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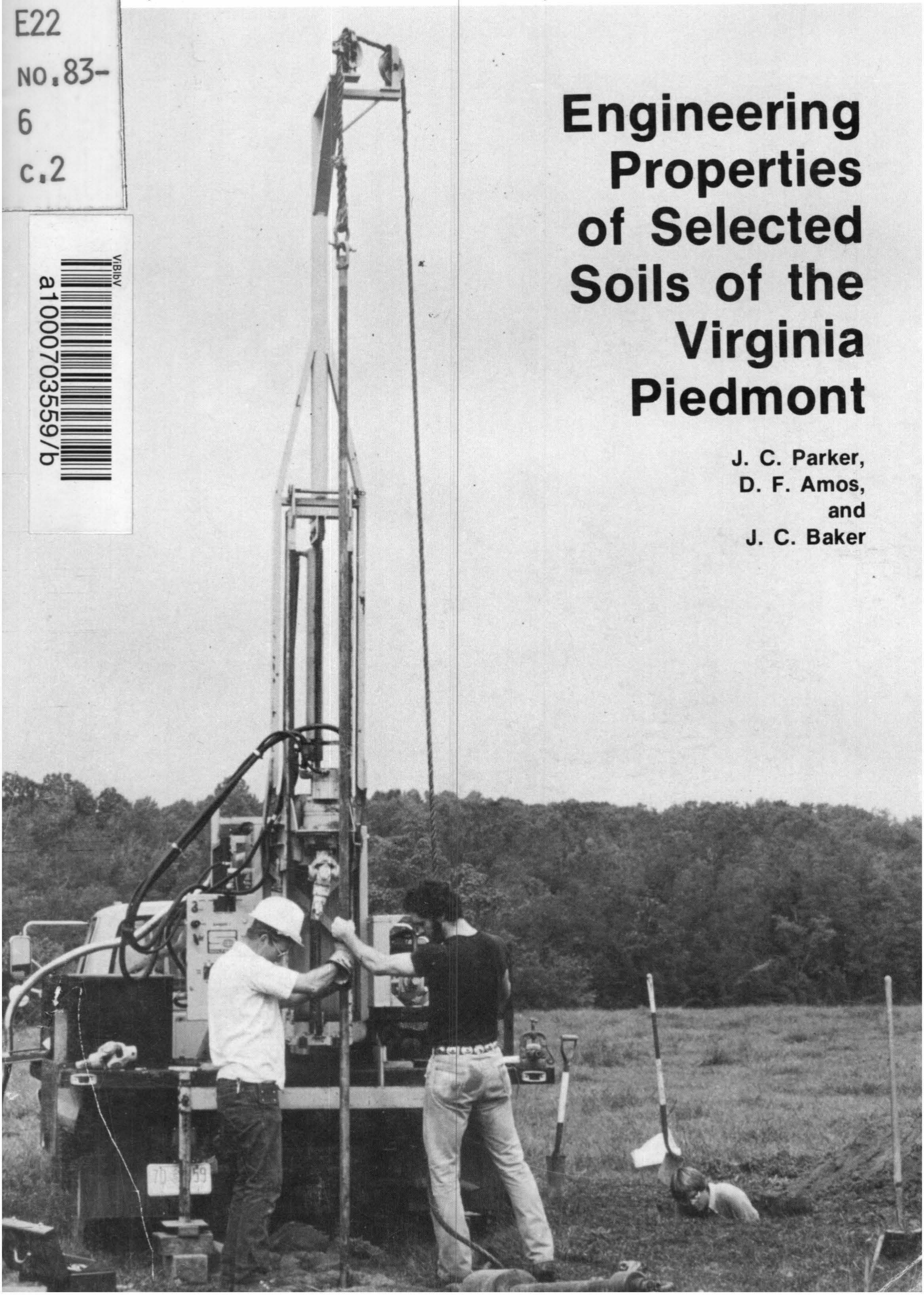

# ENGINEERING PROPERTIES OF SELECTED SOILS OF THE VIRGINIA PIEDMONT

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# ACKNOWLEDGMENTS

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## 1. SCOPE AND PURPOSE OF STUDY

The Piedmont Province in Virginia, running in a north-south direction, is approximately 50 miles wide along the Maryland border, and broadens to the south until it encompasses approximately 150 miles along the North Carolina border. It comprises at least one-third of the land area of the state, with approximately 60% occupied by woodland and 40% by agriculture, primarily beef or dairy enterprises.

Located in the Piedmont are the cities of Leesburg, Fairfax, Manassas, Warrenton, Culpeper, Charlottesville, Lynchburg, Bedford, Farmville, Martinsville, Danville and South Boston. Ian McHargue, in his book Design With Nature, studied the Potomac River watershed and concluded that "the Piedmont is primarily suitable for urbanization with attendant agriculture and undifferentiated recreation" (McHargue 1969).

Because of the development potential of the Piedmont and the intense pressures for future urbanization west of Washington, D.C., in the counties of Fairfax, Prince William and Loudoun; around Richmond in the counties of Hanover, Henrico, Goochland, Powhatan, Amelia and Chesterfield; and in Albemarle, Amherst, Bedford, Campbell, Franklin, Henry and Pittsylvania counties, the need to intensively study the most widely distributed and potentially important Piedmont soils became apparent.

Recent soils and geological studies conducted by the authors and others* have concluded that many areas of the Piedmont are weathered to depths of 15 to 35 meters or greater. Since the Piedmont has been described by many as a dissected peneplain, and since much urban construction (whether highways, airports, shopping centers or sub-divisions) involves cutting, filling and shaping the topography, an understanding of the behavior of the weathered rock material (saprolite) is fully as important as understanding the behavior of the soil solum (A and B horizons).

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*Personal communication. Mylon Pavich, U.S. Geological Survey.

Certainly the characteristics of the saprolite are of prime importance in assessing the suitability of an area for a sanitary landfill. Many of the failing landfills of the past and the present would not have failed had they been placed in satisfactory saprolite. And, of course, the characteristics of the saprolite are of utmost importance in landfills designed for toxic or hazardous wastes, where failure is unacceptable.

As increasing numbers of septic drainfield systems are installed in our soils, we are plagued with nagging doubts about the potential contamination of our groundwater supplies. Here again, characteristics of the saprolite will determine whether contaminants can be contained within a limited sphere or whether they will seep into the aquifer.

Although a considerable amount of research has involved the determination of characteristics and behavior of the A and B horizons of various Virginia soils, this is the first integrated effort to study the entire soil system (sola and saprolite) of the major series of a Virginia physiographic province. We trust the information contained herein will be of increasing value in planning for the future of our state.

# 2. STUDY METHODS

## 2.1 FIELD METHODS

Field sampling was performed with the aid of a truck-mounted drill rig. Undisturbed samples of B and C horizons were taken with 76 mm diameter thin-wall steel tubes. After augering a 10 cm diameter hole to the desired depth, tubes were driven 45 cm into the soil with a 63 kg drop hammer falling a distance of 76 cm. The number of blows to drive the tubes 0-15, 15-30 and 30-45 cm were recorded and the sum of the two largest number of blows for three increments taken as the 'blow count'. Thin-wall tube samples were taken at depths corresponding to the maximum B horizon development and, where possible, in C horizons at depths of 3.0 - 3.45 m and 6.0 - 6.45 m. In some cases, auger refusal or thin-wall tube refusal occurred at shallower depths, precluding sampling at these depths. In some instances, auger hole instability associated with saturated soil conditions prevented sampling of deeper strata. Tubes were sealed in the field with paraffin wax to minimize drying and disturbance during transport and storage. The upper meter of the soil profile was described from bucket auger samples and the deeper material from screw auger samples.

## 2.2 LABORATORY METHODS

### 2.2.1 Multistage Triaxial Tests

In the laboratory, 35.5 mm diameter by 71.0 mm length specimens were removed from the thin-wall tubes. The thin-wall tubes were split in half by milling two cuts down the length. A stainless steel sampling tube of 38.6 mm O.D. with a 35.5 mm I.D. at the cutting edge and 36.2 mm I.D. along the remaining length was driven into the center of the 76mm thin-wall tube sample to extract a specimen for the triaxial test. The specimen was extruded from the subsampling tube and trimmed to length in a miter box.

Details of the multistage triaxial (MST) test have been reported by Parker et al. (1980). We will outline only the most important aspects of the procedure here. In the triaxial apparatus, samples were wet with 0.01 M

$CaCl_2$ using a vacuum saturation technique. Volume changes accompanying wetting under a 7 kPa confining pressure were measured. Hydraulic conductivity was then measured on the saturated soil.

After measuring hydraulic conductivity, the samples were subjected to four stages of isotropic consolidation followed by undrained axial compression. The results were analyzed by utilizing a hyperbolic stress-strain relationship to provide consolidated-undrained shear strength parameters as well as certain compressibility parameters. The shear strength parameters c and $\phi$ are defined by the equation:

$$s = c + n \tan \phi$$

where s is the shear strength in the plane of failure and n is the normal stress on the failure plane.

A close relationship exists between initial undrained axial compressibility and axial rebound on unloading. Since the latter is subject to less error in the MST test, we prefer to use the rebound or resilient modulii (E ) given by the expression:

$$E = \Delta\sigma_1/\varepsilon_1$$

where $\Delta\sigma_1$ is the axial stress decrement and $\varepsilon_1$ is the associated axial strain (change in height per unit height). Values of E were evaluated at each stage in the MST test corresponding to confining lateral pressures of 50, 100, 200 and 400 kPa. These modulii increase with lateral stress in a manner which may be approximated by the relation:

$$E = Mp(\sigma_3/p)^m$$

where p is atmospheric pressure; $\sigma_3$ is the lateral stress and M and m are dimensionless empirical parameters which are evaluated from the experimental results.

Undrained compressibility is important for analyzing settlement caused by transient loads. Continued compression under sustained loads causes the pore volume to decrease as water is extruded from the soil. Measurements of volumetric compression following increases in isotropic stress were measured at each stage in the triaxial test--that is, for compression from 7 to 50, 50 to 100, 100 to 200 and 200 to 400 kPa isotropic pressure. These values were used to calculate secant bulk compression modulii ($\overline{K}$) as:

$$\overline{K} = \Delta\sigma/\varepsilon$$

where $\Delta\sigma$ is the isotropic stress increment and $\varepsilon$ is the concommitant volumetric strain (change in volume per unit volume).

Bulk compression modulii increase with increasing stress in the same manner as undrained modulii:

$$\overline{K} = Np(\sigma/p)^n$$

where p is atmospheric pressure, $\sigma$ is the mean isotropic stress over which the secant modulus is calculated, and N and n are empirical parameters which are evaluated for each sample.

### 2.2.2 Tube Description and Clod Shrinkage

After the triaxial test specimen was removed from the thin-wall tube, the two halves of the milled tube were separated and a morphological description of the soil was made. Four clods of soil approximately 75-150 cm in volume were removed from the tubes for measurements of bulk density. One of the clods was dried at 105°C to determine the soil moisture content. After the initial weights of the other three clods were determined, they were coated with Saran by dipping them in a 1:5 mixture of Saran resin and 2-butanone. Clod volumes were then determined via Archimedes principle by weighing them suspended in water. After being air-dried for two weeks, the clod volumes were measured again in the same manner. Dry masses of the clods were calculated from their initial moist mass and the subsample moisture content. Moist and air-dry clod densities expressed on a 105° C dry mass basis were calculated and volumetric strain on shrinkage ($\varepsilon$) was evaluated as:

$$\varepsilon = 1-\rho_m/\rho_d$$

where $\rho$ denotes the bulk density measured in the initial moist state (m) and final air-dry state (d). Means of the triplicate determinations are reported.

### 2.2.3 Tests on Disturbed Soil

The soil remaining in the thin-wall tubes after removing the bulk density samples was air-dried, ground and sieved through a 2 mm screen. The fragments retained on the 2 mm sieve were soaked in Na-hexametaphosphate and washed on a 2 mm sieve. The dry mass of washed fragments >2 mm was determined and expressed as a percentage of the total dry soil mass. The particle size distribution of the <2 mm fraction was determined by sieving and pipette analysis (Day, 1965). Mean particle density of the whole soil was measured by water displacement in 50 ml pycnometers. Standard methods were used to determine Atterberg limits and Federal Housing Administration (FHA) swell index values. (Sowers, 1965 and Lambe, 1960, respectively).

The pH was determined in 1:1 soil-water suspensions using a combination calomel-glass electrode. Exchangeable bases were determined by pH 7.0 $NH_4OAc$ extraction with quantification by atomic absorption spectroscopy (Soil Survey Staff 1972). Titratable acidity was determined by the $BaCl_2$ - TEA method outlined by Peech (1965). Exchangeable Al was determined by titration after extraction in 1 KCl after a method described by McLean (1965). Mineralogy of the <2mm size fraction of the soils was determined by x-ray diffraction and differential scanning colorimetry after removal of free iron with DCB, as outlined by Harris et al (1980).

Compaction characteristics of the soils were determined by the miniature Harvard procedure (Wilson, 1970). Five layers of soil were compacted with 25 tamps of 9 kg-force per tamp. After optimum moisture for compaction was determined, samples were compacted at optimum moisture in Harvard molds and soaked for 48 hours under an axial stress of 3.2 kPa. Resistance of the wet soil to penetration by a 10.8 mm diameter rod while laterally confined by the mold and still under an axial stress of 3.2 kPa outside the zone of penetration was measured. California Bearing Ratio (CBR) was calculated as the ratio of the measured penetration resistance at a standard depth to the resistance of a standard ideal highway subgrade material (Goodwin, 1965).

## 3. DESCRIPTION AND CLASSIFICATION OF SOILS STUDIED

In selecting soils typical of the Piedmont Province, we strove to choose widely distributed soils of extensive acreage formed on common rock types. We also attempted to select soils which were being widely used for forests or agriculture and which had high potential for urban development. Of the soil series chosen, Appling, Davidson and Madison met these criteria. The fourth soil, Iredell, was chosen because of its wide distribution in the urbanizing areas of northern Virginia and the unique problems it presents in use and development.

The soils studied were selected at representative type locations throughout the Virginia Piedmont - from Loudoun to Pittsylvania and from Bedford to Dinwiddie counties. A total of 4 pedons were selected and sampled for Appling, Davidson and Madison, while 5 pedons of Iredell were studied. Typically these pedons spanned the portion of the Piedmont where these series are recognized and mapped (Fig. 1). Field descriptions of the pedons from the auger borings are given in Tables 1-4. Descriptions of the thin-wall tube samples taken from each pedon are presented in Tables 5-8.

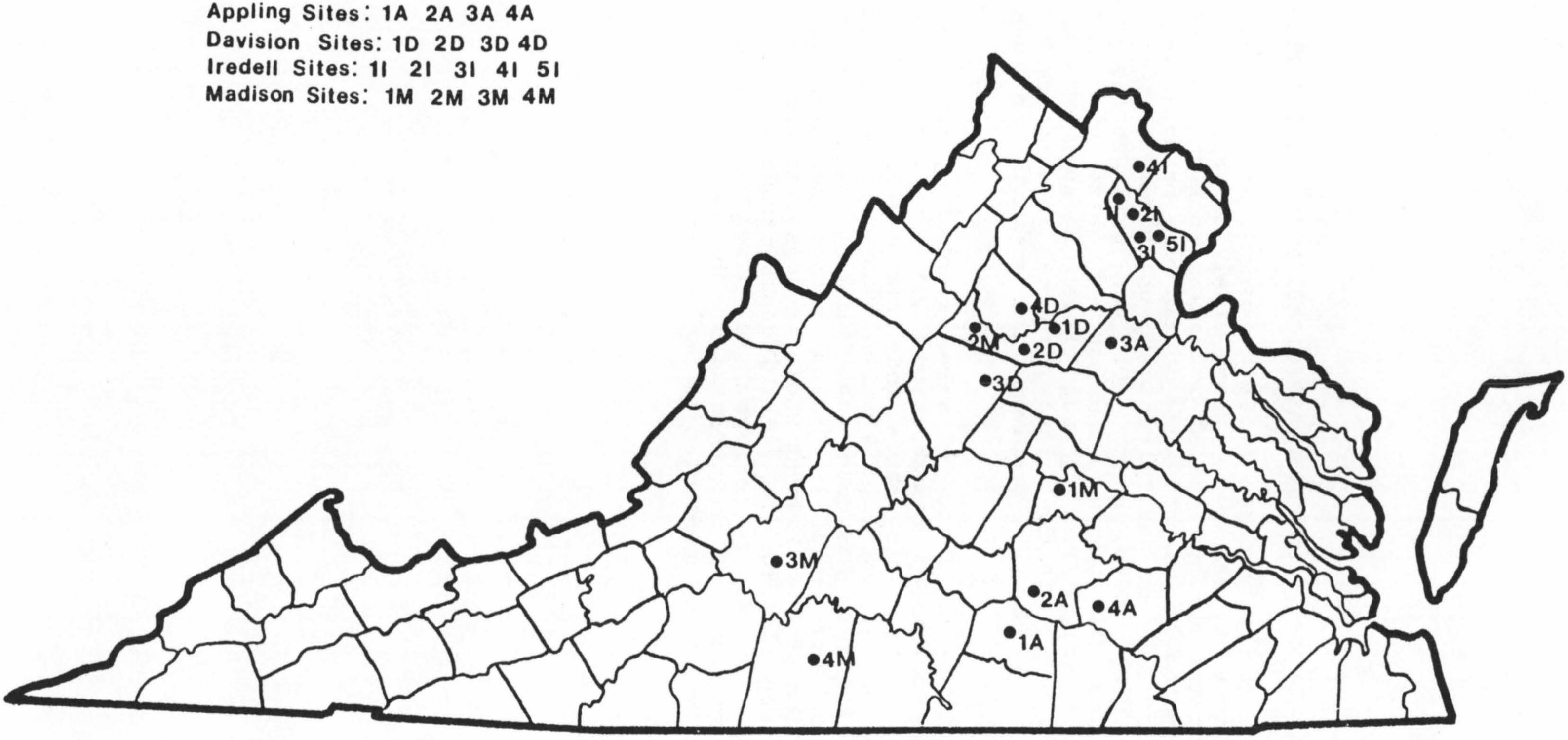

Figure 1. Location of sampling sites in the Virginia Piedmont.

Table 1. Site locations of soils in study and field descriptions from auger borings: Appling Series

| Site No. 1 | | Lunenburg Co. |
|---|---|---|
| **Depth (m)** | **Horizon** | **Description** |
| 0-0.05 | A1 | Brown sandy loam |
| 0.05-0.30 | A2 | Yellowish brown sandy clay loam |
| 0.30-0.81 | B2 | Red clay; BC* 39 |
| 0.81-1.2 | B3 | Red and reddish yellow clay loam |
| 1.2-3.6 | C1 | Reddish yellow clay loam to silt loam; common to many fine mica flakes; BC at 3.3 m |
| 3.6-12.6 | C2 | Yellow to light yellowish brown silt loam to fine sandy loam; common to many mica flakes; occasional lenses containing coarse white grains of weathered feldspar; HC 20 at 6.3 m |
| 12.6 | R | Auger refusal |

| Site No. 2 | | Nottoway Co. |
|---|---|---|
| **Depth (m)** | **Horizon** | **Description** |
| 0-0.30 | Ap | Brown friable sandy loam with weak granular structure |
| 0.30-0.38 | B21 | Reddish yellow to strong brown firm clay loam with weak medium subangular blocky structure |
| 0.38-0.83 | B22 | Strong brown and yellowish brown firm clay with weak medium subangular blocky structure and few fine mica flakes; BC 19 |
| 0.83-1.2 | B3 | Yellowish red firm silty clay with common yellowish brown and pink mottles and fine mica flakes |
| 1.2-1.8 | C1 | Yellowish red friable silt loam with common yellowish brown and pink mottles; fine mica flakes |

*Blow count for 76mm thin-wall tube driven by 63 kg hammer with 0.76 m drop for 0.15-0.45m.

Table 1. (Continued)

Site No. 2, cont. Nottoway Co.

| Depth (m) | Horizon | Description |
|---|---|---|
| 1.8-4.2 | C2 | Complex mixture of strong brown, reddish yellow, red and white granitic saprolite with common mica flakes and angular quartz grains; and lenses up to several inches thick of highly micaceous (biotite) saprolite; material appears to be saturated below saturated below 3 m; BC 22 at 3.3 m. |
| 4.2-6.0 | C3 | Pale brown loamy, saturated saprolite with common fine mica flakes; could not sample below 6 m below 6 m due to caving in of uncased hole |

Site No. 3 Spotsylvania Co.

| Depth (m) | Horizon | Description |
|---|---|---|
| 0-0.22 | Ap | Friable reddish brown sandy clay loam; moderate, fine granular structure |
| 0.22-0.90 | B2 | Firm red clay; moderate fine to medium subangular blocky structure; BC 9 |
| 0.90-1.2 | B3 | Friable, yellowish red clay loam to sandy clay loam; weak fine subangular blocky structure |
| 1.2-3.6 | C1 | Very friable, red, yellow, black and white mottled sandy loam; BC 10 at 3.3 m |
| 3.6-6.6 | C2 | Very friable, light yellowish brown, black and white mottled micaceous sandy loam; BC 10 at 6.3 m |

Table 1. (Continued)

| Site No. 4 | | Dinwiddie Co. |
|---|---|---|
| **Depth (m)** | **Horizon** | **Description** |
| 0-0.15 | Ap | Friable, brown sandy loam; weak, fine granular structure |
| 0.15-0.30 | B1 | Friable, brownish yellow loam-clay loam; weak, fine subangular blocky structure |
| 0.30-1.0 | B2 | Firm, reddish yellow to strong brown clay loam to clay with reddish brown, yellowish borwn and grey mottles; weak, medium subangular blocky structure; lenses of coarse feldspar and quartz grains; BC 18 |
| 1.0-1.2 | B3 | Firm, yellowish brown, reddish brown, and strong brown mottled clay loam |
| 1.2-2.4 | C1 | Strong brown silt loam with 20% 2-3 mm angular quartz grains |
| 2.4-3.0 | C2 | Reddish yellow micaceous loam with 20% 2-3 mm quartz grains |
| 3.0-6.3 | C3 | Light yellowish brown to yellowish brown loam to sandy loam with 40% mm gravel; water table at 4.8 m; BC 14 at 3.3 m; no sample taken 6 m due to instability of hole |

Table 2. Site locations of soils in study and field descriptions from auger borings: Davidson series

| Site No. 1 | | Orange Co. |
|---|---|---|
| Depth (m) | Horizon | Description |
| 0-0.15 | Ap | Dark reddish brown friable clay loam with strong fine to very fine subangular blocky structure |
| 0.15-0.45 | B1 | Dark reddish brown friable clay with strong fine subangular structure |
| 0.45-2.1 | B21 | Dark red friable clay with moderately strong fine subangular blocky structure; BC 28 |
| 2.1-3.6 | B3 | Dark red firm clay with weak subangular blocky structure; few yellowish red mottles; BC 54 |
| 3.6-6.6 | C | Yellowish red loamy saprolite; BC 5 |

| Site No. 2 | | Orange Co. |
|---|---|---|
| Depth (m) | Horizon | Description |
| 0-0.15 | Ap | Dark red friable clay loam |
| 0.15-0.9 | B2 | Dark red friable to firm clay with moderately strong to weak subangular blocky structure; BC 21 |
| 0.9-1.2 | B3 | Dark red clay with weak subangular blocky structure |
| 1.2-1.8 | C1 | Yellowish red silty clay loam saprolite |
| 1.8-2.4 | C2 | Dark yellowish brown silty clay loam to silt loam saprolite |
| 2.4-4.8 | C3 | Reddish brown loam to silt loam saprolite; BC 19 at 3.3 m |
| 4.8-5.4 | C4 | Dark yellowish brown loamy saprolite; saturated; BC 4 |
| 5.4 | R | Auger refusal |

Table 2. (Continued)

| Site No. 3 | | Albemarle Co. |
|---|---|---|
| Depth (m) | Horizon | Description |
| 0-0.10 | Ap | Friable, dark reddish brown clay loam; moderate, fine subangular blocky structure |
| 0.10-1.5 | B2 | Plastic, nonsticky, dark red clay; weak moderate, fine, subangular blocky structure; BC 34 at 0.3-0.6 m |
| 1.5-3.0 | B3 | Friable, dark red to red silty clay loam; weak, fine to very, fine subangular blocky structure |
| 3.0-3.6 | C1 | Friable to very friable, strong brown silt loam with common dark brown mottles; BC 18 |
| 3.6-6.0 | C2 | Friable to very friable, yellowish brown silt loam with common dark brown mottles |
| 6.0 | R | Thin wall tube and auger refusal |

| Site No. 4 | | Madison Co. |
|---|---|---|
| Depth (m) | Horizon | Description |
| 0-0.07 | Ap | Friable, red to dark red clay loam; weak to moderate, very fine subangular blocky structure |
| 0.07-1.8 | B2 | Dark red clay grading from hard to firm to plastic with increasing depth (and moisture); weak to moderate, fine to medium subangular blocky structure; BC 17 at 6.3 m |
| 1.8-3.6 | B3/C1 | Friable to slightly plastic, dark reddish brown silty clay loam with common reddish yellow and red mottles; BC 23 at 3.3 m |
| 3.6-5.7 | C2 | Friable, dark reddish brown silt loam with common reddish yellow and red mottles |
| 5.7-6.6 | C3 | Dark reddish brown, reddish brown and strong brown mottled silt loam; near saturation; BC 17 at 6.3 m |

Table 3. Site locations of soils in study and field descriptions from auger borings: Iredell series

Site No. 1 Prince William Co.

| Depth (m) | Horizon | Description |
|---|---|---|
| 0-0.25 | Ap | Yellowish brown loam |
| 0.25-0.6 | B2 | Dark yellowish brown, very plastic clay, BC 16 |
| 0.6-0.9 | B3 | Yellowish brown clay loam |
| 0.9-4.2 | C | Yellowish brown clay loam to sandy clay loam with lenses of dark brown and very dark grayish brown clay; BC 69 at 2.7 m |
| (2.7 to) 4.2 | R | Rock hit at 2.7-4.2 m in three holes within a few meters of other |

Site No. 2 Prince William Co.

| Depth (m) | Horizon | Description |
|---|---|---|
| 0-0.20 | Ap | Dark yellowish brown and yellowish brown clay loam with common Mn mottles |
| 0.20-0.65 | B2 | Yellowish brown very plastic clay common Mn mottles; BC 15 |
| 0.65-0.9 | B3 | Yellowish brown clay loam |
| 0.9-1.2 | C | Yellowish brown and very black grayish brown weathered rock rock which crushes to a sandy loam; BC 89 |
| 1.2-3.1 | C | Grayish brown pyroclastic rock which produces silty material on grinding (augering) |
| 3.1 | R | Auger refusal |

Table 3. (Continued)

Site No. 3 — Prince William Co.

| Depth (m) | Horizon | Description |
|---|---|---|
| 0-0.30 | A2 | Yellowish brown loam underlying leaf litter 5-10% cobbles |
| 0.30-0.40 | 12B1 | Yellowish brown clay loam |
| 0.40-0.75 | B2 | Yellowish brown plastic clay; BC 16 |
| 0.75-0.90 | C | Dark yellowish brown sandy clay loam |
| 0.90 | R | Auger refusal |

Site No. 4 — Loudoun Co.

| Depth (m) | Horizon | Description |
|---|---|---|
| 0-0.25 | Ap | Dark yellowish brown loam |
| 0.25-0.70 | B2 | Dark yellowish brown very plastic clay; BC 11 |
| 0.70-1.2 | B3 | Dark yellowish brown plastic clay |
| 1.2-1.6 | C | Yellowish brown clay loam when augered; BC 60 |
| 1.6-4.2 | C | Dark grayish brown sandy clay loam when augered; Shelby tube refusal |
| 4.2 | R | Auger refusal |

Site No. 5 — Prince William Co.

| Depth (m) | Horizon | Description |
|---|---|---|
| 0-0.20 | Ap | Yellowish brown loam |
| 0.20-0.35 | B1 | Yellowish brown clay loam |
| 0.35-0.80 | B2 | Dark yellowish brown very plastic clay; BC 14 |
| 0.80-1.2 | B3 | Yellowish brown plastic clay loam |
| 1.2-1.5 | C | Yellowish brown sandy clay loam; Shelby tube refusal |
| 1.5 | R | Auger refusal |

Table 4. Site locations of soils in study and field descriptions from auger borings: Madison series

Site No. 1 Powhatan Co.

| Depth (m) | Horizon | Description |
|---|---|---|
| 0-0.15 | Ap | Yellowish brown gravelly sandy loam with few mica flakes |
| 0.15-0.22 | B1 | Strong brown sandy clay loam |
| 0.22-0.60 | B2 | Red clay with common mica flakes; BC 16 |
| 0.6-1.2 | B3 | Red sandy clay loam; many mica flakes |
| 1.2-6.0 | C1 | Reddish brown micaceous sandy loam BC 11 at 3.3 m |
| 6.0-10.8 | C2 | Weak red to reddish grey micaceous sandy loam; BC 16 at 6.3 m |
| 10.8-14.4 | C3 | Auger could not be extricated from hole without loss of sample |

Site No. 2 Greene Co.

| Depth (m) | Horizon | Description |
|---|---|---|
| 0-0.12 | Ap | Dark brown friable loam to clay loam, with weak fine to medium subangular blocky structure |
| 0.12-0.60 | B2 | Red friable clay with moderately strong, medium subangular blocky structure and thin patchy clay films; common fine mica flakes; BC 29 for 0.45-0.75 m |
| 0.60-0.95 | B3 | Red friable clay loam with weak, coarse subangular blocky structure; many fine mica flakes |
| 0.95-1.8 | C1 | Yellowish red loamy micaceous saprolite |
| 1.8-9.6 | C2 | Yellowish brown loamy micaceous saprolite with lenses of white and black material interspersed; BC 15 at 3.3 m and 3 at 6.3 m |

Table 4. (Continued)

| Site No. 3 | | Bedford Co. |
|---|---|---|
| Depth (m) | Horizon | Description |
| 0-0.15 | Ap | Reddish brown loam with 30% B material inclusions |
| 0.15-0.90 | B2t | Red clay loam with many fine mica flakes; BC 10 |
| 0.90-1.2 | B3 | Red clay loam with many fine mica flakes |
| 1.2-2.1 | C1 | Dark red loamy micaceous saprolite |
| 2.1-6.6 | C2 | Yellowish brown to dark yellowish brown loamy micaceous saprolite; saprolite; BC 14 at 3.3 and 6.3 m |

| Site No. 4 | | Pittsylvania Co. |
|---|---|---|
| Depth (m) | Horizon | Description |
| 0-0.25 | Ap | Strong brown sandy clay loam with fine, weak subangular blocky structure |
| 0.25-0.45 | B21t | Strong brown clay with medium, weak subangular blocky structure and common fine mica flakes |
| 0.45-1.2 | B22t | Red clay with medium, moderately strong subangular blocky structure and many fine mica flakes; BC 27 |
| 1.2-1.5 | B3 | Red clay loam with weak subangular blocky structure and many fine mica flakes |
| 1.5-2.7 | C1 | Red loamy micaceous saprolite |
| 2.7-3.0 | C2 | Yellowish red micaceous saprolite |
| 3.0-14.4 | C3 | Brown and yellowish brown micaceous saprolite with lenses of black, yellowish red, reddish brown and greyish brown material; BC 18 at 3.3 m |
| 14.4-16.2 | C4 | Greyish brown to dark greyish brown micaceous saprolite; common coarse mica flakes (1-3 mm); appears saturated |

Table 5. Descriptions of thin-wall tube samples: Appling series.

| Horizon | Site | Depth (m) | Description |
|---|---|---|---|
| B | 1 | 0.36-0.81 | Strong Brown (7.5 YR 5/6) clay in upper 1/2 of tube and yellowish red (5 YR 5/6) clay in lower 1/2 of tube; moderate medium subangular blocky structure; firm; few fine roots; thin patchy strong brown (7.5 YR 5/6) clay films on surfaces of peds; 2 percent coarse fragments. |
| B | 2 | 0.38-0.84 | Strong brown (7.5 YR 5/6) clay; common coarse prominent red (2.5 YR 5/8) mottles; few fine distinct yellow sand intrusions; strong medium subangular blocky structure; very few fine mica flakes. |
| B | 3 | 0.23-0.69 | Red (2.5 YR 4/6) loam; weak medium subangular blocky structure; patchy blocky structure; blocky structure; patchy thin clay films on faces of peds; many fine mica flakes; few fine roots and krotovinas. |
| B | 4 | 0.46-0.91 | Strong brown (7.5 YR 5/6) clay, with common medium distinct distinct reddish yellow (7.5 YR 7/8) and brownish yellow (10 YR 6/8) mottles occurring in in quartzite veins; weak coarse subangular blocky structure; firm; some angular quartz fragments from 3 to 5 mm; a few root channels from 1 to 3 mm in diameter. |

Table 5. (Continued)

| Horizon | Site | Depth (m) | Description |
|---|---|---|---|
| C1 | 1 | 3.05-3.51 | Yellow (10 YR 7/6) and pale brown (10 YR 6/3) loam in upper 1/2 of tube and light yellowish brown to brownish yellow (10 YR 6/4-6/6) and strong brown (7.5 YR 4/6) loamy saprolite in lower 1/2 of tube; some quartz grains in matrix of weathered feldspar and other minerals; many mica flakes in lower 1/2 of tube; few medium prominent black mottles in lower 0.35 to 0.45 m of the tube. |
| C1 | 2 | 3.05-3.51 | Reddish yellow (7.5 YR 6/8) silt loam with many small mica flakes in the upper 1/2 of the tube; pale yellow (2.5 Y 7/4) weathered granite-gneiss with approximately 5 percent semi-angular quartz crystals in lower 1/2 of the tube. |
| C1 | 3 | 3.05-3.51 | Light yellowish brown (2.5 Y 6/4) silt loam, with common medium prominent yellowish red (5 YR 5/8) mottles; manganese films have begun to form in a very fine fracture plane in the middle of the sample; many very fine mica flakes; few fine prominent red clay flows in the upper 1/4 of tube. |
| C1 | 4 | 3.05-3.51 | Light red (2.5 YR 6/8) silt loam, with many medium prominent pinkish gray (7.5 YR 6/2) mottles; common 2-5 mm angular quartz fragments. |

Table 5. (Continued)

| Horizon | Site | Depth (m) | Description |
|---|---|---|---|
| C2 | 1 | 6.10-6.55 | Yellowish brown (10 YR 5/6) loam, with few medium distinct black (10 YR 2/1) mottles; common mica flakes, many occurring on somewhat foliated planes approximately parallel to surface; interstratified with lenses of brownish yellow (10 YR 6/6) loam to sandy loam; common fine mica flakes; yellow (10 YR 7/6) loam to sandy loam; common fine mica flakes; white (10 YR 8/2) sandy loam; with few fine distinct dark grayish brown (10 YR 4/2) mottles; 2 to 3 mm quartz grains in matrix of weathered feldspar; yellow to to brownish yellow (10 YR 6/6-7/6) fine sandy loam, with few medium distinct reddish yellow (7.5 YR 6/8) mottles; common fine mica flakes. |
| C2 | 3 | 6.10-6.55 | Gray (10 YR 6/1) silt loam, with few medium distinct yellow (10 YR 8/6) and few fine to medium prominent reddish yellow (5 YR 6/8) mottles; many very fine mica flakes; yellowish red (iron coated) mottles occur along the the fracture planes. |
| C2 | 4 | 6.10-6.55 | Light brownish gray (2.5 Y 6/2) sandy clay loam, with common common medium prominent yellow (10 YR 7/6) mottles; few fine prominent pink (5 YR 8/4) mottles occur in the lower 15 cm of the tube; approximately 40 percent fine quartz crystals and 10 percent manganese nodules; there is a distinct fracture plane between the lower 15 cm and the upper portion of the tube. |

Table 6. Descriptions of thin-wall tube samples: Davidson series

| Horizon | Site | Depth (m) | Descriptions |
|---|---|---|---|
| B | 1 | 0.46-0.91 | Dark red (2.5 YR 3/6) clay, with many fine to medium faint dark reddish brown (2.5 YR 3/4) mottles; mottles; weak coarse subangular blocky structure; peds break down under rotational shear to very fine granular to subangular blocky structure; thin patchy clay films on faces of peds; few fine roots. |
| B | 2 | 0.30-0.76 | Dark red (2.5 YR 3/6) clay; massive; very plastic and non-sticky. |
| B | 3 | 0.10-0.56 | Dark red (10 R 3/6) clay; strong fine subangular blocky structure; very firm; very few fine quartz crystals; thin clay films on some faces of peds. |
| B | 4 | 0.61-1.07 | Dark red (10 R 3/6) clay; strong fine subangular blocky structure; firm; approximately 40 percent coarse fragments with size ranging from 4 to 22 mm; coarse fragments are coated with limonite and manganese; thin clay films on faces of peds and coarse fragments; few very fine roots. |
| C1 | 1 | 3.05-3.51 | Red (10 R 4/6) clay; weak medium to coarse subangular blocky structure; firm to very firm; thin patchy clay films on faces of peds; approximately 1 percent 2 to 10 mm coarse fragments (mostly quartz). |

Table 6. (Continued)

| Horizon | Site | Depth (m) | Descriptions |
|---|---|---|---|
| C1 | 2 | 3.05-3.51 | Light olive brown (2.5 Y 5/5) silty clay, with many fine distinct very dark gray (2.5 Y N3/) mottles along intersecting fracture planes, few coarse prominent reddish yellow to strong brown (7.5 YR 5/8) mottles, and many fine prominent reddish yellow (7.5 YR 6/8) mottles; friable; material breaks preferentially along fracture planes. |
| C1 | 3 | 3.05-3.51 | Strong brown (7.5 YR 5/8) silty clay loam, with few fine prominent red (2.5 YR 4/6) and black (7.5 YR N2/) mottles; weak medium subangular blocky structure; common fine clay flow from above horizon; fracture planes run vertically through the sample; manganese films in fracture planes that are approximately 0.1 to 0.2 mm thick; some very fine roots; root channels are present that have diameters from 1 to 2 mm. |
| C1 | 4 | 3.05-3.51 | Dusky red (10 R 3/2) silty clay loam, with common medium distinct red (10 R 4/6), common fine prominent yellowish red (7.5 YR 6/8), few fine prominent white (7.5 YR 8/0), and few fine distinct black (2.5 YR 2.5/0) mottles; weak coarse subangular blocky structure; very friable; common fine clay films on faces of peds; approximately 10 percent manganese concretions. |

Table 6. (Continued)

| Horizon | Site | Depth (m) | Descriptions |
|---|---|---|---|
| C2 | 1 | 6.40-6.71 | Yellowish red (5 YR 4/6), red (2.5 YR 5/8), and reddish yellow (5 YR 6/8) mottled with reticulate mottling of dark brown and black which form planes of weakness in saprolite (apparent remnant fracture zones in parent rock); silty clay texture when rubbed; friable to slightly firm. |
| C2 | 2 | 4.88-5.34 | Equal volumes of yellow brown (10 YR 5/4) loam to silty loam loam and yellow red (5 YR 5/6) loam randomly mixed in swirled pattern; friable to slightly plastic. |
| C2 | 4 | 6.10-6.55 | Reddish brown (2.5 YR 4/4) silty clay loam, with common medium prominent yellow (10 YR 7/6), common medium prominent reddish yellow (7.5 YR 7/6), and common medium prominent strong brown (7.5 YR 5/6) mottles; weak coarse subangular blocky structure; very friable; manganese films in fracture planes and along slickensides; slickensides occur approximately 10 cm from bottom of the tube. |

Table 7. Descriptions of thin-wall tube samples: Iredell series.

| Horizon | Site | Depth (m) | Descriptions |
|---|---|---|---|
| B | 1 | 0.25-0.61 | Dark yellowish brown (10 YR 4/4) very plastic clay; large prismatic fragments break down into very weak, coarse subangular blocky peds; pressure faces common. |
| B | 2 | 0.20-0.54 | Dark yellowish brown (10 YR 4/4) very plastic clay; shear zones of oriented clay evident but clods do not break preferenially along these planes. |
| B | 3 | 0.40-0.70 | Dark yellowish brown (10 YR 4/4) hard clay; structure is massive but with many fissures up to 7 mm wide exhibiting many pressure faces and slickensides. |
| B | 4 | 0.37-0.61 | Yellowish brown (10 YR 5/4) to dark yellowish brown (10 YR 4/6) very plastic clay; massive fragments commonly break apart along slickensides. |
| B | 5 | 0.36-0.81 | Dark brown (10 YR 4/3) very plastic clay with massive strucstructure. |
| C | 1 | 2.44-2.90 | Yellowish brown (10 YR 5/4) slightly firm and brittle material which crushes to a sandy loam, with common medium distinct brown, strong brown, and black mottles; common randomly oriented veins of dark yellowish brown material with higher clay content and/or iron and manganese coatings. Material fractures preferentially along these planes. |

Table 7. (Continued)

| Horizon | Site | Depth (m) | Descriptions |
|---|---|---|---|
| C | 2 | 0.91-1.22 | Yellowish brown, dark yellowish brown and very dark brown (10 YR 5/6, 3/4, 2/2) mottled material which crushes to olive (5 Y 5/3) sandy loam to loam. Soil breaks readily along natural fracture planes in hard to very hard angular fragments 1-5 mm in size. |
| C | 4 | 1.22-1.68 | Dark to very dark grayish brown (2.5 Y 4/2, 3/2), very pale brown (10 YR 7/3), and dark brown (10 YR 3/3) mottled material which crushes readily to a sandy loam to loamy sand; saprolite is firm to friable and sampling appears to have induced some shattering; many 1-2 mm thick dark brown veins running mostly vertically through sample which part to show smooth striated |

Table 8. Descriptions of thin-wall tube samples; Madison Series.

| Horizon | Site | Depth (m) | Description |
|---|---|---|---|
| B | 1 | 0.25-0.71 | Red (2.5 YR 4/6) silty clay; moderate very fine to medium subangular blocky structure; firm; many fine mica flakes; continuous moderate clay films; few fine roots. |
| B | 2 | 0.30-0.76 | Dark red (2.5 YR 3/6) clay; moderate medium subangular blocky structure; firm; continuous clay films; common fine roots at ped faces; description of upper 15 cm of tube. Dark red (2.5 YR 3/6) clay; weak medium to coarse subangular blocky structure; firm to friable; thin continuous clay films; common very fine mica flakes; few roots; description of lower 31 cm of tube. |
| B | 3 | 0.30-0.76 | Red (2.5 YR 4/6) clay; moderate medium subangular blocky structure; firm to friable; common fine roots at ped faces; thin clay films on faces of peds; common very fine mica flakes; description of upper 15 cm of tube. Red (2.5 YR 4/6) clay; weak medium subangular blocky structure; firm; common fine mica flakes; few fine roots; thin clay films on faces of peds; description of lower 31 cm of tube. |
| B | 4 | 0.30-0.76 | Red (2.5 YR 5/6) and strong brown (7.5 YR 5/6) mottled clay; weak weak coarse subangular blocky structure; firm; few roots at ped surfaces; few mica flakes; description of upper 22 cm of tube. Red (2.5 YR 5/6) clay; weak coarse angular blocky structure; firm; common fine mica flakes; description of lower 24 cm of tube. |

Table 8. (Continued)

| Horizon | Site | Depth (m) | Description |
|---|---|---|---|
| C1 | 1 | 3.05-3.51 | Dark reddish brown (2.5 YR 3/4) fine sandy loam to loam, with common medium to coarse distinct to prominent reddish yellow mottles; few coarse lenses or balls of dark red clay; many fine mica flakes. |
| C1 | 2 | 3.05-3.51 | Yellowish brown (10 YR 5/6-5/8) loam to sandy loam saprolite, with many medium prominent white, very pale brown, reddish yellow, and very dark gray mottles; friable; two veins approximately 4 mm thick of very dark gray mineral at approximately 15 and 27 cm depth running diagonally at 30 degree angle from horizontal; many fine mica flakes. |
| C1 | 3 | 3.05-3.51 | Yellowish brown (10 YR 5/4-5/6) micaceous sandy loam, with common medium prominent black mottles; massive breaking to single grain; very friable. |
| C1 | 4 | 3.05-3.51 | Mottled black, yellow brown, red, reddish yellow mica schist saprolite; firm to friable; many muscovite flakes (up to 10 mm in diameter); bedding is approximately 45 degrees from vertical breaks along bedding where where manganese films commonly |

# 4. RESULTS AND DISCUSSION

The laboratory results are summarized by soil series and horizon in Tables 9-32. Means and standard deviations of numerical entries are given for all horizons and taxa. For the Appling, Davidson and Madison series, the horizons designated as C1 represent the samples taken at the 3 m depth and those designated C2 are from 6 m. No C2 samples were obtained from the second Appling and third Davidson sites due to the occurence of rock at depths shallower than 6 m. Because of the very shallow depths to rock at the Iredell sites, C horizon samples could be obtained only at sites 1, 2 and 4 and these were from depths shallower than 3 m. Missing data due to insufficient quantities of certain samples are indicated by periods in the tables.

## 4.1 PARTICLE SIZE DISTRIBUTION AND PARTICLE DENSITY

Particle size distributions and particle densities of Appling, Davidson, Iredell and Madison samples are given in Tables 9-12, respectively. The size fractions reported are those of the USDA system (Soil Survey Staff, 1975):

| | |
|---|---|
| Gravel | >2.0 mm |
| Very coarse sand | 2.0-1.00 mm |
| Coarse sand | 1.0-0.5 mm |
| Medium sand | 0.5-0.25 mm |
| Fine sand | 0.25-0.10 mm |
| Very fine sand | 0.10-0.05 mm |
| Silt | 0.05-0.002 mm |
| Clay | <0.002 mm |

Gravel contents are reported as a percentage of the total soil mass, while the other fractions are expressed as a percentage of the <2 mm soil mass.

All three soils have high clay contents in their B horizons with fairly narrow coefficients of variation (ie., standard deviation/mean) between 7 and 13%. The coefficients of variation for the size fractions generally are considerably greater in the C horizons. The greater variability in the lower horizons reflects the complex geology of the Piedmont region. Intrusive igneous bodies of widely varying dimensions and complex fault patterns result in highly variable saprolites which may exhibit very different weathering rates. The large variability in the clay contents of the Davidson C1 horizons is a striking example of the differences which may occur in depth of weathering.

Table 9. Particle size distribution and particle density: Appling series.

|  |  |  | Sand |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| Hori-zon | Site | Gravel % | V.Cs. % | Cs. % | Med. % | Fine % | V.Fn. % | Silt % | Clay % | Particle Density $g/cm^3$ |
| B | 1 | 0.0 | 2.0 | 2.1 | 5.2 | 7.6 | 4.5 | 17.4 | 61.2 | 2.69 |
| B | 2 | 0.4 | 4.4 | 6.0 | 6.2 | 8.0 | 6.5 | 16.7 | 52.1 | 2.77 |
| B | 3 | 0.0 | 7.5 | 10.0 | 7.5 | 10.2 | 2.8 | 16.2 | 45.8 | 2.70 |
| B | 4 | 7.9 | 8.7 | 6.5 | 4.3 | 3.3 | 3.9 | 17.4 | 56.0 | 2.65 |
| Mean |  | 2.1 | 4.4 | 6.1 | 5.8 | 7.3 | 4.4 | 16.9 | 53.8 | 2.70 |
| Std. Dev. |  | 3.9 | 3.0 | 3.2 | 1.4 | 2.9 | 1.6 | 0.6 | 6.5 | 0.05 |
| C1 | 1 | 0.7 | 4.3 | 9.6 | 13.6 | 22.2 | 16.4 | 24.3 | 9.6 | 2.68 |
| C1 | 2 | . | . | . | . | . | . | . | . | 2.70 |
| C1 | 3 | 0.5 | 5.1 | 10.1 | 23.1 | 27.7 | 10.4 | 14.5 | 9.1 | 2.72 |
| C1 | 4 | 18.2 | 15.0 | 14.1 | 10.6 | 10.4 | 12.5 | 26.7 | 10.7 | 2.70 |
| Mean |  | 6.5 | 13.1 | 11.3 | 15.8 | 20.1 | 13.1 | 21.8 | 9.8 | 2.70 |
| Std. Dev. |  | 10.2 | 6.0 | 2.5 | 6.5 | 8.8 | 3.0 | 6.5 | 0.8 | 0.02 |
| C2 | 1 | 0.0 | 4.1 | 10.4 | 16.6 | 20.9 | 15.5 | 24.9 | 7.6 | 2.70 |
| C2 | 3 | 0.0 | 5.1 | 2.9 | 4.8 | 5.4 | 7.7 | 69.0 | 5.3 | 2.74 |
| C2 | 4 | 0.0 | 6.1 | 3.2 | 2.4 | 3.0 | 5.5 | 70.2 | 9.5 | 2.64 |
| Mean |  | 0.0 | 9.6 | 5.5 | 7.9 | 9.8 | 9.6 | 54.7 | 7.5 | 2.69 |
| Std. Dev. |  | 0.0 | 1.0 | 4.2 | 7.6 | 9.7 | 5.3 | 25.8 | 2.1 | 0.05 |

Table 10. Particle size distribution and particle density: Davidson series.

| | | | Sand | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Horizon | Site | Gravel % | V.Cs. % | Cs. % | Med. % | Fine % | V.Fn. % | Silt % | Clay % | Particle Density g/cm$^3$ |
| B | 1 | 0.7 | 1.0 | 1.7 | 1.7 | 1.9 | 1.9 | 29.4 | 62.2 | 2.84 |
| B | 2 | 1.0 | 1.8 | 1.9 | 1.1 | 1.6 | 0.4 | 37.2 | 56.0 | 2.93 |
| B | 3 | 0.0 | 0.3 | 0.4 | 0.7 | 1.3 | 1.7 | 20.9 | 74.6 | 2.96 |
| B | 4 | 8.0 | 0.9 | 2.1 | 1.9 | 1.9 | 1.5 | 24.0 | 67.7 | 2.93 |
| Mean | | 2.4 | 3.8 | 2.2 | 2.3 | 3.5 | 3.8 | 24.7 | 66.0 | 2.91 |
| Std. Dev. | | 3.7 | 0.6 | 0.6 | 1.6 | 3.5 | 5.1 | 12.2 | 9.5 | 0.05 |
| C1 | 1 | 0.9 | 0.9 | 1.3 | 1.0 | 1.5 | 1.2 | 20.1 | 73.9 | 2.92 |
| C1 | 2 | 0.3 | 1.9 | 5.1 | 3.4 | 3.5 | 0.5 | 67.9 | 17.7 | 2.92 |
| C1 | 3 | 0.0 | 0.6 | 1.1 | 2.2 | 8.5 | 12.0 | 64.5 | 11.1 | 3.00 |
| C1 | 4 | 0.0 | 1.4 | 1.0 | 0.7 | 2.0 | 6.1 | 52.8 | 35.9 | 3.09 |
| Mean | | 0.3 | 4.9 | 2.1 | 1.8 | 3.9 | 4.9 | 51.3 | 34.6 | 2.98 |
| Std. Dev. | | 0.4 | 0.6 | 2.0 | 1.2 | 3.2 | 5.3 | 21.8 | 28.2 | 0.08 |
| C2 | 2 | 2.8 | 2.2 | 3.6 | 4.0 | 7.4 | 3.9 | 51.3 | 27.7 | 2.91 |
| C2 | 4 | 0.0 | 1.3 | 1.5 | 1.9 | 5.4 | 15.8 | 51.4 | 22.8 | 3.05 |
| Mean | | 0.9 | 10.9 | 2.3 | 2.7 | 5.8 | 10.9 | 55.5 | 21.5 | 3.01 |
| Std. Dev. | | 1.6 | 0.9 | 1.1 | 1.1 | 1.5 | 6.2 | 7.2 | 6.9 | 0.09 |

Table 11. Particle size distribution and particle density: Iredell series.

| Hori-zon | Site | Gravel | Sand |  |  |  |  | Silt | Clay | Particle Density |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | V.Cs. | Cs. | Med. | Fine | V.Fn. |  |  |  |
|  |  | % | % | % | % | % | % | % | % | g/cm$^3$ |
| B | 1 | 0.0 | 0.3 | 1.7 | 4.5 | 8.2 | 9.0 | 27.3 | 49.0 | 2.74 |
| B | 2 | 0.0 | 0.5 | 1.1 | 1.0 | 2.6 | 4.2 | 25.5 | 65.1 | 2.75 |
| B | 3 | 0.0 | 1.0 | 3.1 | 3.9 | 6.4 | 4.8 | 16.6 | 64.3 | 2.77 |
| B | 4 | 0.0 | . | . | . | . | . | 17.1 | 67.0 | 2.77 |
| B | 5 | 0.0 | 1.2 | 1.9 | 2.3 | 4.8 | 3.8 | 15.5 | 70.5 | 2.77 |
| Mean |  | 0.0 | 5.4 | 1.9 | 2.9 | 5.5 | 5.4 | 20.4 | 63.2 | 2.76 |
| Std. Dev. |  | 0.0 | 0.4 | 0.8 | 1.6 | 2.4 | 2.4 | 5.5 | 8.3 | 0.01 |
| C | 1 | 0.0 | 4.0 | 20.8 | 14.6 | 16.1 | 16.4 | 19.7 | 8.4 | 2.90 |
| C | 2 | 5.0 | 17.8 | 10.9 | 5.6 | 7.2 | 12.6 | 28.7 | 14.9 | 2.78 |
| C | 4 | 1.2 | 9.0 | 28.3 | 16.2 | 14.4 | 8.8 | 14.9 | 8.3 | 2.98 |
| Mean |  | 2.1 | 12.6 | 20.0 | 12.1 | 12.6 | 12.6 | 21.1 | 10.5 | 2.89 |
| Std. Dev. |  | 2.6 | 7.0 | 8.7 | 5.7 | 4.7 | 3.8 | 7.0 | 3.8 | 0.10 |

Table 12. Particle size distribution and particle density: Madison series.

| | | | Sand | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hori-zon | Site | Gravel % | V Cs % | Cs % | Med % | Fine % | V Fn % | Silt % | Clay % | Particle Density g/cm$^3$ |
| B | 1 | 0.0 | 0.7 | 2.3 | 5.4 | 9.0 | 3.9 | 18.7 | 60.0 | 2.72 |
| B | 2 | 0.0 | 0.6 | 1.0 | 3.7 | 12.8 | 8.3 | 11.0 | 62.6 | 2.82 |
| B | 3 | 0.0 | 0.6 | 2.8 | 8.4 | 12.6 | 6.8 | 12.8 | 56.1 | 2.78 |
| B | 4 | 18.4 | 5.1 | 5.0 | 6.5 | 8.5 | 5.5 | 15.5 | 53.9 | 2.73 |
| Mean | | 4.6 | 6.1 | 2.8 | 6.0 | 10.7 | 6.1 | 14.5 | 58.1 | 2.76 |
| Std. Dev. | | 9.2 | 2.2 | 1.7 | 2.0 | 2.3 | 1.9 | 3.4 | 3.9 | 0.05 |
| C1 | 1 | 0.0 | 4.1 | 19.4 | 24.1 | 24.9 | 10.4 | 10.2 | 6.9 | 2.68 |
| C1 | 2 | 0.4 | 1.4 | 4.8 | 11.0 | 28.4 | 21.7 | 25.2 | 7.5 | 2.78 |
| C1 | 3 | 0.7 | 3.0 | 14.4 | 29.0 | 32.6 | 10.7 | 7.7 | 2.5 | 2.76 |
| C1 | 4 | 3.4 | 8.4 | 19.2 | 24.5 | 22.6 | 11.0 | 11.4 | 2.9 | 2.68 |
| Mean | | 1.1 | 13.4 | 14.4 | 22.1 | 27.1 | 13.4 | 13.6 | 4.9 | 2.72 |
| Std. Dev. | | 1.5 | 3.0 | 6.8 | 7.8 | 4.4 | 5.5 | 7.9 | 2.6 | 0.05 |
| C2 | 1 | 0.0 | 0.7 | 2.3 | 5.1 | 8.4 | 3.4 | 77.0 | 3.1 | 2.69 |
| C2 | 2 | 0.3 | 1.3 | 3.7 | 9.1 | 25.2 | 24.2 | 30.2 | 6.2 | 2.79 |
| C2 | 3 | 0.7 | 3.2 | 11.2 | 24.9 | 32.3 | 14.1 | 10.4 | 3.7 | 2.81 |
| C2 | 4 | 7.8 | 9.9 | 16.0 | 19.9 | 17.5 | 11.7 | 22.6 | 2.4 | 2.76 |
| Mean | | 2.2 | 13.3 | 8.3 | 14.7 | 20.8 | 13.3 | 35.0 | 3.8 | 2.76 |
| Std. Dev. | | 3.7 | 4.2 | 6.5 | 9.2 | 10.3 | 8.6 | 29.1 | 1.7 | 0.05 |

## 4.2 CLAY MINERALOGY

The results of the mineralogical analyses of the clay fractions are presented in Tables 13-16. Abbreviations used in the tables are as follows: KT = kaolinite, CV = chloritized vermiculite, VR = vermiculite, MT = montmorillonite, MI = mica, QZ = quartz, GB = gibbsite, VR/MI = interstratified vermiculite and mica, KT/MT = interstratified kaolinite and expansive 2:1, CR = crandallite, FD = feldspar and Tr = trace quantities present.

The mineralogy of the clay fraction largely governs the chemical properties of the soil and greatly influences the physical behavior. Adsorption of water and organic and inorganic ions and molecules is largely governed by the surface characteristics of the clay fraction. These processes in turn affect the attenuation of potential pollutants to groundwater and surface water and the retention and movement of water in the soil. Clay-water interactions markedly affect the stress-strain behavior of soils.

Table 13. Mineralogy of the clay fraction as percentages of total clay content after free iron removal: Appling series.

| Horizon | Site | KT | CV | VR | MT | MI | QZ | GB | Other |
|---|---|---|---|---|---|---|---|---|---|
| B | 1 | 42 | 40 | 0 | 0 | 9 | 4 | 5 | |
| B | 2 | 62 | 21 | 5 | 0 | 5 | 5 | 2 | |
| B | 3 | 73 | 20 | 0 | 0 | 5 | Tr | 2 | FD (Tr) |
| B | 4 | 72 | 15 | 0 | 0 | 5 | 5 | 3 | FD (Tr) |
| Mean | | 62 | 24 | 1 | 0 | 6 | 4 | 3 | |
| Std. Dev. | | 14 | 11 | 2 | 0 | 2 | 2 | 1 | |
| C1 | 1 | 50 | Tr | 0 | 5 | 30 | 15 | 0 | |
| C1 | 2 | . | . | . | . | . | . | . | |
| C1 | 3 | 73 | 17 | 0 | 0 | 5 | 5 | Tr | |
| C1 | 4 | 81 | 12 | 0 | 0 | Tr | 5 | 2 | FD (Tr) |
| Mean | | 51 | 7 | 0 | 1 | 9 | 6 | 1 | |
| Std. Dev. | | 36 | 9 | 0 | 2 | 14 | 6 | 1 | |
| C2 | 1 | 69 | 0 | 0 | 0 | 31 | 0 | 0 | Mica is Illite |
| C2 | 3 | 72 | Tr | 0 | 0 | 18 | 10 | 0 | |
| C2 | 4 | 78 | 17 | 0 | 0 | 0 | 5 | Tr | |
| Mean | | 73 | 7 | 0 | 0 | 16 | 5 | 0 | |
| Std. Dev. | | 5 | 10 | 0 | 0 | 16 | 5 | 0 | |

Table 14. Mineralogy of the clay fraction as percentages of total clay content after free iron removal: Davidson series.

| Horizon | Site | KT | CV | VR | MT | MI | QZ | GB | Other |
|---|---|---|---|---|---|---|---|---|---|
| B | 1 | 55 | 32 | 0 | 0 | 5 | 5 | 3 | FD (Tr) |
| B | 2 | 66 | 24 | 0 | 0 | 5 | 5 | 0 | FD (Tr) |
| B | 3 | 70 | 18 | 0 | 0 | 5 | 5 | 2 | FD (Tr) |
| B | 4 | 67 | 27 | 0 | 0 | Tr | 5 | 1 | |
| Mean | | 65 | 25 | 0 | 0 | 4 | 5 | 2 | |
| Std. Dev. | | 7 | 6 | 0 | 0 | 2 | 0 | 1 | |
| C1 | 1 | 68 | 27 | Tr | 0 | 5 | Tr | 0 | FD (Tr) |
| C1 | 2 | 62 | 33 | 0 | 0 | 0 | 5 | 0 | |
| C1 | 3 | 63 | 32 | 0 | 0 | 0 | 5 | Tr | FD (Tr) |
| C1 | 4 | 70 | 25 | 0 | 0 | Tr | 5 | Tr | |
| Mean | | 66 | 29 | Tr | 0 | 1 | 4 | Tr | |
| Std. Dev. | | 4 | 4 | - | 0 | 2 | 2 | - | |
| C2 | 1 | 65 | 34 | 0 | 0 | Tr | Tr | 1 | |
| C2 | 2 | 58 | 37 | 0 | 0 | 0 | 5 | Tr | |
| C2 | 4 | 66 | 29 | 0 | 0 | 0 | 5 | 0 | |
| Mean | | 63 | 33 | 0 | 0 | Tr | 3 | 0 | |
| Std. Dev. | | 4 | 4 | 0 | 0 | - | 3 | 1 | |

Table 15. Mineralogy of the clay fraction as percentages of total clay content after free iron removal: Iredell series.

| Horizon | Site | KT | CV | VR | MT | MI | QZ | GB | Other |
|---|---|---|---|---|---|---|---|---|---|
| B | 1 | 25 | 5 | 0 | 55 | Tr | 5 | 0 | KT/MT (10) |
| B | 2 | . | . | . | . | . | . | . | |
| B | 3 | 23 | 0 | Tr | 62 | 0 | 5 | 0 | KT/MT (10) |
| B | 4 | 17 | 0 | 5 | 58 | 0 | 5 | 0 | KT/MT (15) |
| B | 5 | 20 | 0 | 5 | 53 | 0 | 5 | 0 | KT/MT (17) |
| Mean | | 21 | 1 | 3 | 57 | Tr | 5 | 0 | |
| Std. Dev. | | 3 | 2 | 3 | 4 | - | 0 | 0 | |
| C | 1 | 0 | 0 | 0 | 70 | 0 | Tr | 0 | KT/MT (30) |
| C | 2 | 14 | 0 | 0 | 66 | 0 | 10 | 0 | KT/MT (10) |
| C | 4 | 14 | 0 | Tr | 71 | 0 | 5 | 0 | KT/MT (10) |
| Mean | | 9 | 0 | 0 | 69 | 0 | 5 | 0 | |
| Std. Dev. | | 8 | 0 | 0 | 3 | 0 | 5 | 0 | |

Table 16. Mineralogy of the clay fraction as percentages of total clay content after free iron removal: Madison series.

| Horizon | Site | KT | CV | VR | MT | MI | QZ | GB | Other |
|---|---|---|---|---|---|---|---|---|---|
| B | 1 | 49 | 41 | 0 | Tr | 5 | 5 | 0 | |
| B | 2 | 63 | 20 | 15 | 0 | Tr | Tr | 2 | |
| B | 3 | 75 | 10 | 7 | 0 | 5 | Tr | 0 | |
| B | 4 | 58 | 12 | 12 | 0 | 10 | 0 | 8 | FD (Tr) |
| Mean | | 61 | 21 | 9 | Tr | 5 | 1 | 3 | |
| Std. Dev. | | 11 | 14 | 7 | - | 4 | 2 | 4 | |
| C1 | 1 | 50 | Tr | 20 | 0 | 10 | 5 | 0 | VR/MI (15) |
| C1 | 2 | 71 | 0 | 0 | 0 | 10 | 5 | 0 | CR (15) |
| C1 | 3 | 47 | 0 | 0 | 0 | 24 | 0 | 0 | VR/MI (27), CR(2) |
| C1 | 4 | 68 | Tr | 5 | 0 | 22 | 5 | Tr | |
| Mean | | 59 | Tr | 6 | 0 | 17 | 4 | Tr | |
| Std. Dev. | | 12 | - | 9 | 0 | 8 | 2 | - | |
| C2 | 1 | 56 | Tr | 15 | Tr | 14 | 5 | 0 | VR/MI (10) |
| C2 | 2 | 73 | 0 | 0 | 0 | 27 | 0 | 0 | CR (Tr) |
| C2 | 3 | 57 | 5 | 0 | 0 | 25 | 0 | 0 | VR/MI (12), CR (1) |
| C2 | 4 | 76 | Tr | 0 | 0 | 19 | 5 | 0 | |
| Mean | | 66 | 1 | 4 | Tr | 21 | 3 | 0 | |
| Std. Dev. | | 10 | 2 | 7 | - | 6 | 3 | 0 | |

## 4.3 SOIL CLASSIFICATION BY PARTICLE SIZE DISTRIBUTION AND ATTERBERG LIMITS

Atterberg limits, textural classification and engineering classifications of the soils are given in Tables 17-20. When all samples of a particular horizon were nonplastic(NP), as determined by the plastic limit test, liquid limits (LL) were not measured. The plasticity indices (PI) of such samples were regarded to be zero. The liquid limits and plasticity indices of the B horizons exhibit coefficients of variation between 4 and 39%. Appling, Iredell and Madison C horizon samples were all non-plastic while the Atterberg limits of Davidson C horizons were quite variable.

USDA textural classifications are based solely on particle size distribution (Soil Survey Staff, 1975). Abbreviations for the classes which occur in this study are:

sand (S)
loamy sand (LS)
sandy loam (SL)
loam (L)
silt loam (SIL)
silty clay loam (SICL)
clay loam (CL)
clay (C)

For engineering purposes soils are commonly classified by one of two systems: the Unified classification system or the American Association of State Highway and Transportation Officials (AASHTO) system. Both systems are based upon particle size distribution and Atterberg limits. The Unified system (ASTM, 1969) divides soils into one of three divisions: coarse-grained, fine grained and organic. Coarse-grained soils are divided into gravelly soils (G) and sandy soils (S) which are further subdivided depending on details of the particle size distribution and soil consistence. Fine-grained soils are classed as silty (M) or clayey (C) groups which are again further subdivided based upon particle size distribution and consistence. Silty and clayey classes are differentiated by differences in consistence rather than by actual particle size distribution. The Unified classifications of the soils in this study fall into one of four categories described as follows:

SM - Silty sands

ML - Fine textured soil with low liquid limit and low plasticity

MH - Fine textured soil with high liquid limit and moderate plasticity

CH - Fine textured soil with high liquid limit and high plasticity

The AASHTO classification system (Krebs and Walker, 1971) groups soils according to their suitability as a highway subgrade. There are seven major groups ranging from A-1, with the highest subgrade bearing capacity, to A-7 with the lowest. In some cases the major classes are subdivided into subclasses designated by a numeric suffix. The group index is a subsidiary classification frequently appended in parentheses to the AASHTO class. Group index values are computed from particle size and consistence data. They can range in value from 0 to 50 or more with higher values representing increasingly poorer subgrade material.

Table 17. Atterberg limits, textural classification and engineering classification: Appling series.

| Horizon | Site | Liquid Limit % | Plasticity Index % | USDA Texture | Unified Class | AASHTO Class | Group Index |
|---|---|---|---|---|---|---|---|
| B | 1 | 77.9 | 29.7 | C | MH | A-7-5 | 31 |
| B | 2 | 74.7 | 36.9 | C | MH | A-7-5 | 32 |
| B | 3 | 73.5 | 32.7 | C | MH | A-7-5 | 21 |
| B | 4 | 69.9 | 36.8 | C | CH | A-7-5 | 30 |
| Mean | | 74.0 | 34.0 | | | | 29 |
| Std. Dev. | | 3.3 | 3.5 | | | | 5 |
| C1 | 1 | NP | 0.0 | SL | SM | A-4 | 0 |
| C1 | 2 | . | . | | | | . |
| C1 | 3 | NP | 0.0 | SL | SM | A-2-4 | 0 |
| C1 | 4 | NP | 0.0 | SL | ML | A-4 | 0 |
| Mean | | NP | 0.0 | | | | 0 |
| Std. Dev. | | - | 0.0 | | | | 0 |
| C2 | 1 | NP | 0.0 | SL | SM | A-4 | 0 |
| C2 | 3 | NP | 0.0 | SIL | ML | A-4 | 0 |
| C2 | 4 | NP | 0.0 | SIL | ML | A-4 | 0 |
| Mean | | NP | 0.0 | | | | 0 |
| Std. Dev. | | - | 0.0 | | | | 0 |

Table 18. Atterberg limits, textural classification and engineering classification: Davidson series.

| Horizon | Site | Liquid Limit % | Plasticity Index % | USDA Texture | Unified Class | AASHTO Class | Group Index |
|---|---|---|---|---|---|---|---|
| B | 1 | 59.2 | 28.8 | C | CH-MH | A-7-5 | 32 |
| B | 2 | 71.2 | 30.9 | C | MH | A-7-5 | 37 |
| B | 3 | 69.1 | 22.2 | C | MH | A-7-5 | 22 |
| B | 4 | 82.4 | 44.8 | C | MH | A-7-5 | 45 |
| Mean |  | 70.5 | 31.7 |  |  |  | 34 |
| Std. Dev. |  | 9.5 | 9.5 |  |  |  | 10 |
| C1 | 1 | 70.9 | 7.3 | C | MH | A-5 | 18 |
| C1 | 2 | 46.1 | 0.0 | SIL | ML | A-4 | 0 |
| C1 | 3 | 43.3 | 0.0 | SIL | ML | A-4 | 0 |
| C1 | 4 | 60.3 | 23.2 | SICL | MH | A-7-5 | 28 |
| Mean |  | 55.2 | 7.6 |  |  |  | 12 |
| Std. Dev. |  | 12.9 | 10.9 |  |  |  | 14 |
| C2 | 1 | 72.7 | 16.9 | SIL | MH | A-7-5 | 23 |
| C2 | 2 | 49.7 | 3.8 | CL | MH-ML | A-5 | 21 |
| C2 | 4 | 55.1 | 14.3 | SIL | MH | A-7-5 | 16 |
| Mean |  | 59.2 | 11.7 |  |  |  | 20 |
| Std. Dev. |  | 12.0 | 6.9 |  |  |  | 4 |

Table 19. Atterberg limits, textural classification and engineering classification: Iredell series.

| Horizon | Site | Liquid Limit % | Plasticity Index % | USDA Texture | Unified Class | AASHTO Class | Group Index |
|---|---|---|---|---|---|---|---|
| B | 1 | 66.2 | 36.8 | C | CH | A-7-6 | 33 |
| B | 2 | 89.3 | 58.9 | C | CH | A-7-5 | 54 |
| B | 3 | 77.4 | 43.4 | C | CH | A-7-5 | 41 |
| B | 4 | 98.2 | 60.6 | C | CH | A-7-5 | 61 |
| B | 5 | 91.5 | 51.0 | C | CH | A-7-5 | 54 |
| Mean | | 84.5 | 50.1 | | | | 49 |
| Std. Dev. | | 12.7 | 10.1 | | | | 11 |
| C | 1 | NP | 0.0 | SL | SM | A-4 | 0 |
| C | 2 | NP | 0.0 | SL-L | SM | A-4 | 0 |
| C | 4 | NP | 0.0 | SL-LS | SM | A-2-4 | 0 |
| Mean | | NP | 0.0 | | | | 0 |
| Std. Dev. | | - | 0.0 | | | | 0 |

Table 20. Atterberg limits, textural classification and engineering classification: Madison series.

| Horizon | Site | Liquid Limit % | Plasticity Index % | USDA Texture | Unified Class | AASHTO Class | Group Index |
|---|---|---|---|---|---|---|---|
| B | 1 | 69.5 | 22.9 | C | MH | A-5 | 12 |
| B | 2 | 76.0 | 22.5 | C | CH | A-7-5 | 24 |
| B | 3 | 56.5 | 10.3 | C | MH | A-5 | 11 |
| B | 4 | 77.3 | 30.3 | C | MH | A-7-5 | 18 |
| Mean | | 69.8 | 21.5 | | | | 14 |
| Std. Dev. | | 9.5 | 8.3 | | | | 10 |
| C1 | 1 | NP | 0.0 | LS | SM | A-2-4 | 0 |
| C1 | 2 | NP | 0.0 | SL | SM | A-4 | 0 |
| C1 | 3 | NP | 0.0 | S | SM | A-2-4 | 0 |
| C1 | 4 | NP | 0.0 | LS | SM | A-2-4 | 0 |
| Mean | | NP | 0.0 | | | | 0 |
| Std. Dev. | | - | 0.0 | | | | 0 |
| C2 | 1 | NP | 0.0 | SIL | ML | A-4 | 0 |
| C2 | 2 | NP | 0.0 | SL | SM | A-4 | 0 |
| C2 | 3 | NP | 0.0 | LS | SM | A-2-4 | 0 |
| C2 | 4 | NP | 0.0 | LS | SM | A-2-5 | 0 |
| Mean | | NP | 0.0 | | | | 0 |
| Std. Dev. | | - | 0.0 | | | | 0 |

## 4.4 COMPACTION CHARACTERISTICS AND TESTS ON COMPACTED SOIL

Maximum compacted densities, optimum compaction moisture contents, California Bearing Ratio (CBR) and FHA Swell Index values are presented in Tables 21-24. Maximum densities are generally higher and optimum moisture contents are lower in C horizons than in B horizons, reflecting the coarser textures of the deeper materials. The average coefficient of variation for all the B horizons was 4% for maximum density and 11% for optimum moisture contents. For the C horizons, the corresponding values were 7 and 16%.

California bearing ratios are a measure of the bearing capacity of saturated compacted soil under conditions approximating those of a highway subgrade. The values are expressed as a percentage of the bearing strength of an ideal highway base material. Good highway base materials have CBR values of 50 or more, while subbase materials may be somewhat less. Soils with CBR values greater than 20 are good subgrade materials, while soils between 10-20 are generally satisfactory. The CBR values of soils in this study ranged from a low of 2 in the B horizon of the fourth Iredell site to a high of 36% in the C horizon from the same site. The coefficients of variation of the CBR values within a given horizon and series were rather high, averaging 45% in the B horizons and 33% in the C horizons. The higher coefficients of variation in the B horizons reflect generally lower CBR values in the more clayey B horizons. Standard deviations of CBR values in B and C horizons were very similar, averaging 4.5 and 5.8 over all series.

Swell index is a measure of the pressure exerted by a compacted soil sample submerged in distilled water. The values have been statistically correlated with the magnitude of soil shrinking and swelling associated with moisture content changes. The potential for damage to shallow foundations is generally interpreted as follows:

| Potential for damage | Swell index |
|---|---|
| Non-critical | 0-1700 |
| Marginal | 1700-3200 |
| Critical | 3200-4700 |
| Very critical | >4700 |

Appling B horizons range from non-critical to critical values. Appling C1 samples are non-critical to marginal and the C2 samples are all non-critical. In Davidson, values range from non-critical to marginal in the B horizons while all C horizons are marginal. Iredell B horizons are uniformly very critical, while Iredell C horizons are non-critical to marginal. Madison samples exhibit non-critical to critical values in the B horizons, while the C horizons are all non-critical. Coefficients of variation range from 5% to over 100%, averaging about 58% for all series and depths.

Table 21. Compaction characteristics and tests on compacted soil: Appling series.

| Horizon | Site | Maximum Density g/cm$^3$ | Optimum Moisture % | CBR % | Swell Index psf |
|---|---|---|---|---|---|
| B | 1 | 1.36 | 32.0 | 18.5 | 4127 |
| B | 2 | 1.38 | 33.0 | 13.0 | 3604 |
| B | 3 | 1.44 | 29.5 | 19.0 | 1085 |
| B | 4 | 1.42 | 31.8 | 5.4 | 2649 |
| Mean | | 1.40 | 31.6 | 14.0 | 2866 |
| Std. Dev. | | 0.04 | 1.5 | 5.5 | 1336 |
| C1 | 1 | 1.52 | 21.5 | 18.0 | 1899 |
| C1 | 2 | . | . | . | . |
| C1 | 3 | 1.60 | 21.5 | 11.0 | 1214 |
| C1 | 4 | 1.53 | 25.3 | 12.7 | 860 |
| Mean | | 1.55 | 22.8 | 13.9 | 1324 |
| Std. Dev. | | 0.04 | 2.2 | 3.7 | 528 |
| C2 | 1 | 1.57 | 20.5 | 12.7 | 567 |
| C2 | 3 | 1.67 | 18.6 | 11.0 | 205 |
| C2 | 4 | 1.75 | 18.5 | 8.0 | 573 |
| Mean | | 1.66 | 19.2 | 10.6 | 448 |
| Std. Dev. | | 0.09 | 1.1 | 2.4 | 211 |

Table 22. Compaction characteristics and tests on compacted soil: Davidson series.

| Horizon | Site | Maximum Density g/cm$^3$ | Optimum Moisture % | CBR % | Swell Index psf |
|---|---|---|---|---|---|
| B | 1 | 1.50 | 28.3 | 17.7 | 2664 |
| B | 2 | 1.44 | 33.3 | 10.5 | 3168 |
| B | 3 | 1.37 | 38.0 | . | 410 |
| B | 4 | 1.39 | 36.0 | 6.8 | 410 |
| Mean | | 1.42 | 33.9 | 11.7 | 1663 |
| Std. Dev. | | 0.06 | 4.2 | 5.4 | 1461 |
| C1 | 1 | 1.41 | 33.6 | 8.3 | 2863 |
| C1 | 2 | 1.28 | 39.4 | 17.8 | . |
| C1 | 3 | 1.36 | 33.5 | 14.2 | 1649 |
| C1 | 4 | 1.52 | 30.5 | . | 1762 |
| Mean | | 1.39 | 34.2 | 13.4 | 2091 |
| Std. Dev. | | 0.10 | 3.7 | 4.8 | 671 |
| C2 | 1 | 1.26 | 41.5 | 19.7 | . |
| C2 | 2 | 1.56 | 27.1 | 9.7 | 2146 |
| C2 | 4 | 1.42 | 36.3 | . | 2000 |
| Mean | | 1.41 | 35.0 | 14.7 | 2073 |
| Std. Dev. | | 0.15 | 7.3 | 7.1 | 103 |

Table 23. Compaction characteristics and tests on compacted soil: Iredell series.

| Horizon | Site | Maximum Density g/cm$^3$ | Optimum Moisture % | CBR % | Swell Index psf |
|---|---|---|---|---|---|
| B | 1 | 1.45 | 30.5 | 6.0 | 6424 |
| B | 2 | . | . | . | 9665 |
| B | 3 | . | . | . | . |
| B | 4 | 1.40 | 30.0 | 2.0 | 7281 |
| B | 5 | 1.32 | 36.0 | 4.0 | 9161 |
| Mean | | 1.39 | 32.2 | 4.0 | 8133 |
| Std. Dev. | | 0.07 | 3.3 | 2.0 | 1533 |
| C | 1 | 1.62 | 20.5 | 20.0 | 345 |
| C | 2 | 1.56 | 22.5 | 20.0 | 2997 |
| C | 4 | 1.96 | 15.0 | 36.0 | 1134 |
| Mean | | 1.71 | 19.3 | 25.3 | 1492 |
| Std. Dev. | | 0.22 | 3.9 | 9.2 | 1362 |

Table 24. Compaction characteristics and tests on compacted soil: Madison series.

| Horizon | Site | Maximum Density g/cm$^3$ | Optimum Moisture % | CBR % | Swell Index psf |
|---|---|---|---|---|---|
| B | 1 | 1.40 | 27.5 | 16.0 | 4318 |
| B | 2 | 1.32 | 38.5 | 11.9 | 3048 |
| B | 3 | 1.34 | 36.3 | 13.7 | 784 |
| B | 4 | 1.45 | 30.2 | 13.0 | 634 |
| Mean | | 1.38 | 33.1 | 13.6 | 2196 |
| Std. Dev. | | 0.06 | 5.1 | 1.7 | 1795 |
| C1 | 1 | 1.55 | 19.6 | 13.0 | 405 |
| C1 | 2 | 1.47 | 26.0 | 18.8 | . |
| C1 | 3 | 1.46 | 28.5 | 15.0 | 973 |
| C1 | 4 | 1.56 | 23.0 | 15.0 | 102 |
| Mean | | 1.51 | 24.3 | 15.4 | 493 |
| Std. Dev. | | 0.05 | 3.8 | 2.1 | 442 |
| C2 | 1 | 1.46 | 17.0 | 17.0 | 535 |
| C2 | 2 | 1.56 | 23.0 | 9.6 | . |
| C2 | 3 | 1.49 | 30.0 | 14.0 | 102 |
| C2 | 4 | 1.63 | 19.5 | 11.0 | 102 |
| Mean | | 1.53 | 22.4 | 12.9 | 246 |
| Std. Dev. | | 0.08 | 5.6 | 3.3 | 250 |

## 4.5 DENSITY, VOLUME CHANGE AND HYDRAULIC CONDUCTIVITIES OF UNDISTURBED SOIL

Undisturbed soil bulk density data, soil moisture contents at time of sampling, volumetric strains during wetting and drying, and saturated hydraulic conductivities are given in Tables 25-28. Initial sample bulk densities reported are of clods removed from the thin-wall tubes. Moisture contents of the samples at the time of sampling are given as percentages of the saturated moisture contents calculated from the soil bulk densities and particle densities. Clod densities were generally more variable in the C horizons than in B horizons. The average coefficient of variation in the B horizons was 6% and that in the C horizons was 14%. Ratios of clod densities to triaxial sample (core) densities are reported as an index of the disturbance induced by the extraction of triaxial samples from the thin-wall tubes. Values less than unity indicate compaction accompanied the process while values greater than one indicate a reduction in density.

Clod shrinkage figures represent the volumetric strain accompanying air-drying of clods from their in situ moisture contents. Core swelling is the volumetric strain accompanying saturation during the triaxial test. The sum of the two represents an estimate of the total shrink-swell potential of the soil. According to Holtz and Gibbs (1956) probable danger of damage to shallow foundations caused by shrinking and swelling may be estimated as follows:

| Potential for damage | Shrink-swell potential |
|---|---|
| Non-critical | 0-10% |
| Marginal | 10-20% |
| Critical | 20-30% |
| Very critical | >30% |

Comparing estimates of shrink-swell hazards from the volume change measurements to those made from swell indices, one finds that in general the latter measurements predict a greater hazard. The correlation (r) between measured shrink-swell values and swell indices is 0.84 for the regression equation: clod shrinkage + core swelling = 3.5 + swell index/300.

Saturated hydraulic conductivities (K(sat)) of the soils vary over several orders of magnitude even within a given series and horizon. Such large differences in saturated hydraulic conductivities of soils are common and reflect the sensitivity of this property to even small variations in soil structure. The coefficients of variation of hydraulic conductivities in most cases exceed 100%. If this variability occurs over small enough distances, the use of mean conductivity values may be a justifiable practice. However, if the variations have a large-scale spatial structure, such a practice would be questionable. The sampling pattern used in this study, however, is inadequate to evaluate the spatial structure of variations in soil properties, nor is the sample number large enough to estimate the population mean with any reliability.

Table 25. Density, volume change and saturated hydraulic conductivity of 'undisturbed' soil: Appling series.

| Horizon | Site | Initial Clod Density $g/cm^3$ | Clod/ Core Density | Initial Saturation Ratio % | Clod Shrinkage % | Core Swelling % | K(Sat) cm/day |
|---|---|---|---|---|---|---|---|
| B | 1 | 1.28 | 0.94 | 92 | 10.9 | 0.5 | 0.095 |
| B | 2 | 1.46 | 1.06 | 92 | 4.7 | 1.3 | 1.6 |
| B | 3 | . | . | 71 | . | 0.6 | 120. |
| B | 4 | 1.32 | 1.03 | 74 | 8.7 | 0.3 | 11. |
| Mean |  | 1.35 | 1.01 | 82 | 8.1 | 0.7 | 33. |
| Std. Dev. |  | 0.09 | 0.06 | 11 | 3.1 | 0.4 | 59. |
| C1 | 1 | 1.25 | 0.98 | 76 | 1.6 | 1.3 | 35. |
| C1 | 2 | . | . | 86 | . | 0.3 | 2200. |
| C1 | 3 | 1.47 | 1.09 | 52 | 1.6 | 0.1 | 79. |
| C1 | 4 | 1.43 | 1.08 | 72 | 2.1 | 0.3 | 22. |
| Mean |  | 1.38 | 1.05 | 72 | 1.8 | 0.5 | 600. |
| Std. Dev. |  | 0.12 | 0.06 | 14 | 0.3 | 0.5 | 1100. |
| C2 | 1 | 1.37 | 1.05 | 80 | 3.5 | 3.3 | 2.1 |
| C2 | 3 | 1.17 | 0.91 | 46 | 1.1 | 1.8 | 50. |
| C2 | 4 | 1.73 | 0.81 | 100 | 1.9 | 0.7 | 6.5 |
| Mean |  | 1.42 | 0.92 | 75 | 2.2 | 1.9 | 20. |
| Std. Dev. |  | 0.28 | 0.12 | 27 | 1.2 | 1.3 | 27. |

Table 26. Density, volume change and saturated hydraulic conductivity of 'undisturbed' soil: Davidson series.

| Horizon | Site | Initial Clod Density g/cm$^3$ | Clod/ Core Density | Initial Saturation Ratio % | Clod Shrinkage % | Core Swelling % | K(Sat) cm/day |
|---|---|---|---|---|---|---|---|
| B | 1 | 1.50 | 1.01 | 99 | 15.1 | 2.2 | 0.27 |
| B | 2 | 1.35 | 1.15 | 89 | 16.4 | 0.9 | 0.54 |
| B | 3 | 1.33 | 0.99 | 90 | 11.7 | 1.4 | 1.4 |
| B | 4 | 1.45 | 1.27 | 89 | 11.7 | 0.9 | 25. |
| Mean | | 1.41 | 1.10 | 92 | 13.7 | 1.3 | 6.8 |
| Std. Dev. | | 0.08 | 0.13 | 5 | 2.4 | 0.6 | 12. |
| C1 | 1 | 1.48 | 0.97 | 93 | 15.4 | 0.2 | 0.52 |
| C1 | 2 | 1.18 | 1.10 | 58 | 9.5 | 1.4 | 0.54 |
| C1 | 3 | 1.15 | 1.19 | 63 | 1.6 | 1.1 | 66. |
| C1 | 4 | 1.39 | 1.09 | 87 | 13.0 | 1.2 | 6.9 |
| Mean | | 1.30 | 1.09 | 75 | 9.9 | 1.0 | 22. |
| Std. Dev. | | 0.16 | 0.09 | 17 | 6.0 | 0.5 | 38. |
| C2 | 1 | 0.91 | 0.99 | 86 | . | 1.0 | 220. |
| C2 | 2 | . | . | 88 | . | 1.0 | 0.18 |
| C2 | 4 | 1.04 | 0.95 | 95 | 5.4 | 0.8 | 35. |
| Mean | | 0.97 | 0.97 | 90 | 5.4 | 0.9 | 87. |
| Std. Dev. | | 0.09 | 0.03 | 5 | . | 0.1 | 120. |

Table 27. Density, volume change and saturated hydraulic conductivity of 'undisturbed' soil: Iredell series.

| Horizon | Site | Initial Clod Density g/cm$^3$ | Clod/ Core Density | Initial Saturation Ratio % | Clod Shrinkage % | Core Swelling % | K(Sat) cm/day |
|---|---|---|---|---|---|---|---|
| B | 1 | 1.38 | 1.06 | 77 | 19.2 | 1.4 | 0.30 |
| B | 2 | 1.26 | 0.93 | 86 | 29.0 | 4.7 | 0.36 |
| B | 3 | 1.46 | 0.97 | 82 | 19.7 | 14.4 | 0.076 |
| B | 4 | 1.35 | 1.01 | 94 | 27.0 | 3.3 | 0.65 |
| B | 5 | 1.33 | .01 | 92 | 28.3 | 5.2 | 0.027 |
| Mean |  | 1.36 | 1.00 | 86 | 24.6 | 5.8 | 0.28 |
| Std. Dev. |  | 0.07 | 0.05 | 7 | 4.8 | 5.0 | 0.25 |
| C | 1 | 1.48 | 0.89 | 64 | 8.2 | 0.8 | 67. |
| C | 2 | 2.05 | 1.39 | 97 | 6.3 | 1.9 | 1.3 |
| C | 4 | 1.65 | 1.23 | 77 | 2.9 | 0.0 | 150. |
| Mean |  | 1.73 | 1.17 | 79 | 5.8 | 0.9 | 72. |
| Std. Dev. |  | 0.29 | 0.26 | 17 | 2.7 | 1.0 | 73. |

Table 28. Density, volume change and saturated hydraulic conductivity of 'undisturbed' soil: Madison series.

| Horizon | Site | Initial Clod Density g/cm$^3$ | Clod/ Core Density | Initial Saturation Ratio % | Clod Shrinkage % | Core Swelling % | K(Sat) cm/day |
|---|---|---|---|---|---|---|---|
| B | 1 | 1.26 | 0.98 | 76 | 8.9 | 0.3 | 9.5 |
| B | 2 | 1.36 | 1.02 | 92 | 11.4 | 1.1 | 1.7 |
| B | 3 | 1.27 | 1.05 | 77 | 10.8 | 2.3 | 2.8 |
| B | 4 | 1.52 | 1.06 | 80 | 1.8 | 0.5 | 4.8 |
| Mean | | 1.35 | 1.03 | 81 | 8.2 | 1.0 | 4.7 |
| Std. Dev. | | 0.12 | 0.04 | 7 | 4.4 | 0.9 | 3.4 |
| C1 | 1 | 1.11 | 0.92 | 26 | 5.9 | 0.0 | 200. |
| C1 | 2 | 1.34 | 1.02 | 40 | 2.4 | 1.7 | 61. |
| C1 | 3 | 1.39 | 1.26 | 25 | 3.5 | 0.4 | 130. |
| C1 | 4 | 1.81 | 1.47 | 49 | 0.5 | 2.1 | 74. |
| Mean | | 1.41 | 1.17 | 35 | 3.1 | 1.0 | 120. |
| Std. Dev. | | 0.29 | 0.25 | 12 | 2.3 | 1.0 | 63. |
| C2 | 1 | 1.19 | 1.01 | 28 | 1.4 | 0.0 | 220. |
| C2 | 2 | 1.14 | 0.84 | 37 | 2.7 | 2.6 | 56. |
| C2 | 3 | 1.40 | 1.02 | 36 | 0.6 | 1.2 | 200. |
| C2 | 4 | 1.57 | 1.13 | 43 | 6.9 | 3.9 | 27. |
| Mean | | 1.32 | 1.00 | 36 | 2.9 | 1.9 | 120. |
| Std. Dev. | | 0.20 | 0.12 | 6 | 2.8 | 1.7 | 97. |

## 4.6 SOIL STRENGTH AND COMPRESSIBILITY

The soil strength and compressibility parameters obtained from the triaxial tests are given in Tables 29-32 along with the in situ blow count results. In general, values of c are higher and those of $\phi$ are lower in the B horizons than in the C horizons. Values of c tended to be more variable than those of $\phi$, the average coefficient of variation for all series and horizons being 63 for the former and 19 for the latter. A significant amount of the variability in the strength parameters is probably attributable to sample disturbance. In ideal circumstances, undisturbed samples are difficult to obtain and in many cases the circumstances were far from ideal. Particular difficulties were encountered with B horizon samples having pronounced macrostructure and with drier low cohesion C horizon samples. Some indication of the sample disturbance may be gleaned from the ratios of clod to triaxial core densities given in Tables 25-28. High clod-to-core density ratios suggest compaction of the triaxial samples which would tend to produce excessive values of $\phi$ . Low ratios suggest dilation which would tend to produce the opposite results.

Large differences in clod and triaxial core densities were especially pronounced in the Iredell C horizon samples. These horizons are very dense and hard in situ (note blow count data) and have high cohesion due to natural cementation but undergo brittle failure when subjected to small strains. The variation in measured values of $\phi$ shows some correspondence to the clod/core density ratios. Accordingly, the values of $\phi$ for sites 2 and 3 are quite likely underestimates of the true values and site 1 may be an overestimate.

The compressibility parameters m, M, n and N relate the drained (bulk) and undrained (rebound) compression modulii to confining pressures in accordance with Equations 3 and 5. The undrained modulii parameters may be used to estimate short term settlement due to transient loads, whereas the drained parameters are applicable to the calculation of compression during long term loading. If it is assumed that bulk compression modulii can be used as estimates of vertical at-rest drained compression modulii (Parker et al., 1980), then vertical settlement H under sustained loads may be calculated as:

$$\Delta H = \int_0^Z \int_{\sigma_o}^{\sigma_f} \overline{K}^{-1} \, d\sigma \, dz$$

where z is depth, $\sigma_o$ is the initial vertical stress; $\sigma_f$ is the final vertical stress; and K is the bulk compression modulus. Substituting Equation 5 for $\overline{K}$ and integrating once for $n \neq 1$ gives:

$$\Delta H = \int_0^Z \left[ p^{n-1} \quad (\sigma_f^{n+1} - \sigma_o^{n+1}) \right] /N(n+1)\ dz$$

which may be solved numerically by dividing the soil into layers as:

$$\Delta H = \sum_{i=1}^{j} \left[ \Delta z_i p^{n_i+1} \quad (\sigma_{f_i}^{n_i+1} - \sigma_{o_i}^{n_i+1}) \right] /N_i(n_i+1)$$

where j is the number of layers; $\Delta z_i$ is the thickness of layer i; $n_i$ and $N_i$ are the compressibility parameters of layer i; and $\sigma_{oi}$ and $\sigma_{fi}$ are the initial and final vertical stresses in layer i.

Because of the nonlinear nature of Equations 3 and 5, it is difficult to obtain an intuitive feeling for the significance of the variations in the compressibility parameters n, N, m and M. More useful comparisons would be possible if _in situ_ compression modulii could be calculated from the compressibility parameters. This calculation may be done given the _in situ_ stress conditions. As a first approximation, we have assumed at-rest earth pressure coefficients of unity and calculated the stresses in Equations 3 and 5 as the integral of total soil density with depth. Total soil density was taken to be constant at 2.0 g/cm³. The results of these calculations are given in Table 33 for depths corresponding to the various horizons.

Table 29. Strength and compressibility parameters of 'undisturbed' soil and *in situ* blow count results: Appling series.

| | | | | Compressibility | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Strength | | Drained | | Undrained | | Blow Count |
| Horizon | Site | c kPa | $\phi$ deg | n | N | m | M | |
| B | 1 | 77 | 21 | 0.07 | 175 | 0.44 | 314 | 39 |
| B | 2 | 58 | 18 | 0.27 | 128 | 0.41 | 235 | 19 |
| B | 3 | 19 | 17 | 0.47 | 129 | 0.55 | 163 | 9 |
| B | 4 | 47 | 19 | . | . | 0.92 | 154 | 18 |
| Mean | | 50 | 19 | 0.27 | 144 | 0.69 | 202 | 21 |
| Std. Dev. | | 24 | 2 | 0.20 | 27 | 0.24 | 75 | 13 |
| C1 | 1 | 13 | 24 | 0.65 | 75 | 0.72 | 190 | 13 |
| C1 | 2 | 77 | 24 | 0.25 | 128 | 0.87 | 175 | 22 |
| C1 | 3 | 36 | 21 | 0.79 | 117 | 0.74 | 195 | 10 |
| C1 | 4 | 11 | 27 | 0.52 | 98 | 0.94 | 157 | 14 |
| Mean | | 34 | 24 | 0.67 | 94 | 0.85 | 178 | 15 |
| Std. Dev. | | 31 | 2 | 0.12 | 18 | 0.09 | 16 | 5 |
| C2 | 1 | 24 | 25 | 0.60 | 48 | 0.79 | 178 | 20 |
| C2 | 3 | 25 | 23 | 0.74 | 86 | 0.88 | 191 | 10 |
| C2 | 4 | 24 | 35 | . | . | 0.64 | 267 | . |
| Mean | | 24 | 28 | 0.67 | 67 | 0.77 | 212 | 15 |
| Std. Dev. | | 1 | 6 | 0.10 | 27 | 0.12 | 48 | 7 |

Table 30. Strength and compressibility parameters of 'undisturbed' soil and *in situ* blow count results: Davidson series.

| | | Strength | | Compressibility | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Drained | | Undrained | | |
| Horizon | Site | c kPa | $\phi$ deg | n | N | m | M | Blow Count |
| B | 1 | 93 | 19 | 0.54 | 158 | 0.50 | 492 | 28 |
| B | 2 | 74 | 14 | 0.27 | 74 | 0.66 | 168 | 21 |
| B | 3 | 154 | 8 | 0.76 | 218 | 0.41 | 343 | 34 |
| B | 4 | 24 | 19 | 0.62 | 185 | 0.52 | 197 | 17 |
| Mean | | 86 | 15 | 0.55 | 159 | 0.52 | 300 | 25 |
| Std. Dev. | | 54 | 5 | 0.21 | 62 | 0.10 | 149 | 8 |
| C1 | 1 | 125 | 16 | . | . | 0.59 | 410 | 54 |
| C1 | 2 | 48 | 28 | 0.88 | 47 | 0.97 | 204 | 19 |
| C1 | 3 | 28 | 26 | 0.64 | 59 | 0.76 | 225 | 18 |
| C1 | 4 | 20 | 26 | 0.63 | 67 | 0.82 | 110 | 23 |
| Mean | | 55 | 24 | 0.72 | 58 | 0.78 | 237 | 29 |
| Std. Dev. | | 48 | 5 | 0.14 | 10 | 0.16 | 126 | 17 |
| C2 | 1 | 29 | 24 | 0.81 | 108 | 0.61 | 180 | 5 |
| C2 | 2 | 25 | 20 | 0.53 | 48 | 0.82 | 145 | 4 |
| C2 | 4 | 49 | 24 | 0.58 | 58 | 0.71 | 211 | 17 |
| Mean | | 34 | 23 | 0.64 | 71 | 0.71 | 179 | 9 |
| Std. Dev. | | 13 | 2 | 0.15 | 32 | 0.11 | 33 | 7 |

Table 31. Strength and compressibility parameters of 'undisturbed' soil and *in situ* blow count results: Iredell series.

| Horizon | Site | Strength | | Compressibility | | | | Blow Count |
|---|---|---|---|---|---|---|---|---|
| | | | | Drained | | Undrained | | |
| | | c kPa | $\phi$ deg | n | N | m | M | |
| B | 1 | 19 | 16 | 0.48 | 67 | 0.66 | 254 | 16 |
| B | 2 | 13 | 10 | 0.74 | 69 | 0.39 | 278 | 15 |
| B | 3 | 11 | 8 | 0.63 | 51 | 0.32 | 147 | 16 |
| B | 4 | 19 | 10 | 0.63 | 49 | 0.30 | 141 | 11 |
| B | 5 | 24 | 12 | 0.46 | 48 | 0.46 | 108 | 14 |
| Mean | | 17 | 11 | 0.59 | 57 | 0.43 | 186 | 14 |
| Std. Dev. | | 5 | 3 | 0.12 | 10 | 0.15 | 75 | 2 |
| C | 1 | 1 | 43 | 0.37 | 117 | 0.99 | 313 | 69 |
| C | 2 | 13 | 27 | 0.47 | 97 | 0.79 | 218 | 89 |
| C | 4 | 5 | 32 | 0.38 | 91 | 0.85 | 279 | 60 |
| Mean | | 6 | 34 | 0.41 | 102 | 0.88 | 269 | 73 |
| Std. Dev. | | 6 | 8 | 0.06 | 14 | 0.10 | 48 | 15 |

Table 32. Strength and compressibility parameters of 'undisturbed' soil and *in situ* blow count results: Madison series.

| | | | | Compressibility | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Strength | | Drained | | Undrained | | |
| Horizon | Site | c<br>kPa | φ<br>deg | n | N | m | M | Blow Count |
| B | 1 | 105 | 17 | 0.63 | 415 | 0.28 | 293 | 16 |
| B | 2 | 26 | 19 | 0.41 | 189 | 0.39 | 334 | 29 |
| B | 3 | 81 | 13 | 0.84 | 247 | 0.60 | 187 | 10 |
| B | 4 | 35 | 25 | 0.34 | 178 | 0.45 | 263 | 27 |
| Mean | | 62 | 19 | 0.55 | 257 | 0.43 | 268 | 21 |
| Std. Dev. | | 38 | 5 | 0.23 | 109 | 0.13 | 64 | 9 |
| C1 | 1 | 8 | 25 | 0.46 | 62 | 0.74 | 249 | 11 |
| C1 | 2 | 2 | 31 | 0.92 | 84 | 0.74 | 222 | 15 |
| C1 | 3 | 28 | 20 | 0.92 | 37 | 0.66 | 161 | 14 |
| C1 | 4 | 21 | 20 | 0.94 | 89 | 0.61 | 194 | 18 |
| Mean | | 15 | 24 | 0.81 | 68 | 0.69 | 207 | 15 |
| Std. Dev. | | 12 | 5 | 0.23 | 24 | 0.06 | 38 | 3 |
| C2 | 1 | 9 | 25 | 0.51 | 81 | 0.76 | 217 | 16 |
| C2 | 2 | 5 | 23 | 0.87 | 39 | 0.87 | 85 | 3 |
| C2 | 3 | 26 | 23 | 0.88 | 68 | 0.78 | 172 | 14 |
| C2 | 4 | 25 | 25 | 0.94 | 70 | 0.75 | 167 | 17 |
| Mean | | 16 | 24 | 0.80 | 65 | 0.79 | 160 | 13 |
| Std. Dev. | | 11 | 1 | 0.20 | 18 | 0.05 | 55 | 6 |

Table 33. *In situ* drained and undrained compression modulii as estimated from triaxial test results.

| Series | Horizon | Modulus ( std. dev.) MPa | |
|---|---|---|---|
| | | Drained | Undrained |
| Appling | B | 10.0 (5.0) | 9.5 (5.4) |
| Appling | C1 | 8.0 (2.4) | 11.8 (1.7) |
| Appling | C2 | 7.6 (3.1) | 24.3 (5.0) |
| Davidson | B | 6.1 (0.9) | 13.5 (7.6) |
| Davidson | C1 | 4.0 (0.9) | 16.2 (9.9) |
| Davidson | C2 | 8.1 (3.9) | 20.3 (3.6) |
| Iredell | B | 2.2 (0.5) | 9.3 (3.5) |
| Iredell | C | 5.3 (1.0) | 6.5 (0.5) |
| Madison | B | 10.4 (3.5) | 14.1 (5.3) |
| Madison | C1 | 4.5 (1.5) | 14.5 (2.3) |
| Madison | C2 | 7.5 (1.9) | 18.4 (6.2) |

## 4.7 CHEMICAL PROPERTIES

Cation exchange capacity (CEC) reflects the ability of the soil to retain cationic compounds in exchangeable form. In the soils studied the exchange complex is dominated by the basic cations calcium (Ca), magnesium (Mg) and potassium (K) and the acidic cations hydrogen (H) and aluminum (Al) -- the latter considered acidic because of its tendency to readily hydrolyze in aqueous solution. The CEC may be calculated as the sum of these ions extracted from the soil. Base saturation is the ratio of exchangeable bases to CEC and reflects to a degree the fertility of the soil.

The standard procedure for determining CEC and base saturation used by the U.S. Soil Conservation Service utilizes titratable acidity measured by titration of a pH 8.2 buffered $BaCl_2$-triethanolamine extract as a measure of exchangeable acidity. Due to the high pH dependent charge in many soils of the southeastern United States, this method overestimates exchangeable acidity and CEC and hence underestimates base saturation. To alleviate this problem, CEC and base saturation may be calculated using an unbuffered neutral salt N KCl extract in lieu of the pH 8.2 buffered solution to evaluate exchangeable acidity. We assume the neutral salt extractable acidity represents exchangeable trivalent Al. CEC values calculated using these exchangeable Al values are more representative of the actual _in situ_ exchange capacity of the soil.

Values of exchangeable Ca, Mg, K and Al are given in Tables 34-37 along with CEC's calculated as the sum of these cations. Titratable acidity ($BaCl_2$-TEA extracts), pH and base saturation values are given in Tables 38-41. Base saturation values by Method 1 utilize neutral unbuffered KCl extractions for exchangeable acidity. Base saturation values by Method 2 utilize pH 8.2 $BaCl_2$-TEA extractable acidity. In all cases Method 1 yields higher values than Method 2, in many instances much higher. Method 1 is more representative of the _in situ_ soil behavior.

The higher Ca, Mg, P, and base saturations observed in the B horizons for the Appling, Davidson, and Madison when compared to the C1 and C2 horizons of the three soils are most likely a result of liming and fertilization practices that throughout the years have enriched the upper soil horizons. That Iredell has higher base status in both B and C horizons indicates there are more bases in the parent material as well as less intensive leaching of the soil.

The pH values show no significant change between the B and C horizons for the Appling, Davidson, and Madison. The Iredell showed a pH increase from B to C and values were consistently higher than the other three soils. Cation exchange capacity, magnesium, and titratable acidity showed the greatest variation with depth, a reflection, probably, of the variable clay content of the C1 and C2 horizons. Exchangeable calcium, potassium, and aluminum, and base saturation showed greater variation in the B over the C1 and C2 horizons and is most likely due partially to differences induced by cultural practices.

Table 34. Cation exchange capacity and exchangeable cations: Appling Series.

| Horizon | Site | Ca meq/100g | Mg meq/100g | K meq/100g | Al meq/100g | CEC meq/100g |
|---|---|---|---|---|---|---|
| B | 1 | 0.08 | 0.57 | 0.26 | 3.55 | 4.46 |
| B | 2 | 0.51 | 0.47 | 0.17 | 4.35 | 5.50 |
| B | 3 | 0.63 | 1.37 | 0.23 | 2.05 | 4.28 |
| B | 4 | 3.12 | 1.90 | 0.22 | 0.65 | 5.89 |
| Mean | | 1.09 | 1.08 | 0.22 | 2.65 | 5.03 |
| Std. Dev. | | 1.38 | 0.68 | 0.04 | 1.64 | 0.78 |
| C1 | 1 | 0.10 | 0.09 | 0.08 | 2.45 | 2.72 |
| C1 | 2 | 0.02 | 0.11 | 0.14 | 3.15 | 3.42 |
| C1 | 3 | 0.08 | 0.23 | 0.12 | 2.65 | 3.08 |
| C1 | 4 | 0.30 | 0.18 | 0.10 | 1.95 | 2.53 |
| Mean | | 0.13 | 0.15 | 0.11 | 2.55 | 2.94 |
| Std. Dev. | | 0.12 | 0.06 | 0.03 | 0.50 | 0.39 |
| C2 | 1 | 0.09 | 0.14 | 0.10 | 2.05 | 2.38 |
| C2 | 3 | 0.12 | 0.53 | 0.12 | 3.35 | 4.12 |
| C2 | 4 | 0.07 | 0.10 | 0.12 | 2.05 | 2.34 |
| Mean | | 0.09 | 0.26 | 0.11 | 2.48 | 2.95 |
| Std. Dev. | | 0.03 | 0.24 | 0.01 | 0.75 | 1.02 |

Table 35. Cation exchange capacity and exchangeable cations: Davidson Series.

| Horizon | Site | Ca meq/100g | Mg meq/100g | K meq/100g | Al meq/100g | CEC meq/100g |
|---|---|---|---|---|---|---|
| B | 1 | 3.10 | 2.00 | 0.20 | 0.35 | 5.65 |
| B | 2 | 6.08 | 1.42 | 0.13 | 0.05 | 7.64 |
| B | 3 | 0.56 | 1.85 | 0.05 | 4.65 | 7.11 |
| B | 4 | 2.83 | 1.30 | 2.40 | 0.05 | 6.58 |
| Mean | | 3.14 | 1.64 | 0.70 | 1.28 | 6.75 |
| Std. Dev. | | 2.27 | 0.34 | 1.14 | 2.25 | 0.85 |
| C1 | 1 | 0.21 | 0.95 | 0.28 | 2.45 | 3.89 |
| C1 | 2 | 1.83 | 1.42 | 0.10 | 1.15 | 4.50 |
| C1 | 4 | 1.35 | 1.31 | 0.22 | 2.45 | 5.33 |
| Mean | | 1.13 | 1.23 | 0.20 | 2.02 | 4.57 |
| Std. Dev. | | 0.83 | 0.25 | 0.09 | 0.75 | 0.72 |
| C2 | 1 | 0.87 | 0.93 | 0.22 | 0.75 | 2.77 |
| C2 | 2 | 1.40 | 1.35 | 0.12 | 3.15 | 6.02 |
| Mean | | 1.14 | 1.14 | 0.17 | 1.95 | 4.40 |
| Std. Dev. | | 0.37 | 0.30 | 0.07 | 1.70 | 2.30 |

Table 36. Cation exchange capacity and exchangeable cations: Iredell Series.

| Horizon | Site | Ca meq/100g | Mg meq/100g | K meq/100g | Al meq/100g | CEC meq/100g |
|---|---|---|---|---|---|---|
| B | 1 | 15.60 | 16.00 | 0.20 | 0.25 | 32.05 |
| B | 4 | 12.20 | 20.10 | 0.29 | 0.45 | 33.04 |
| B | 5 | 9.50 | 10.70 | 0.29 | 3.55 | 24.04 |
| Mean | | 12.43 | 15.60 | 0.26 | 1.42 | 29.71 |
| Std. Dev. | | 3.06 | 4.71 | 0.05 | 1.85 | 4.94 |
| C | 1 | 15.60 | 8.60 | 0.09 | 0.05 | 24.34 |
| C | 2 | 14.50 | 17.10 | 0.14 | 0.35 | 32.09 |
| C | 4 | 7.02 | 6.60 | 0.08 | 0.05 | 13.75 |
| Mean | | 12.37 | 10.77 | 0.10 | 0.15 | 23.39 |
| Std. Dev. | | 4.67 | 5.58 | 0.03 | 0.17 | 9.21 |

Table 37. Cation exchange capacity and exchangeable cations: Madison Series.

| Horizon | Site | Ca meq/100g | Mg meq/100g | K meq/100g | Al meq/100g | CEC meq/100g |
|---|---|---|---|---|---|---|
| B | 2 | 0.04 | 0.62 | 0.43 | 3.05 | 4.14 |
| B | 3 | 0.08 | 0.80 | 0.21 | 1.15 | 2.24 |
| B | 4 | 1.18 | 1.00 | 0.19 | 1.35 | 3.72 |
| Mean | | 0.43 | 0.81 | 0.28 | 1.85 | 3.37 |
| Std. Dev. | | 0.65 | 5.58 | 0.03 | 0.17 | 9.21 |
| C1 | 2 | 0.04 | 0.31 | 0.14 | 4.45 | 4.94 |
| C1 | 3 | 0.06 | 0.24 | 0.32 | 4.75 | 5.37 |
| C1 | 4 | 0.09 | 0.08 | 0.08 | 1.15 | 1.40 |
| Mean | | 0.06 | 0.21 | 0.18 | 3.45 | 3.90 |
| Std. Dev. | | 0.03 | 0.12 | 0.12 | 2.00 | 2.18 |
| C2 | 1 | 0.15 | 0.54 | 0.13 | 1.45 | 2.27 |
| C2 | 2 | 0.07 | 0.34 | 0.21 | 3.25 | 3.87 |
| C2 | 3 | 0.08 | 1.20 | 0.20 | 4.85 | 6.33 |
| C2 | 4 | 0.02 | 0.12 | 0.08 | 1.35 | 1.57 |
| Mean | | 0.08 | 0.55 | 0.16 | 2.73 | 3.51 |
| Std. Dev. | | 0.05 | 0.47 | 0.06 | 1.66 | 2.11 |

Table 38. Titratable acidity, base saturation, and pH: Appling.

| Horizon | Site | pH | Titratable Acidity meq/100g | Base Saturation Method 1 % | Base Saturation Method 2 % |
|---|---|---|---|---|---|
| B | 1 | 4.80 | 8.56 | 20.40 | 9.61 |
| B | 2 | 4.62 | 9.80 | 20.91 | 10.50 |
| B | 3 | 4.57 | 9.60 | 52.10 | 18.85 |
| B | 4 | 4.86 | 8.00 | 88.96 | 39.58 |
| Mean | | 4.71 | 8.99 | 45.59 | 19.64 |
| Std. Dev. | | 0.14 | 0.86 | 32.49 | 13.93 |
| C1 | 1 | 5.00 | 5.97 | 9.93 | 4.33 |
| C1 | 3 | 4.73 | 6.40 | 13.96 | 6.30 |
| C1 | 4 | 4.54 | 2.20 | 22.92 | 20.86 |
| Mean | | 4.76 | 4.86 | 15.60 | 10.50 |
| Std. Dev. | | 0.23 | 2.31 | 6.65 | 9.03 |
| C2 | 1 | 5.24 | 3.58 | 13.87 | 8.44 |
| C2 | 3 | 4.40 | 4.00 | 18.69 | 16.14 |
| C2 | 4 | 4.31 | 2.00 | 12.39 | 12.66 |
| Mean | | 4.65 | 3.19 | 14.98 | 12.41 |
| Std. Dev. | | 0.51 | 1.05 | 3.29 | 3.86 |

Table 39. Titratable acidity, base saturation, and pH. Davidson.

| Horizon | Site | pH | Titratable Acidity meq/100g | Base Saturation Method 1 % | Base Saturation Method 2 % |
|---|---|---|---|---|---|
| B | 1 | 5.37 | 10.20 | 93.81 | 34.19 |
| B | 2 | 5.31 | 10.20 | 99.93 | 42.79 |
| B | 3 | 4.72 | 15.20 | 34.60 | 13.93 |
| B | 4 | 4.83 | 8.80 | 99.24 | 42.60 |
| Mean | | 5.06 | 11.10 | 81.90 | 33.38 |
| Std. Dev. | | 0.33 | 2.81 | 31.65 | 13.57 |
| C1 | 1 | 4.62 | 15.00 | 37.02 | 8.76 |
| C1 | 2 | 5.41 | 12.94 | 74.44 | 20.56 |
| C1 | 4 | 4.18 | 10.80 | 54.03 | 21.05 |
| Mean | | 4.74 | 12.91 | 55.16 | 16.79 |
| Std. Dev. | | 0.62 | 2.10 | 18.74 | 6.96 |
| C2 | 1 | 4.65 | 11.80 | 72.92 | 14.62 |
| C2 | 2 | 4.73 | 14.20 | 47.67 | 16.81 |
| Mean | | 4.69 | 13.00 | 60.30 | 15.72 |
| Std. Dev. | | 0.06 | 1.70 | 17.85 | 1.55 |

Table 40. Titratable acidity, base saturation, and pH: Iredell.

| Horizon | Site | pH | Titratable Acidity meq/100g | Base Saturation Method 1 % | Base Saturation Method 2 % |
|---|---|---|---|---|---|
| B | 1 | 5.64 | 6.20 | 99.22 | 83.68 |
| B | 4 | 5.60 | 9.20 | 98.64 | 85.16 |
| B | 5 | 4.90 | 14.93 | 85.23 | 57.85 |
| Mean | | 5.38 | 10.11 | 94.36 | 75.56 |
| Std. Dev. | | 0.42 | 4.44 | 7.92 | 15.36 |
| C | 1 | 6.50 | 5.00 | 99.79 | 82.93 |
| C | 2 | 6.04 | 4.58 | 98.91 | 87.39 |
| C | 3 | 6.30 | 1.79 | 99.64 | 88.44 |
| Mean | | 6.28 | 3.79 | 99.45 | 86.25 |
| Std. Dev. | | 0.23 | 1.74 | 0.47 | 2.93 |

Table 41. Titratable acidity, base saturation, and pH: Madison.

| Horizon | Site | pH | Titratable Acidity meq/100g | Base Saturation Method 1 % | Base Saturation Method 2 % |
|---|---|---|---|---|---|
| B | 2 | 4.57 | 13.20 | 26.33 | 9.90 |
| B | 3 | 5.52 | 7.76 | 48.66 | 12.32 |
| B | 4 | 4.44 | 7.60 | 63.71 | 23.77 |
| Mean | | 4.84 | 9.52 | 46.23 | 15.33 |
| Std. Dev. | | 0.59 | 3.19 | 18.81 | 7.41 |
| C1 | 2 | 4.41 | 8.20 | 9.92 | 5.46 |
| C1 | 3 | 4.45 | 10.60 | 11.55 | 5.53 |
| C1 | 4 | 4.86 | 7.60 | 63.71 | 23.77 |
| Mean | | 4.57 | 8.80 | 28.39 | 11.59 |
| Std. Dev. | | 0.25 | 1.59 | 30.68 | 10.55 |
| C2 | 1 | 5.30 | 3.58 | 36.12 | 18.64 |
| C2 | 2 | 4.40 | 7.60 | 16.02 | 7.54 |
| C2 | 3 | 4.61 | 9.40 | 23.38 | 13.60 |
| C2 | 4 | 4.53 | 1.00 | 14.01 | 18.03 |
| Mean | | 4.71 | 5.40 | 22.38 | 14.45 |
| Std. Dev. | | 0.40 | 3.81 | 10.00 | 5.13 |

## 5. SUMMARY AND CONCLUSIONS

It is evident from the results that the variability of physical soil properties differs with the property under consideration as well as with soil series and soil horizons. Coefficients of variation offer a convenient means of comparing the variability of different properties since the variation is normalized with respect to the mean. We have calculated the coefficients of variation of selected properties for each set of genetically similar horizons of the same series. As a means to evaluate any general trends in the magnitude of variability with depth, we have also calculated arithmetic averages of the coefficients of variation for the B horizons and upper and lower C horizons of each series. As an overall estimate of the variability of each property, the arithmetic means of the coefficients of variation for all horizons and series were computed.

Particle density, maximum compacted density, pH, initial clod density, optimum compaction moisture, liquid limit, the undrained compression index m and the angle of internal friction had average coefficients of variation less than 20% (Table 42). The compressibility parameters n, M and N, sand and clay contents, CBR, CEC and base saturation had average coefficients of variation between 20 and 40% (Table 43). Blow count, group index, swell index, plasticity index, clod shrinkage and cohesion c had average coefficients of variation between 40 and 65%. (Table 44). Saturated hydraulic conductivity is in a class of its own with an average coefficient of variation of 126% (Table 44).

The classification of soils into different series is based on soil properties to depths seldom greater than 2 meters. One of the objectives of this study was to evaluate the variation of the underlying saprolites in relation to that in the solum. Not surprisingly, for a number of properties the coefficients of variability generally increase with depth. Properties in this category include clay and sand contents, CEC, particle density, maximum compacted density, clod density and soil shrinkage. In spite of the increase in variability of these properties with depth, values of the strength parameter , compressibility parameters, and CBR values generally showed reductions in variability with depth.

Table 42. Coefficients of variation of soil properties having low variability within genetically similar horizons.

| Series | Hor- izon | Part. Dens. | Max. Dens. | pH | Init. Clod Dens. | Opt. Moist. | Liquid Limit | Undrn Compr m | Fric- tion $\phi$ |
|---|---|---|---|---|---|---|---|---|---|
| Appling | B | 1.8 | 3 | 3 | 7 | 7 | 4 | 35 | 9 |
|  | C1 | 0.7 | 3 | 5 | 8 | 10 | - | 11 | 10 |
|  | C2 | 1.8 | 5 | 11 | 20 | 6 | - | 16 | 23 |
| Davidson | B | 1.7 | 4 | 7 | 6 | 12 | 14 | 19 | 35 |
|  | C1 | 2.7 | 7 | 13 | 12 | 11 | 23 | 21 | 23 |
|  | C2 | 3.0 | 11 | 1 | 9 | 21 | 20 | 15 | 10 |
| Iredell | B | 0.4 | 5 | 8 | 5 | 10 | 15 | 35 | 27 |
|  | C | 3.5 | 13 | 4 | 17 | 20 | - | 11 | 24 |
| Madison | B | 1.8 | 4 | 12 | 9 | 16 | 14 | 30 | 27 |
|  | C1 | 1.8 | 3 | 5 | 21 | 16 | - | 9 | 22 |
|  | C2 | 1.8 | 5 | 9 | 15 | 25 | - | 6 | 5 |
| Avg of B's |  | 1.4 | 4 | 7 | 6 | 11 | 12 | 30 | 25 |
| Avg upper C's |  | 2.2 | 7 | 7 | 14 | 14 | - | 13 | 20 |
| Avg lower C's |  | 2.2 | 7 | 7 | 15 | 17 | - | 12 | 13 |
| Avg depths |  | 1.9 | 6 | 7 | 12 | 14 | 14 | 18 | 19 |

Table 43. Coefficients of variation of soil properties having moderate variability within genetically similar horizons.

| Series | Hor-izon | Drn. Compr. n | Undrn. Compr. M | CEC | Clay | Drn. Compr. N | Sand | CBR | Base Sat. |
|---|---|---|---|---|---|---|---|---|---|
| Appling | B | 74 | 37 | 16 | 12 | 19 | 23 | 39 | 71 |
| | C1 | 18 | 9 | 13 | 8 | 19 | 10 | 26 | 43 |
| | C2 | 15 | 23 | 34 | 28 | 40 | 68 | 23 | 22 |
| Davidson | B | 38 | 50 | 13 | 14 | 39 | 26 | 48 | 39 |
| | C1 | 19 | 53 | 16 | 81 | 17 | 56 | 36 | 34 |
| | C2 | 23 | 18 | 52 | 32 | 45 | 11 | 48 | 30 |
| Iredell | B | 20 | 40 | 17 | 13 | 18 | 31 | 50 | 8 |
| | C | 15 | 18 | 39 | 36 | 14 | 16 | 36 | 0 |
| Madison | B | 42 | 24 | 30 | 7 | 42 | 17 | 13 | 41 |
| | C1 | 28 | 18 | 56 | 53 | 35 | 11 | 14 | 108 |
| | C2 | 25 | 34 | 60 | 43 | 28 | 47 | 26 | 45 |
| Avg of B's | | 44 | 38 | 19 | 12 | 29 | 24 | 38 | 40 |
| Avg upper C's | | 20 | 25 | 19 | 44 | 22 | 23 | 28 | 46 |
| Avg lower C's | | 21 | 25 | 49 | 34 | 38 | 42 | 32 | 32 |
| Avg depths | | 28 | 29 | 29 | 30 | 30 | 30 | 33 | 39 |

Table 44. Coefficients of variation of soil properties having high to very high variability within genetically similar horizons.

| Series | Horizon | Blow Count | Group Index | Swell Index | Plas-ticity Index | Clod Shrink-age | Cohe-sion Param. c | Sat. Hyd. Cond. |
|---|---|---|---|---|---|---|---|---|
| Appling | B | 60 | 18 | 47 | 10 | 39 | 48 | 175 |
| | C1 | 35 | - | 40 | - | 16 | 90 | 185 |
| | C2 | 47 | - | 47 | - | 56 | 2 | 136 |
| Davidson | B | 30 | 28 | 88 | 30 | 17 | 62 | 179 |
| | C1 | 60 | 121 | 32 | 143 | 61 | 87 | 169 |
| | C2 | 84 | 18 | 5 | 59 | - | 37 | 139 |
| Iredell | B | 14 | 22 | 19 | 20 | 19 | 30 | 88 |
| | C | 20 | - | 91 | - | 46 | 96 | 101 |
| Madison | B | 44 | 7 | 82 | 39 | 54 | 61 | 73 |
| | C1 | 20 | - | 90 | - | 73 | 80 | 54 |
| | C2 | 52 | - | 101 | - | 97 | 66 | 88 |
| Avg of B's | | 37 | 35 | 59 | 25 | 32 | 50 | 129 |
| Avg upper C's | | 34 | - | 34 | - | 49 | 88 | 127 |
| Avg lower C's | | 61 | - | 51 | - | 76 | 50 | 121 |
| Avg depths | | 44 | 45 | 45 | 46 | 52 | 63 | 126 |

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