Some Physical and Chemical Properties of Some Piedmont Residual Soils

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Abstract

A laboratory testing program was performed to determine both the physical and chemical characteristics of 25 residual soil samples collected throughout the Piedmont Region. The primary focus of the work was to document the characteristics and investigate the interrelation between physical and chemical properties. Laboratory tests included: grain-size distribution, Atterberg liquid, plastic, and shrinkage limits, linear shrinkage, external and internal surface area, cation exchange capacity, carbonate content, 1:1 pH, specific gravity and intrinsic compressibility. Results of the lab tests are presented and a discussion of the influence of chemical composition and other characteristics on the physical properties is given.

Resumen(needs to be translated)

A laboratory testing program was performed to determine both the physical and chemical characteristics of 25 residual soil samples collected throughout the Piedmont Region. The primary focus of the work was to document the characteristics and investigate the interrelation between physical and chemical properties. Laboratory tests included: grain-size distribution, Atterberg liquid, plastic, and shrinkage limits, linear shrinkage, external and internal surface area, cation exchange capacity, carbonate content, 1:1 pH, specific gravity and intrinsic compressibility. Results of the lab tests are presented and a discussion of the influence of chemical composition and other characteristics on the physical properties is given.

1 INTRODUCTION

In the eastern U.S., the Piedmont Physiographic Province extends from near Philadelphia, Pennsylvania in the north to near Auburn, Alabama in the south. In places, the Piedmont is almost 200 km wide, covering a total area of approximately 240,000 sq. km. The surficial soils in this region are composed of residual soils weathered in place from metamorphic and igneous bedrock. As a result of the variability and complexity of the bedrock and variability of mechanical and chemical weathering, it is expected that the resulting surficial residual soils may be highly variable, especially considering the wide distribution of the area.

Previous investigations have presented general descriptions of the geology of soils from the Piedmont (e.g., Sowers 1963; Sowers and Richardson 1983) and a number of investigations have described specific characteristics related interpretation of lab and in situ tests (e.g., Martin and Mayne 1998; Schneider et al. 1999; Finke et al. 1999; Mayne et al. 2000); settlement of shallow foundations (e.g., Martin 1977; Barksdale et al 1982; Willmer et al. 1982); and behavior of deep foundations (e.g., Harris and Mayne 1994; Lutenegger and Adams 1999). While these investigations provide valuable information for specific design problems there appears to be a complete lack of availability of basic data related to the composition and there has been no detailed evaluation of the relationship between the basic geotechnical properties of this material and composition.

2 THE PIEDMONT PROVINCE

The Piedmont Physiographic Province, Figure 1, is an extensive and important geologic region that covers a large area of the eastern United States. According to Sowers and Richardson (1983) the Piedmont is “Paleozoic or older.” The region runs approximately parallel to the Atlantic Coast and extends about 1200 km north to south. A number of important urban areas are located within the Province, including the metropolitan areas of Philadelphia, Baltimore, Washington-DC, Richmond, Charlotte, Raleigh, and Atlanta. Primary rock types include Paleozoic metamorphic and igneous rocks, predominantly schist, gneiss, and granite, with some localized areas that include phyllite, amphiboles, quartzite, marble, slate, soapstone, gabbro and diabase.

The upper mantel of materials covering the bedrock is an overburden that consists of residual soils derived from the in place weathering of the parent rock. The thickness and composition of the overburden varies extensively as a result of differential weathering of the various parent rock materials located throughout the region. Large variations in the residual soils can occur over relatively short distances as might be expected.

The residual soils of the Piedmont have wide classification characteristics. In some areas, the residual soils consist of loose to medium dense micaceous silty sands (SM) to sandy clays (SC). In other areas, the materials are more predominantly sandy silts (ML). In the southern Piedmont, the term “Georgia Red Clay” has been used historically to describe the materials. In fact, the Unified Soil Classification System (USCS) is not particularly well suited to these soils and the USCS nomenclature can be misleading in some cases.

3 INVESTIGATION

This work involved the collection of residual soil samples from throughout the Piedmont Province and a laboratory testing program to determine soil characteristics. The primary focus of the work was to document the physical-chemical characteristics, in particular the Cation Exchange Capacity and Specific Surface and to investigate any interrelationships between these properties and other common soil characteristics.

3.1 Soil Samples

Samples were collected from a number of locations within the Piedmont Physiographic Province shown by the squares in Figure 1. Samples were obtained by hand from a number of open excavations. The samples represent a broad distribution within the Piedmont. In addition to the samples collected by the authors, several samples were provided by individual researchers located throughout the region. The focus of the sampling was to obtain predominantly fine-grained samples for testing.

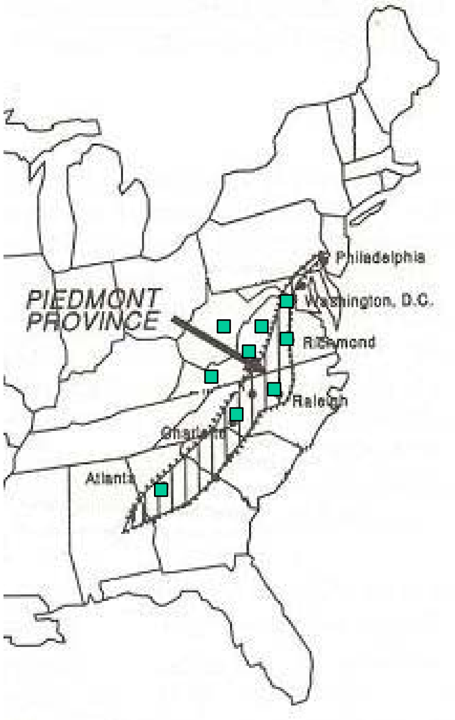


Figure 1. Map of Piedmont Region.

3.2 Laboratory Testing

Laboratory tests were performed on each sample to determine specific physical and chemical properties of the samples. In order to provide uniformity in the test procedures and to provide a basis for future comparison with results of other soils that the authors have tested, all laboratory tests were performed on samples that were allowed to air dry and then were crushed using a rubber tipped pestle and ceramic mortar to pass a No. 40 sieve. While the authors understand that for some tests this procedure may have an effect on the results, it is a necessary sample preparation for the geochemical tests performed.

Laboratory tests performed included:

- Grain-Size Distribution (ASTM D 422-63)
- Atterberg Liquid and Plastic Limits (ASTM D 4318-95a)
- Shrinkage Limit (ASTM D 427-93)
- Linear Shrinkage (BS 1377)
- Specific Gravity (ASTM D 854-92)
- Cation Exchange Capacity
- Total Surface Area
- External Surface Area
- Carbonate Content
- 1:1 pH
- intrinsic compressibility

3.3 Test Procedures

As indicated above, applicable ASTM test procedures were used for a number of the tests. Linear shrinkage was determined using the bar shrinkage test as described in British Standard BS 1377:1975. Cation Exchange Capacity was determined using the 1 N ammonium acetate extraction method (Rhoades 1982). These tests were performed by a commercial soil testing laboratory (Harris Laboratory, Inc.) in Lincoln, Nebraska. Total surface area was determined using the Ethylene Glycol Monoethyl Ether (EGME) methods described by Cerato and Lutenegger (2002). External surface area was measured using the Nitrogen Adsorption Method using a BET apparatus. Internal Surface are was obtained by the difference. Carbonate content was measured using the gasometric Chittick apparatus as described by Dreimanis (1962), which provides a measure of both calcite and dolomite content. pH was measured on a 1:1 soil:water suspension using distilled deionized water.

One-dimensional intrinsic compressibility was conducted on five selected samples using incremental loading oedometer tests and the test procedure described by Burland (1990). Each sample was mixed from its natural water content to provide an initial water content of approximately 1.25 times the Liquid Limit.

4.0 RESULTS

4.1 Grain-Size, Classification and Composition

Results of the laboratory tests are presented in Tables 1 and 2. A summary of the grain-size characteristics is presented on the ternary diagram shown in Figure 2. As can be seen, there is a wide distribution in individual grain-size characteristics of the samples, however, the majority of the samples classify as "fine-grained" with more than 50% passing the No. 200 (0.074mm) sieve. The clay size fraction (<0.002 mm) ranged from 5 to 77 percent. The carbonate content was low as would be expected considering the composition of the parent rocks, and ranged from about 2 to 7 percent.

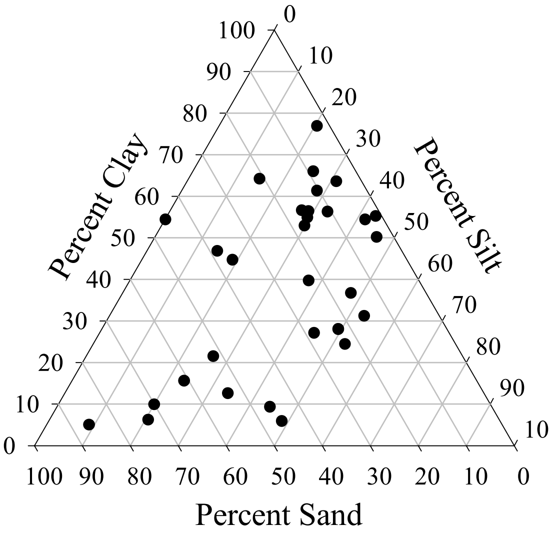


Figure 2: Ternary Diagram.

Figure 3 shows the location of the samples on a Casagrande Plasticity Chart. Liquid Limit values obtained from the Casagrande cup ranged from about 26 to 74 and PI ranged from about 13 to 33. Most of the samples tested generally fall along the A-Line and are classified as either CL or CH. Some of the samples with large sand fractions were nonplastic. Although many samples of Piedmont material fall well below the A-line, a specific attempt was made in this study to obtain more "clay" samples of this region.

The Specific Gravity ranged from 2.67 to 2.88. The pH of 1:1 soil:water suspensions ranged from 5.4 to 9.4.

The Activity of the samples is shown in Figure 4. Most of the samples fall between an Activity of

Table 1. Physical Properties of Residual Soil Samples.

		Atterberg Limits (%)					Grain Size Distribution			Activity
Sample	SG (Mg/m^3)	LL %	PL %	PI %	SL %	LS %	Clay Fraction % (< .002mm)	% Silt	% Sand (>.075 mm)	PI/Clay Fraction
Soil #1	2.75	NP	NP	-	27.6	0.2	5.0	8.9	86.1	-
Soil #2	2.70	NP	NP	-	19.5	5.7	21.5	26.5	52.0	-
Soil #3	2.88	31.9	NP	-	29.8	2.4	9.9	20.0	70.1	-
Soil #4	2.81	50.8	NP	-	24.6	9.7	44.7	18.9	36.4	-
Soil #5	2.80	NP	NP	-	33.8	1.1	6.2	20.1	73.2	-
Soil #6	2.78	60.9	43.9	17.0	18.2	14.7	76.9	20.4	2.7	0.22
Soil #7	2.76	57.1	26.0	31.1	23.1	10.9	55.2	43.5	1.3	0.56
Soil #8	N/A	68.9	41.1	27.8	16.5	16.7	61.3	28.2	10.5	0.45
Soil #9	2.72	59.6	39.0	20.6	19.0	14.8	54.4	41.7	3.9	0.38
Soil #10	2.74	49.9	31.9	18.0	18.7	12.8	39.7	37.3	23.0	0.45
Soil #11	2.72	49.0	31.0	18.0	8.1	10.8	36.7	47.6	15.7	0.49
Soil #12	2.67	53.0	34.5	18.5	25.6	12.8	50.2	46.2	3.6	0.37
Soil #13	2.82	53.6	29.2	24.4	17.1	15.9	63.6	31.1	5.3	0.38
Soil #14	2.68	47.6	28.8	18.8	28.8	7.3	31.2	53.1	15.7	0.60
Soil #15	2.69	49.1	26.5	22.6	18.0	14.5	46.8	14.7	38.5	0.48
Soil #16	2.80	29.3	NP	-	23.8	1.0	12.6	34.0	53.4	-
Soil #17	2.82	67.3	34.6	32.7	33.7	15.0	64.2	14.8	21.0	0.51
Soil #18	2.75	54.2	24.1	30.1	21.1	11.9	52.9	29.8	17.3	0.57
Soil #19	2.72	64.8	40.8	24.0	34.0	15.3	56.4	28.9	14.7	0.43
Soil #20	2.79	25.8	NP	-	24.9	3.1	15.6	23.5	61.0	-
Soil #21	2.81	74.0	50.5	23.5	15.0	15.6	66.0	25.1	8.9	0.36
Soil #22	2.73	35.7	22.5	13.2	24.2	5.8	24.4	52.5	23.1	0.54
Soil #23	2.73	34.3	21.3	13.0	17.8	9.0	28.0	49.3	22.7	0.46
Soil #24	N/A	38.0	18.0	20.0	18.0	9.3	30.1	34.1	35.8	0.66
Soil #25	N/A	57.7	30.5	27.2	17.0	12.5	56.6	27.4	16.0	0.48

Table 2. Chemical Properties of Residual Soil Samples.

Sample	Total SSA m^2/g	External SSA (m^2/g)	Internal SSA (m^2/g)	Ratio of Ext./Int. SSA	CEC (meq/100gm)	Calcite %	Dolomite %	Total Carbonates %	Relative Activity	pH
Soil #1	20	-	-	-	1.9	0.5	2.0	2.5	-	9.4
Soil #2	31	12	19	0.63	3.9	1.9	2.3	4.2	-	-
Soil #3	18	12	6	2.00	2.1	0.2	6.3	6.5	-	-
Soil #4	49	26	23	1.13	3.4	1.3	4.4	5.7	-	9.0
Soil #5	45	13	32	0.41	3.6	1.8	2.4	4.2	-	8.9
Soil #6	133	-	-	-	14.2	1.0	4.7	5.7	0.11	7.9
Soil #7	88	25	63	0.40	24.1	1.1	5.3	6.4	0.27	8.4
Soil #8	124	47	77	0.61	20.9	1.1	5.2	6.3	0.17	6.1
Soil #9	86	41	45	0.91	14.1	0.9	1.2	2.1	0.16	6.0
Soil #10	61	26	35	0.74	5.2	1.2	4.2	5.4	0.09	6.8
Soil #11	44	19	25	0.76	4.0	1.7	2.4	4.1	0.09	7.3
Soil #12	58	30	28	1.07	3.9	1.2	3.5	4.7	0.07	5.7
Soil #13	102	44	58	0.76	12.3	2.0	5.2	7.2	0.12	7.6
Soil #14	40	18	22	0.82	2.5	0.9	3.6	4.5	0.06	5.6
Soil #15	71	-	-	-	12.9	0.8	4.6	5.4	0.18	-
Soil #16	60	10	50	0.20	2.8	1.7	3.1	4.8	-	-
Soil #17	65	14	51	0.27	9.4	1.7	0.9	2.6	0.14	-
Soil #18	78	30	48	0.63	9.9	1.8	3.8	5.6	0.13	5.4
Soil #19	86	40	46	0.87	14.5	1.3	4.7	6.0	0.17	5.5
Soil #20	28	8	20	0.40	4.1	0.7	1.8	2.5	-	6.8
Soil #21	121	45	76	0.59	11.8	1.3	0.5	1.8	0.10	6.9
Soil #22	18	12	6	2.00	4.1	0.2	3.7	3.9	0.23	7.2
Soil #23	34	15	19	0.79	6.6	0.2	3.7	3.9	0.19	7.8
Soil #24	45	32	13	2.46	7.2	0.5	2.0	2.5	0.16	9.2
Soil #25	69	41	28	1.46	9.8	0.5	5.0	5.5	0.14	6.5

about 0.33 and 0.60. This indicates generally low activity associated with predominantly kaolinitic clay minerals.

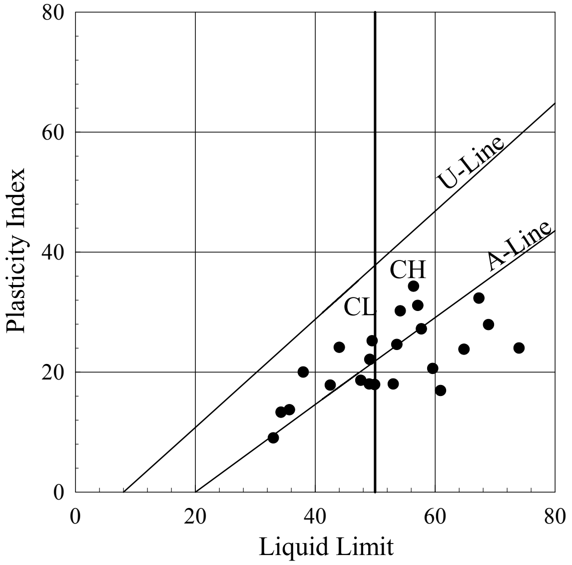


Figure 3. Plasticity Chart.

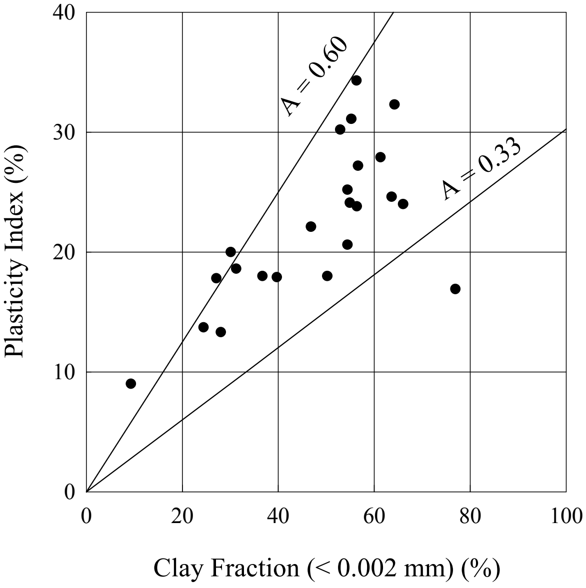


Figure 4. Activity Chart.

4.2 Cation Exchange and Specific Surface

As would be expected from soils with predominantly kaolinitic clay minerals, the Cation Exchange Capacity of the samples was relatively low, ranging from about 2 to 25 meq/100g. The CEC is related to the clay fraction as shown in Figure 5. The ratio of CEC/clay content may be defined as “CEC Activity” and would vary in the order: kaolinite<illite<montmorillonite. Values for pure clays with 100% clay size materials would be on the order of 0.05; 0.3; and 1.2, respectively. For fine-grained soils with a given geology, this ratio, like Activity, generally exhibits a relatively small range. While the relationship for these samples is not a strong as in some geologies, the results show that the CEC of the whole sample results from the clay fraction. Within the clay fraction however, there are likely to be constituents other that clay minerals. This accounts for some of the scatter in Figure 5. Even on the high end, the CEC is considered low in comparison to other soils that contain illitic and montmorillonitic clay minerals.

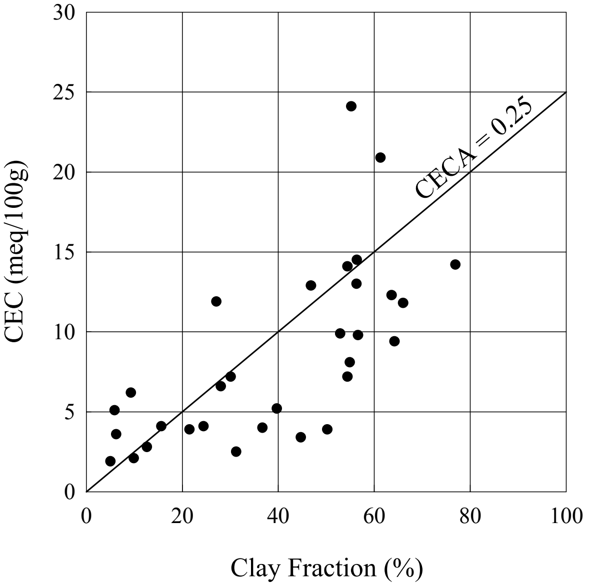


Figure 5. Cation Exchange Capacity Activity.

The Specific Surface Area (SSA) is also generally low as expected. Total SSA ranged from 18 to 133 m^2/gm. These data are consistent with low CEC and values of SSA generally less than about 30 m^2/gm are characteristic of predominantly kaolinitic clay minerals. Higher SSA values measured on a number of the samples suggest that their composition consists of mixed layer minerals. The ratio of External to Internal SSA provides an indication of mineralogy, and is expected to be very high for 1:1 lattice clay minerals and very low for expanding 2:1 minerals.

Theoretically, the value would be infinity for pure kaolinite since there is no internal surface area. Values obtained from the samples tested generally are in the range of 0.5 to 2.0, but the results are scattered since tests are performed on the whole sample. Samples with ratios less than about 0.2 indicate the presence of expanding clay minerals. The relationship between SSA and CEC is shown in Figure 6. The ratio of CEC to SSA is defined as the "Surface Charge". Within a single clay mineral suite, it is generally expected that CEC and SSA would be linearly related.

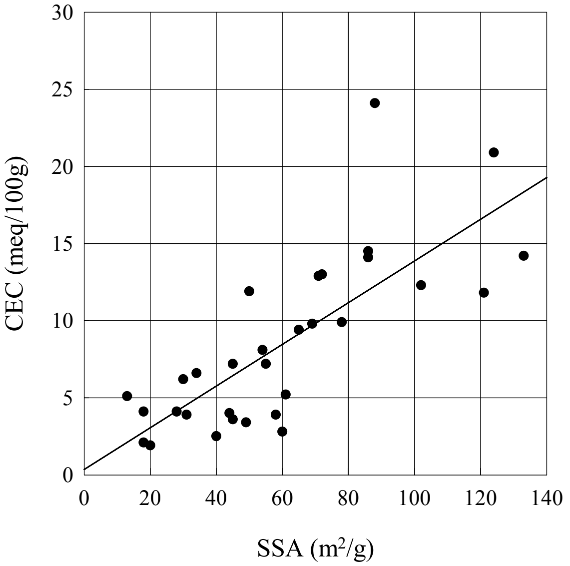


Figure 6. Surface Charge.

The general trend for the results from this study is an increase in CEC with increasing SSA. however, there is some scatter shown in Figure 6. Figure 7 shows the relationship between clay fraction and SSA. As can be seen, there is a strong trend, which is to be expected if CEC and SSA are related. As was done with CEC, the ratio of SSA to clay fraction may be defined as the "Surface Area Activity." The data in Figure 7 suggest a value of about 1.45 for Surface Area Activity of Residual Soils. Similarly, as with CEC, it would be expected that this ratio would vary in the order kaolinite<illite<montmorillonite. Values for pure clays with 100% clay size materials would be on the order of 0.15; 0.8; and 8.0, respectively.

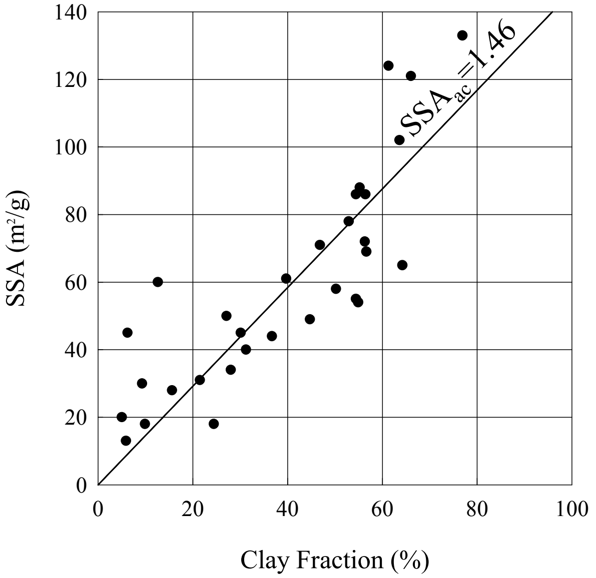


Figure 7. Surface Area Activity.

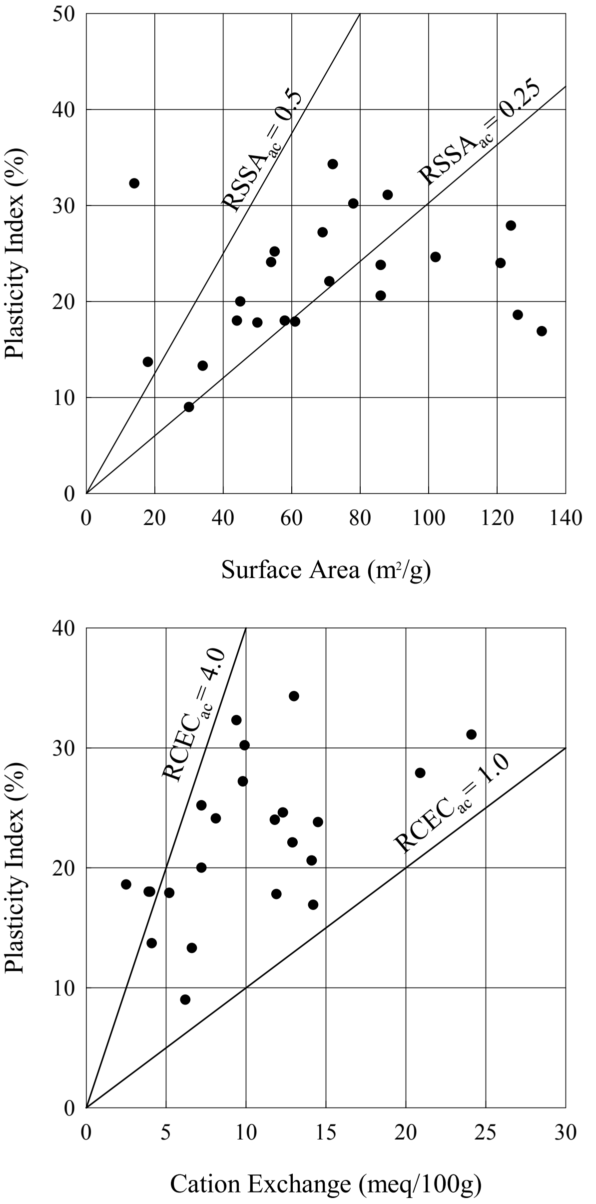
An alternative to the traditional definition of Activity of fine-grained soils can also be considered using the SSA and CEC by defining "Relative Surface Area Activity" and "Relative CEC Activity" using the Plasticity Index and the SSA and CEC, respectively. Figure 8 shows these values for the soils tested.

4.3 Shrinkage Characteristics

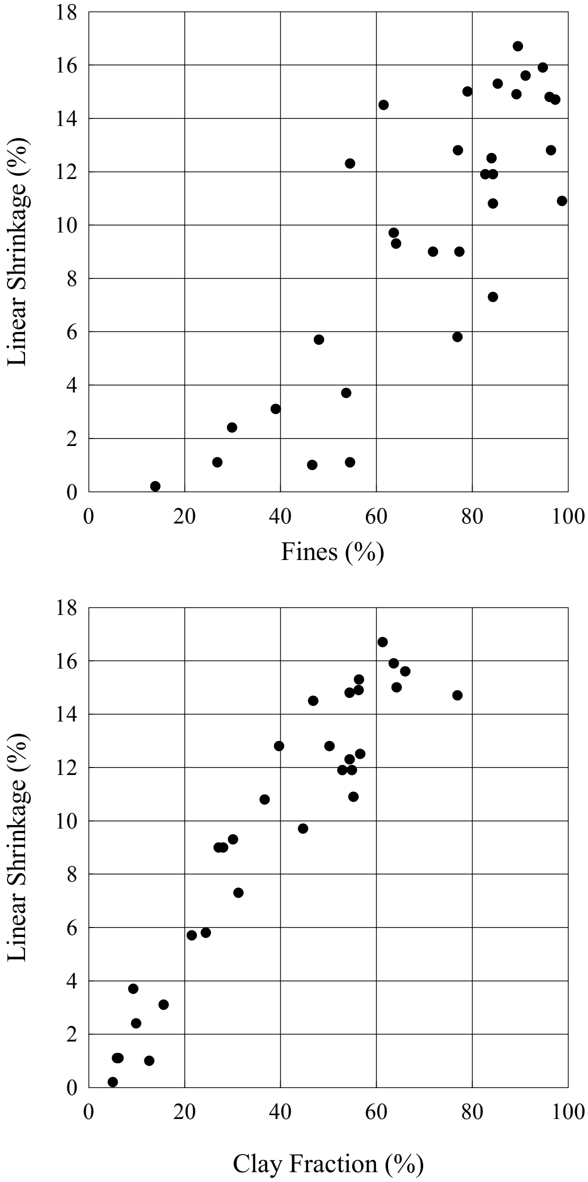
Shrinkage characteristics, like Atterberg Liquid and Plastic Limits, are conducted on remolded samples, however, they may be useful index tests. For samples with low clay content or low fines content, Shrinkage Limit values were close to the Plastic Limit. Shrinkage Limit did not show any trend with grain-size, CEC or SSA. The relationship between Linear Shrinkage and fines content and clay fraction is shown in Figures 9a and 9b, respectively. As can be seen there is a very strong relationship between linear shrinkage and clay fraction. Since SSA is dependent on clay content, a similar correlation could be established between Linear Shrinkage and SSA.

4.4 Intrinsic Compressibility

The e-log p curves obtained for the five remolded samples are shown in Figure 10a. These curves can be represented in normalized fashion by using the void ratio at the Liquid Limit as indicated in Figure 10b. Babu et al. (1992) have suggested that residual soils can be placed into this framework. They suggested that the individual curves generally tend to collapse onto a single line, shown for reference in Figure 10b. As can be seen in Figure 10b the results from the current investigation did not follow a single relationship and fall above the trend line suggested by Babu et al. (1992). While the samples tested in this study are not sedimentary materials, they are "geologic materials" and the results shown in Figure 10b are consistent with other tests performed on a number of sedimentary clays by the authors and with test results reported by Burland (1990).



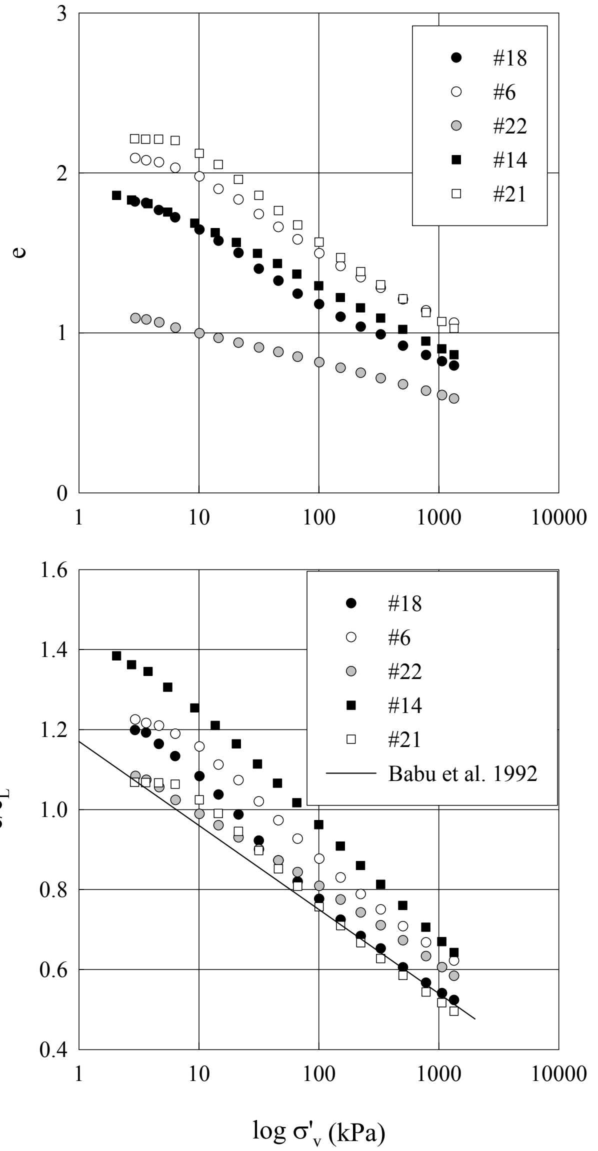
Figures 8a & 8b. Relative Activity and Cation Exchange Activity.



Figures 9a & 9b. Variation in Linear Shrinkage with Fines Content and Clay Fraction.

5 CONCLUSIONS

The results of laboratory tests performed on 25 residual soil samples from the Piedmont Physiographic Province of the Eastern United States show wide range in characteristics. All of the samples show low Cation Exchange Capacity and low Specific Surface. CEC and SSA are related to the percentage clay fraction in the whole sample. The “SSA Activity” and “CEC Activity” may provide useful indication of mineralogy, when compared with other soils. Linear Shrinkage was found to be directly related to the clay content.



Figures 10a & 10b. Intrinsic Compressibility Curves.

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