite at 19.19A^{o} which most probably is dominately montmorillonite as indicated by the formation of a peak at 10.16A^{o} when the potassium saturated sample was heat treated, collapsing the montmorillonite and forming a new peak. Probably very little mica is present even though some second order mica is seen at about 5.04A^{o}.

The coarse clay of this profile produces sharp peaks for 2:1 type clay minerals and identifies the presence of montmorillonite, vermiculite and chlorite. Fine clay x-ray diffraction identifies the presence of montmorillonite and indicates it is probably the most important clay mineral present in the profile.

X-ray diffraction patterns for the A and B horizons of the Norge pedon are given in Figure 9. The coarse clay fraction of the A horizons exhibit some influence of the diffraction pattern by montmorillonite, vermiculite and chlorite with low angle scatter indicating interlayering and interstratification. Sharp peaks are produced at about 10.15A^{o} indicating micas and quartz produces peaks at 3.35A^{o}.

The fine clay produces its most intense peaks at 10.27A^{o} indicating

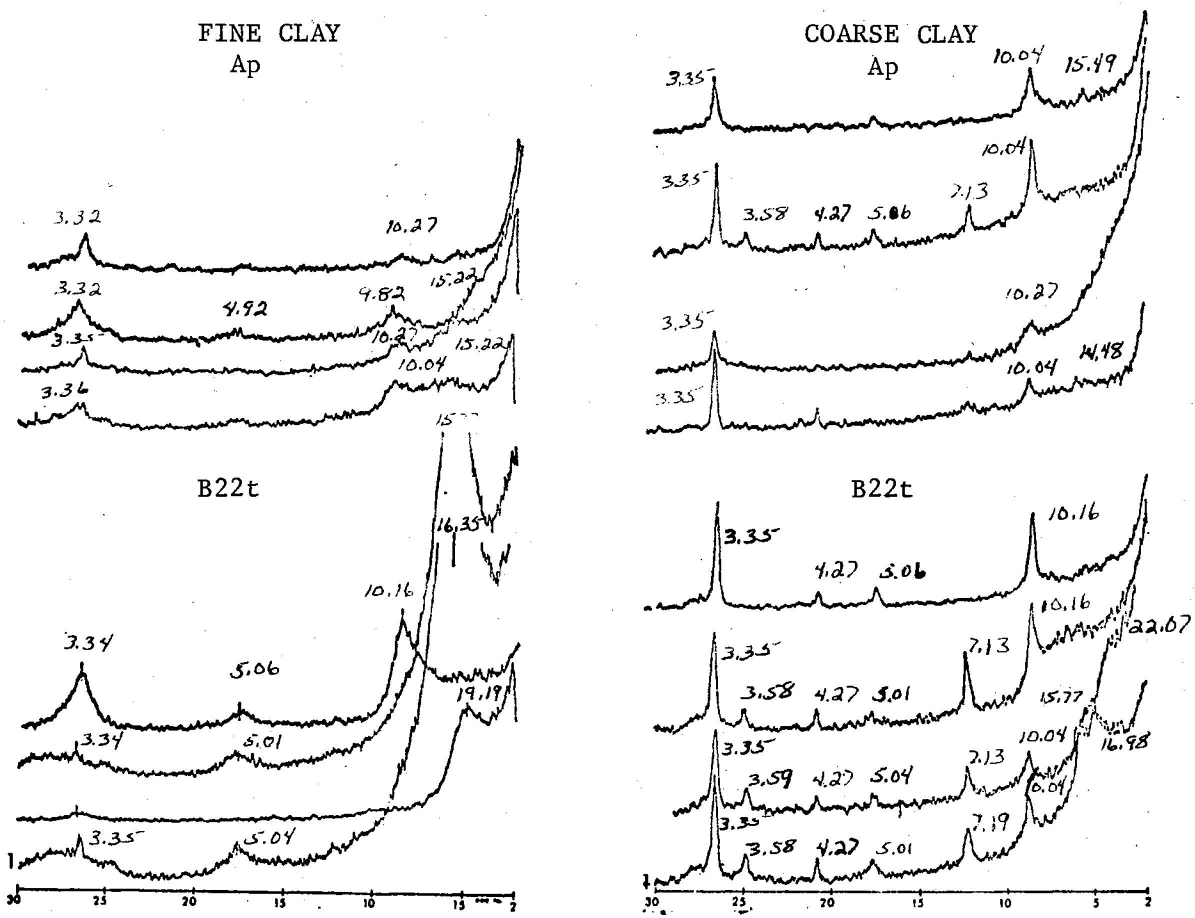

Figure 9. X-ray Diffractograms for the Norge Pedon; (1) Mg-Saturated, (2) Glycerol Solvated, (3) K-Saturated and, (4) Heated to 500°C. Measurements in Angstroms.

the presence of micas. The 10.27A^{o} peak becomes more intense as vermiculite and montmorillonite are collapsed. Fine quartz also produces a peak at 3.35A^{o}.

The B horizon produces somewhat the same diffraction patterns as the A horizon but with more intensity.

Montmorillinite, vermiculite and chlorite express a peak at about 14.72A^{o} for the calcium saturated coarse clay sample. The glycerol solvated sample produced no strong peak of any kind and the potassium treated sample produced a weak peak at 14.72A^{o} indicating vermiculite and chlorite. A diffraction peak at about 10.04A^{o} indicates micas are present and this peak intensifies as the vermiculite and montmorillonite are collapsed. Some second order illite shows up at 5.04 and quartz produces a peak at 3.35A^{o}.

The fine clay produces more low angle diffraction than the coarse clay and indicates interstratified montmorillonite and interlayered illite at 19.19A^{o}. Mica exhibits a peak near 10.0A^{o}. This peak intensifies with the collapse of vermiculite and montmorillonite.

C.E.C. of the Fine and Coarse Clays

The cation exchange capacity of the coarse and fine clay fractions was determined for indications of dominate clay minerals. The exchange capacity of the fine clays were generally higher than the exchange capacity of the coarse clays.

The difference in exchange capacities for fine and coarse clays were relatively small for both the Bethany and the Norge pedons (Table VII).

The B1 horizon of the Bethany has almost equal exchange capacities

TABLE VII

CATION EXCHANGE CAPACITY OF COARSE AND FINE CLAYS

Horizon	C.E.C. meq/100g Coarse Clay	Coarse Clay	Fine Clay / Coarse Clay
	Norge		
A11	31.42	66.99	2.31
B1	52.38	63.89	4.23
B22t	50.74	55.33	3.46
	Kirkland		
Ap	30.78	79.27	2.85
B22tca	38.45	85.00	2.64
B31	35.44	84.36	
	Bethany		
A11	45.70	77.30	3.48
B1	68.95	63.06	
B22tca	62.07	94.10	4.75
B23t	41.16	23.24	

for the fine and coarse clays. This is due to either vermiculite in the coarse clay fraction or poor sample dispersion.

The lowest exchange capacities for coarse clays and the highest exchange capacities for fine clays were observed in the Kirkland pedon (Table VII). The low exchange capacity of the Kirkland coarse clay indicates the presence of illite as the dominate clay mineral of that fraction. The high exchange capacity of the Kirkland fine clay indicates montmorillonite dominates that fraction.

The Bethany and Norge pedons are of mixed clay mineralogy while the Kirkland pedon has a montmorillonitic clay mineralogy.

Engineering Properties and Interpretations

Atterburg Limits

Atterburg limits indicate the desirability of a soil for various engineering purposes. Tables VIII and IX contain data for Atterburg limits measured by the Oklahoma State Highway Department. The tests were made for the purpose of determining shrinkage, volume change, liquid limit, and plasticity index.

When samples have textures of sand, sandy loam and loamy sand the clay content is considered too small for effect regardless of its properties. Coarse soils such as the Grandfield and Nobscot have little or no plasticity. However, clay percentages of the Grandfield exceed twenty eight percent in the B21t and 10% in all other horizons making it a desirable precaution to test for Atterburg limits (Table VIII). The plastic indexes fall in the low to medium range and liquid limits, except in the B21t are far below the significant 35% value (Table VIII). Plotting plastic index vs. liquid limit (Figure 10) shows the affect of

TABLE VIII

SOME ENGINEERING PROPERTIES OF THE GRANDFIELD AND NOBSCOT PEDONS[1/]

Horizon	Depth Centimeters	Thickness Centimeters	Liquid Limit	Plastic Index	Shrinkage Limit	Shrinkage Ratio	Volume Change
			Grandfield				
Ap	00-20	20	22	5	14	1.86	10
B1	20-31	10	23	7	14	1.86	14
B21t	31-51	20	42	22	13	1.91	46
B22t	51-79	28	31	16	14	1.90	33
B23t	79-114	36	28	11	18	1.75	17
B24t	114-130	15	32	14	16	1.80	27
B31	130-163	33	25	6	18	1.74	10
			Nobscot				
A1	00-13	13	NP[2]	NP	NP	NP	NP
A2	13-58	46	NP	NP	NP	NP	NP
B21t	58-91	33	NP	NP	NP	NP	NP
B22t	91-135	43	NP	NP	NP	NP	NP
B23t	135-180	46	NP	NP	NP	NP	NP
B3	180-203	23	NP	NP	NP	NP	NP

[1] Oklahoma Highway Department Soils Laboratory

[2] Nonplastic

TABLE IX

SOME ENGINEERING PROPERTIES OF THE BETHANY, KIRKLAND AND NORGE SOILS

Horizon	Depth Centimeters	Thickness Centimeters	Liquid Limit	Plastic Limit	Shrinkage Limit	Shrinkage Ratio	Volume Change
			Bethany				
A11	00-15	15	34	8	21	1.62	19
A12	15-31	16	32	11	17	1.72	23
B1	31-46	13	39	18	15	1.83	35
B21t	46-97	51	47	27	11	1.98	57
B22tca	97-137	40	47	27	10	2.02	66
B23t	137-180	43	46	26	11	2.00	61
B3	180-203	23	47	28	11	2.02	51
			Kirkland				
Ap	00-23	23	26	4	15	1.80	17
A1	23-33	10	26	6	16	1.80	17
B21t	33-76	43	52	30	9	2.07	68
B22t	76-114	38	53	32	9	2.09	68
B31	114-137	23	53	31	9	2.10	71
B32	137-183	46	53	31	10	2.06	73
			Norge				
A11	00-20	20	33	7	20	1.67	20
A12	20-43	23	33	12	17	1.76	26
B1	43-64	21	38	17	15	1.86	42
B21t	64-107	43	47	26	13	1.94	51
B22t	107-135	28	50	29	15	1.86	46
B23t	135-191	56	48	28	12	2.00	51

[1] Oklahoma State Highway Department Soils Laboratory.

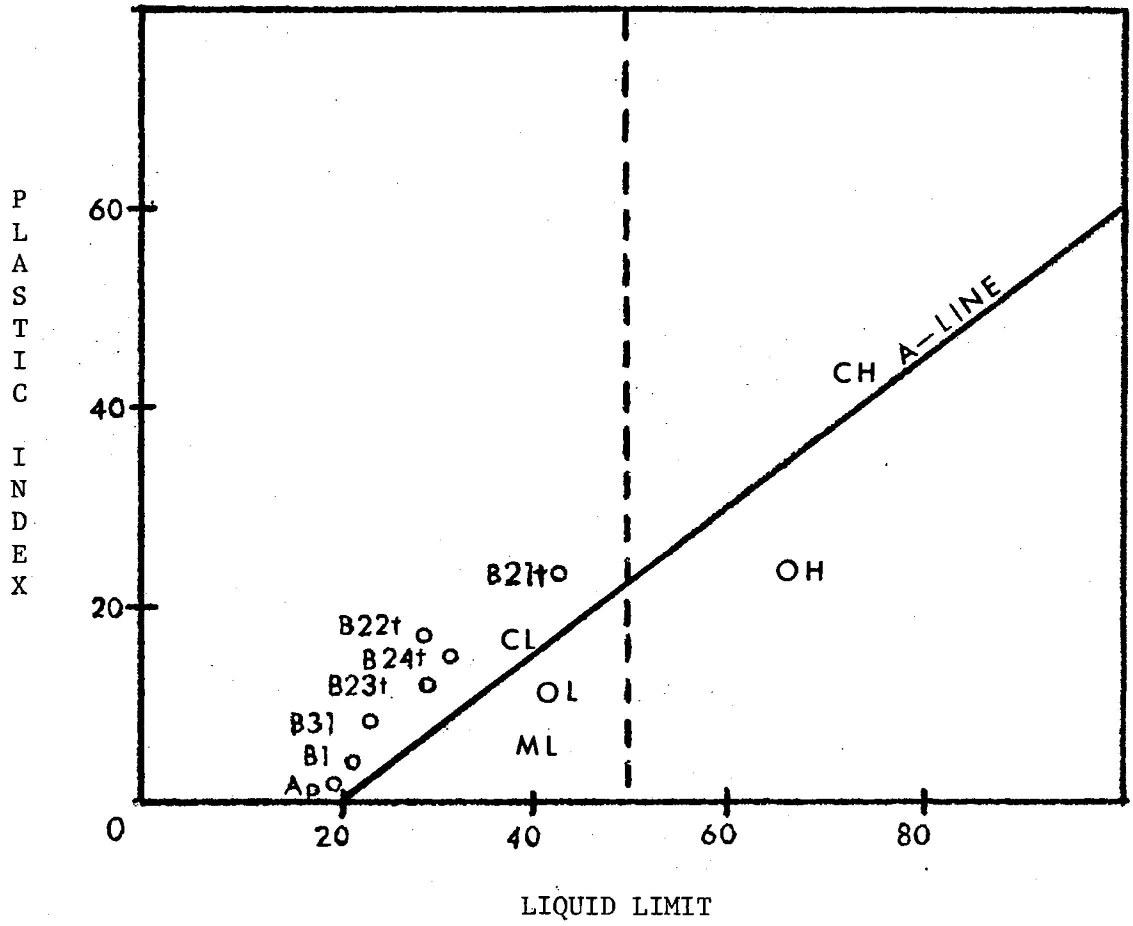

Figure 10. Plasticity Chart for the Grandfield Pedon. (ML), Inorganic Silts and Fine Sands with Slight Plasticity. (CL), Inorganic Clays of Low to Medium Plasticity. (OL), Organic Silts and Organic Silty-Clays of Low Plasticity. (CH), Inorganic Clays of High Plasticity, Fat Clays. (OH), Organic Clays of Medium to High Plasticity.

2:1 type clays on engineering properties to be minimal.

The liquid limits of the Norge profile exceed thirty percent and the plastic indexes of the B horizon fall in the medium to high range. However, the shrinkage ratios exceed 15% which is low, indicating a significant but not great amount of shrinking and swelling (Table IX). The high clay content produces high liquid limits and plastic indexes, however, the pedon is relatively low in swelling type clays. The plotting of plastic index vs. liquid limit(as seen in Figure 11) shows the effect of swelling type clays on engineering properties of this pedon as low to moderate.

Liquid limits of the Kirkland B horizon exceed fifty percent and plastic indexes are high. The shrinkage ratio is less than eleven in all horizons indicating high shrink-swell clays (Table IX). A plotting of plastic limit versus liquid limit (as seen in Figure 12) shows the significant affect of the swelling clays. The engineering properties confirm the undesirability of this soil for most engineering purposes.

The liquid limits and plastic indexes of the Bethany pedon are about medium. The shrinkage ratios are also about medium indicating appreciable but not extreme amounts of swelling clays (Table IX). The plotting of plastic limit vs. liquid limit (as seen in Figure 13) shows the affect of swelling clays to be significant.

<u>Interpretations of Engineering Qualities</u>

The study pedons were rated for various engineering purposes based on field descriptions and laboratory data presented in this thesis. Interpretations and ratings were made using data in Tables VIII, IX and X. Table X includes USDA textures, available water holding capacities,

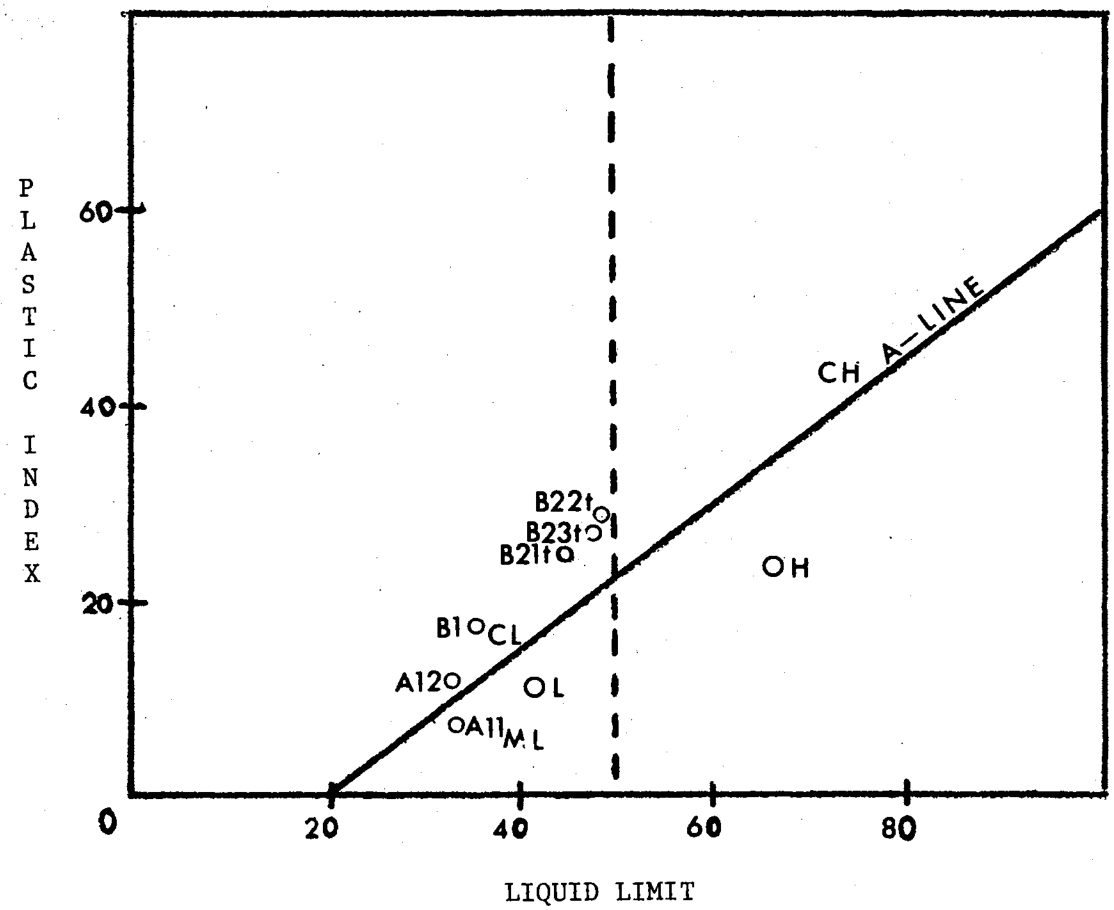

Figure 11. Plasticity Chart for the Norge Pedon. (ML), Inorganic Silts and Fine Sands with Slight Plasticity. (CL), Inorganic Clays of Low to Medium Plasticity. (OL), Organic Silts and Organic Silty-Clays of Low Plasticity. (CH), Inorganic Clays of High Plasticity, Fat Clays. (OH), Organic Clays of Medium to High Plasticity.

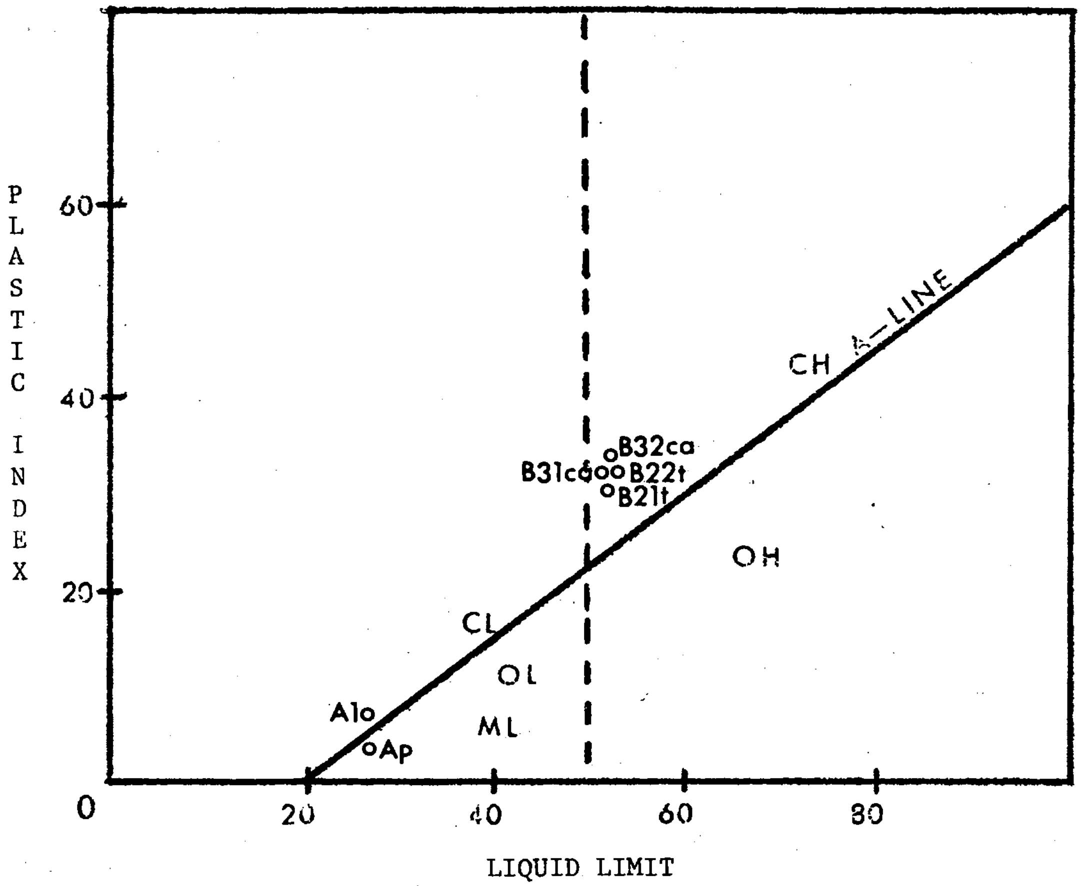

Figure 12. Plasticity Chart for the Kirkland Pedon. (ML), Inorganic Silts and Fine Sands with Slight Plasticity. (CL), Inorganic Clays of Low to Medium Plasticity. (OL), Organic Silts and Organic Silty-Clays of Low Plasticity. (CH), Inorganic Clays of High Plasticity, Fat Clays. (OH), Organic Clays of Medium to High Plasticity.

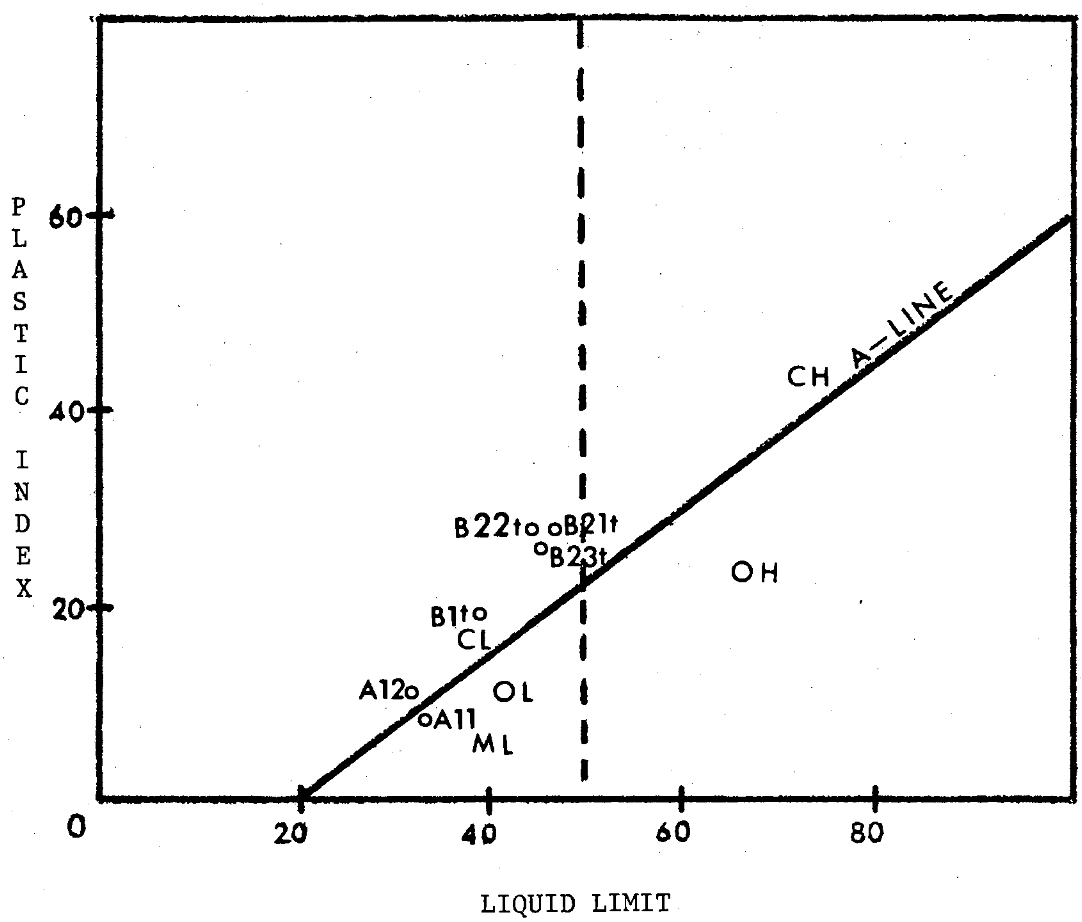

Figure 13. Plasticity Chart for the Bethany Pedon. (ML), Inorganic Silts and Fine Sands with Slight Plasticity. (CL), Inorganic Clays of Low to Medium Plasticity. (OL), Organic Silts and Organic Silty-Clays of Low Plasticity. (CH), Inorganic Clays of High Plasticity, Fat Clays. (OH), Organic Clays of Medium to High Plasticity.

TABLE X

ENGINEERING PROPERTIES AND QUALITIES OF FIVE IMPORTANT SOILS

Soil Name	Depth From Surface (cm)	USDA Texture	Available Water Capacity[1]	Reaction	Shrink-Swell Potential
Bethany silt loam	0-30	Silt loam	0.15-0.17	6.4-6.7	Low
	30-137	Silty clay loam	0.15-0.17	6.6-8.5	Moderate
	137-203	Clay loam	0.15-0.17	7.6-7.7	Moderate
Grandfield loamy sand	0-30	Loamy sand	0.05-0.10	6.9-7.3	Low
	30-51	Sandy clay loam	0.10-0.15	6.4-6.4	Low
	51-163	Sandy loam	0.05-0.10	6.2-6.3	Low
Kirkland silt loam	0-33	Silt loam	0.15-0.17	6.4-6.6	Low
	33-137	Silty clay loam	0.15-0.17	6.6-8.0	High
	137-183	Silt loam	0.15-0.17	7.4-7.4	High
Nobscot sandy loam	0-58	Sandy loam	0.05-0.10	7.3-8.1	Low
	58-135	Sandy loam	0.05-0.10	6.3-6.6	Low
	135-203	Loamy sand	0.03-0.07	6.4-6.5	Low
Norge silt loam	0-43	Silt loam	0.15-0.17	6.5-6.6	Low
	43-64	Silty clay loam	0.15-0.17	6.6-6.6	Moderate
	64-191	Clay	0.10-0.15	6.6-8.3	Moderate

[1]Inches per inch of soil

reaction and ratings for shrink-swell potential. These tables and the field descriptions were the bases for engineering interpretations and ratings found in Tables XI, XII, XIII, and XIV.

In Table XI the soils are rated for suitability as sources of topsoil, select material and roadfill. The Bethany, Kirkland and Norge are good to fair sources of topsoil while the Grandfield and Nobscot are good sources of select material and road fill.

Table XII gives ratings and indicates features affecting suitability as sites for highways, farm ponds, drainage, irrigation systems, waterways, terraces and diversions. All the study pedons have limitations for highway locations, embankments, irrigation or terraces and diversions. The Bethany, Kirkland and Norge pedons have features most suited for reservoir areas and waterways.

Interpretive ratings for specific soil uses are given in Tables XII and XIV. The soils are rated for septic tank filter fields, sewage lagoons, sanitary land fill, sites for low buildings, roads and streets, lawns, shrubs and tree gardens, golf fairways, picnic areas, intensive play areas, paths and trails, camping areas, and parks. The ratings are for soils in place.

The sandier Nobscot and Grandfield soils have severe to moderate limitations for uses requiring slow permeability, high fertility or trafficability. The Bethany and Norge soils generally have moderate to severe ratings for those uses requiring high permeability and low shrink-swell. However, they are only slightly limited for most recreational uses. Due to high clay content, clay mineralogy, and resulting engineering properties the Kirkland soil has limitation for every use except ponding water.

TABLE XI

ENGINEERING INTERPRETATIONS OF FIVE IMPORTANT SOILS
SUITABILITY AS A SOURCE

Soil Name	Topsoil	Selected Materials	Road Fill
Bethany silt loam	Good to fair to a depth of 1½ feet: easily eroded on steep slopes.	Unsuitable	Poor Moderate shrink-swell potential, unstable
Grandfield loamy sand	Poor: low fertility easily eroded	Good	Good if entire profile is used
Kirkland	Good to fair to a depth of 1 foot: easily eroded on steep slopes	Unsuitable	Very poor: Unstable: high shrink-swell potential
Nobscot fine sandy loam	Poor: low fertility; easily eroded	Good	Good
Norge silt loam	Fair to good: Some what easily eroded on steep slopes	Poor: Elastic	Fair to poor: Unstable

TABLE XII

ENGINEERING INTERPRETATIONS OF FIVE IMPORTANT SOILS
-SOIL FEATURES AFFECTING-

		Farm Ponds					
Soil Name	Highway Location	Reservoir Area	Embankment	Agricultural Drainage	Irrigation	Terraces and Diversions	Waterways
Bethany-like silt loam	Moderate shrink-swell potential; very slow internal drainage; unstable	Features favorable	Susceptible to cracking when dry; low shear strength	Good drainage	Slow rate of intake; slow permeability	Susceptible to ponding in channels	Features favorable
Grandfield loamy sand	Erodible soils	High rate of seepage	High erodibility	Good drainage	Undulating topography; wind erosion	Susceptible to wind erosion	Susceptible to wind and gully erosion
Kirkland	High shrink-swell potential; unstable	Features favorable	Cracks when dry	Very slow internal drainage	Very slow rate of intake; cracks when dry	Ponded water in channels	Features favorable
Nobscot fine sandy loam	Erodible soils	High rate of seepage	High erodibility	Good drainage	Wind erosion; humocky topography	Humocky topography; subject to wind erosion	Soil subject to wind and gully erosion
Norge silt loam	Moderate: shrink-swell potential; very slow internal drainage; unstable	Features favorable	Susceptible to cracking when dry; low shear strength	Good drainage	Slow rate of intake; slow permeability	Susceptible to ponding in channels	Features favorable

TABLE XIII

DEGREE AND KIND OF LIMITATION TO NON-FARM USES OF FIVE IMPORTANT SOILS

Soil Name	Septic tank filter field	Sewage Lagoons	Sanitary Landfill	Sites for low buildings	Roads and Streets	Lawn Shrubs and trees
Bethany silt loam	Severe: slow percolation	Slight	Moderate: Material difficult to excavate	Moderate: Moderate shrink-swell potential	Moderate: Moderate shrink-swell potential	Slight
Grandfield loamy sand	Slight	Severe: Rapid Percolation	Slight	Slight	Slight	Moderate: low fertility
Kirkland silt loam	Severe: slow percolation	Slight	Moderate: Material difficult to excavate	Severe: High shrink-swell potential	Severe: High shrink-swell potential	Severe: Droughtiness; clayey
Nobscot sandy loam	Slight	Severe: Rapid percolation	Slight	Slight	Slight	Moderate: low fertility
Norge silt loam	Severe: slow percolation	Slight	Slight	Moderate: Moderate shrink-swell potential	Moderate: Moderate shrink-swell potential	Slight

TABLE XIV

DEGREE AND KIND OF LIMITATION TO NON-FARM USES OF FIVE IMPORTANT SOILS

Soil Name	Gardens	Golfways	Picnic Area	Intensive Play Area	Paths and Trails	Camping Areas	Parks
Bethany silt loam	Slight	Slight	Slight	Slight	Slight	Slight	Slight
Grandfield loamy sand	Moderate: low fertility	Severe: Sandy surface low water holding capacity low productivity	Severe: Traffic-ability	Severe: Sandy Surface	Moderate: Sandy Surface Layers	Severe: Traffic-ability	Moderate: Traffic-ability
Kirkland silt loam	Severe: Droughti-ness Clayey	Severe: Droughtiness clayey, soil cracks when dry	Moderate: Clayey	Moderate: very slow permeability	Moderate: very slow Permea-bility	Moderate: very slow perma-bility	Moderate: very slow permea-bility
Nobscot sandy loam	Moderate: low fertility	Severe: Sandy surface low water-holding capacity; low productivity	Severe: Traffic-ability	Severe: Sandy surface	Moderate: Sandy surface	Severe: Traffic-ability	Moderate: Traffic-ability
Norge silt loam	Slight	Slight	Slight	Slight	Slight	Slight	Slight

Classification of the Soils

The soils of this study were classified according to the 7th Approximation (21). The soils were systematically classified using the data presented in this thesis and additional data in the Appendix. The results are listed in Table XV.

The Bethany and Norge pedons classified respectively as fine silty and fine clayey, mixed, thermic Udic Paleustolls, however, textural limitations prohibit naming them as models for their series. Percent clay of the Bethany control section was too low and percent clay of the Norge control section was too high for current series definitions. If all pedons of these mapping units contained similar morphological variations new soil series would need to be proposed.

TABLE XV

CLASSIFICATION OF THE STUDY PEDONS

Soil Series	Family	Subgroup	Order
Bethany	fine-silty, mixed, thermic	Udic Paleustolls	Mollisols
Grandfield	fine-loamy, mixed, thermic	Udic Haplustalfs	Alfisols
Kirkland	fine-clayey, mixed, thermic	Udertic Paleustolls	Mollisols
Nobscot	loamy, mixed, thermic	Arenic Haplustalfs	Alfisols
Norge	fine-clayey, mixed, thermic	Udic Paleustolls	Mollisols

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to obtain a more complete characterization of five key Oklahoma soils in order to make better engineering interpretations. The soils selected occur under an ustic moisture regime in two Oklahoma resource areas. Study of the pedons encompassed morphological, physical, chemical and mineralogical investigations with emphasis on particle size distribution, clay mineralogy, shrink-swell and plasticity.

The Grandfield and Nobscot pedons classified as Haplustalfs with somewhat similar characteristics and properties resulting in similar interpretations. Both, relatively young soils, developed in wind reworked pleistocene materials. Due to youth and parent material the sand fraction dominates textures and the low clay content has little effect on chemical and physical properties. Moisture variations have little effect on engineering properties, as stable plasticity limits and low shrink-swell potentials indicate. These soils make good building sites and sources of construction materials. However, they possess low suitabilities for any purpose requiring water retention. They are coarse, have rapid permeability, and little or no natural binding of soil particles.

The Bethany, Kirkland, and Norge pedons classified as Paleustolls with somewhat similar greatgroup characteristics and properties resulting in similar interpretations. Laboratory analysis of the Bethany pedon proved the control section too low in percent clay, under current definitions, for classification into the Bethany series. Laboratory analysis of the Norge pedon proved its control section too high in percent clay for classification into the Norge series. Clay content of the B horizons and mixed clay mineralogy with significant smectite produce soils unstable for many engineering purposes. Moderate to high plasticities and moderate to high shrink-swell make them unstable soils restricted for uses requiring soil disturbance or a more rapid permeability. They have limitations as sources of building materials, as sewage filter fields, and as building sites. They are however, excellent sites for reservoirs, water retention areas, and water diversions. They are best for those engineering projects requiring little manipulation, light use, or a slow permeability.

The Kirkland pedon classified as a Udertic Paleustol, an inherently unstable soil. This instability results from high clay contents dominated by the montmorillonitic clay group. The soil is very plastic and highly expansive restricting its use for most engineering purposes. Projects requiring displacement, more rapid permeability, low shrink-swell and heavy use _in situ_ encounter heavy restrictions. They are best adapted to those purposes requiring ponding or restriction of water movement.

The results of this study will allow a more exact interpretation of properties associated with these five important soils. Furthermore, results may be extrapolated to closely related soils not yet as thoroughly characterized. Special land use management interpretations and recommendations may be found for each soil in Chapter IV.

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APPENDIX A

TERMS

Coefficient of linear extensibility (COLE) - The volume change of soil with change in water content defined as:

$$\text{COLE} = \frac{Lm - Ld}{Ld} = \frac{Lm}{Ld} - 1 = \sqrt[3]{\frac{Dbod}{Dbm}} - 1$$

where Lm = length of moist sample, Ld = length of dry sample. Dbod = bulk density of the dry clod, Dbm = bulk density of the moist clod.

Cumulative vertical linear extensibility - Summation of the vertical linear extensibilities for the horizons.

Extensibility - Increase in volume of the soil fabric with increased water content.

Linear extensibility - The linear increase of the soil fabric with increased volume.

Liquid limit - That water content expressed as a percentage of the dry weight of a soil at which the soil mass just starts to become fluid under the influence of a series of standard shocks.

Plastic index - The difference between the liquid and plastic limits, representing the range of moisture within which the soil is plastic.

Plastic limit - That water content expressed as a percentage of the dry weight of a soil at which the soil mass ceases to be plastic and becomes brittle.

Shrinkage limit - The water content below which a reduction in moisture will not cause a decrease in the volume of the soil mass.

Shrinkage ratio - The ratio between a soils volume change and the corresponding change in water content above the shrinkage limits.

It is theoretically the apparent specific gravity of the dried soil peds.

Vertical linear extensibility - COLE multiplied by the thickness of the horizon.

Volume change - The volume change, expressed as a percentage of the dry volume of the soil mass when the moisture content is reduced from the field capacity to the shrinkage limit.

APPENDIX B

TABLES

TABLE XVI

ADDITIONAL CHEMICAL ANALYSES OF THE GRANDFIELD AND NOBSCOT PEDONS

	Extractable Cations MEQ/100GMS						Base Saturation		P.P.M. Total
CEC	H	CA	Mg	K	Na	Al	NAAC	Sum of Cat.	P
					Grandfield				
12.4	0.87	6.55	2.95	0.71	0.08	0.00	83.1	92.2	16.3
12.6	0.34	6.68	3.28	0.42	0.09	0.00	83.3	96.9	15.9
21.2	3.54	9.89	6.35	0.48	0.09	0.00	79.3	82.7	18.1
13.7	2.09	7.73	4.45	0.29	0.07	0.00	91.4	85.8	10.8
11.0	0.68	5.76	4.59	0.19	0.08	0.00	96.5	94.0	7.9
7.9	0.73	6.68	4.98	0.22	0.09	0.00	152.0	94.3	7.0
7.2	0.87	4.85	4.65	0.13	0.09	0.00	134.7	91.8	6.0
					Nobscot				
3.5	0.00	4.32	0.52	0.07	0.08	0.00	144.6	100.0	2.8
1.3	0.00	1.57	0.52	0.03	0.12	0.00	171.6	100.0	8.8
7.9	0.87	5.24	2.57	0.21	0.09	0.00	102.1	90.3	4.1
5.5	1.21	3.01	2.49	0.21	0.09	0.00	104.3	82.5	5.0
6.0	0.34	2.29	2.03	0.07	0.09	0.00	112.2	93.0	5.6
3.7	0.00	1.31	2.10	0.06	0.09	0.00	97.2	100.0	4.3

TABLE XVII

ADDITIONAL CHEMICAL ANALYSES OF THE BETHANY, KIRKLAND AND NORGE PEDONS

	Extractable Cations MEQ/100GMS						Base Saturation		P.P.M. Total
CEC	H	CA	Mg	K	Na	Al	NAAC	Sum of Cat.	P
					Bethany				
18.2	3.25	11.92	4.91	0.97	0.25	0.00	99.3	84.8	43.2
17.7	2.09	11.53	6.22	0.78	0.40	0.00	107.2	90.1	35.2
20.4	2.76	12.18	8.71	0.70	1.18	0.00	111.9	89.2	29.4
28.9	1.07	17.75	15.26	0.71	2.34	0.00	124.9	97.2	44.4
29.1	0.00	43.56	20.11	0.71	5.59	0.00	240.1	100.0	32.6
26.3	0.15	42.31	17.55	0.73	5.76	0.00	252.6	99.8	42.3
29.6	1.26	23.58	14.15	0.52	5.26	0.00	147.2	97.2	31.3
					Kirkland				
12.8	2.86	7.42	5.69	0.56	0.29	0.00	109.3	83.0	27.4
13.8	2.09	10.35	5.96	0.50	0.69	0.00	126.5	89.4	25.5
33.2	1.75	21.81	17.10	0.71	3.49	0.00	129.9	96.2	32.6
30.9	0.00	42.58	25.02	0.73	5.23	0.00	238.2	100.0	39.0
30.1	0.00	46.51	16.64	0.75	4.92	0.00	229.0	100.0	62.4
30.1	0.58	60.92	15.85	0.73	5.99	0.00	277.4	99.4	32.3
					Norge				
10.7	2.33	11.53	4.45	1.04	0.43	0.00	162.5	88.3	44.4
12.3	2.81	7.99	9.83	0.53	0.09	0.00	150.3	86.8	37.1
16.0	3.54	11.20	0.13	0.28	0.12	0.00	74.0	77.0	34.9
18.9	3.49	12.51	11.33	0.52	0.35	0.00	130.9	87.7	22.3
18.3	2.91	13.10	11.40	0.59	0.54	0.00	140.3	89.9	21.1
27.5	0.00	21.22	11.68	0.64	0.98	0.00	125.5	100.0	23.5

VITA

Dennis Arthur Voss

Candidate for the Degree of

Master of Science

Thesis: UTILIZING THE MORPHOLOGY OF SELECTED OKLAHOMA SOILS FOR THE INTERPRETATION OF SOME ENGINEERING QUALITIES

Major Field: Agronomy

Biographical:

Personal Data: Born in Perry, Oklahoma, September 24, 1948, the son of Mr. and Mrs. Will Art Voss.

Education: Graduated from Perry High School, Perry, Oklahoma in May, 1967; received the Bachelor of Science degree from Oklahoma State University in 1971, with a major in Agronomy Science Option; completed requirements for the Master of Science degree at Oklahoma State University in May, 1974 with a major in soils.

Experience: Born and reared in a small farm community; worked on the farm during summers; worked on harvest crew one summer; worked for Morrow Construction Company for three summers; Graduate Assistant in teaching and research in Soil Morphology, Genesis, and Classification, Department of Agronomy, Oklahoma State University from 1972-1974.