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Comparative Analyses Of Physiochemical Assessment Of Sedimentary And Basement Clay Soils, Southwestern, And Nigeria: Implication For Engineering Applications

Ikubuwaje C.O[1], Fakolade O. R[2]. Rotimi I. A[3]
School of Engineering, Federal Polytechnic, Ado-Ekiti, Nigeria
[1, *]Corresponding Author: tosofakolade@gmail.com

***Abstract*—Studies that used Physiochemical quantifications analyses to explain engineering behavior of soils are limited. This study attempts to evaluate and compare physiochemical properties of Sedimentary clay (SC) and Basement clay (BC) with a view to determining the soils' potentials for engineering applications. Ten disturbed samples of the soils were collected and analyzed in the laboratory using Index, geochemical and Mineralogical techniques. The results revealed inorganic clay of Kaolinite clay mineral, indicating non-swelling potentials. The consistency limits classify the SC as fat clay and BC as lean clay. This indicates BC as more competent soils than those of SC. The grain size analysis revealed more clay and lower sand fraction for SC than those of BC, thereby indicating better workability, compaction and shear strength properties for the BC soil samples than SC. The geochemical results revealed more stability and shear strength, associated minerals and lateritization and less hydrophobic properties for BC soil samples than those of SC. The weathering indices showed lower kaolinization for BC soil samples, therefore, thereby making BC soil samples more relevance and suitable for civil engineering construction materials than those of SC.**

Keywords—Geochemical Quantifications, Shear Resistance, Stability, and Inorganic Clay.

Introduction

The physicochemical properties of earth materials arise from their fabric (texture and structure) and mineralogical compositions. Fabric and mineralogical compositions usually determine the response of these earth materials to events occurring during construction and operation of engineering works (Mukherjee, 2013). Vast quantities of earth materials contain clays which are important to the construction engineer because their structures frequently rest on clayey formations (Richard and Myrle, 2012). In engineering practices, clay is generally seen as a problematic soil. When these soils are used as embankments and substructure fills, to impound water; such as earth dams; during construction of slurry walls and landfills, it becomes more important to address (Nazile, 2018). Through recognition of the characteristics of clay, the civil engineer can overcome the challenges associated with clayey formations in construction and operation of engineering works. The understanding and prediction of the engineering properties of clay soils are of vital importance in geotechnical engineering practice. The link between the mineralogy of parent rocks and engineering properties of the derived lateritic clay in the southwestern part of Nigeria has been studied (Badmus, 2010; Bayewu et al., 2012). However, most of these works, according to Adeyemi (1995), placed little emphasis on the quantitative aspect, which is more important in geotechnical engineering practice. In addition, previous studies on clay soils were rather centered on provenance and industrial applications especially for refractory and ceramics usage (Olaolorun and Oyinloye, 2010; Akinola and Obasi, 2014; Abel et al., 2012: Akinyemi et al., 2014). Hardly had any research work be done on the physicochemical quantitative analysis of engineering properties and performance of clays especially from the sedimentary part of southwestern Nigeria, therefore, the necessity for this study. The comprehensive information on the soils geotechnical properties required to ensure safe design and the construction of civil engineering structures is very crucial. Studies on soil behaviour that do not consider the physicochemical properties of clay soils may be missing important information regarding the soil's geotechnical properties. This is because most physical and mechanical behaviours can be explained by the soil's physico-chemical and microstructural properties (Nazile, 2018). To backup this short coming, some authors (Kamtchueng et al. 2015; Millogo et al. 2008) suggest that chemical and mineralogical analysis must be conducted on soils in addition to the geotechnical classic tests**.** Much more remains to be learned about the interrelation of physicochemical phenomena and engineering performance. The present work therefore investigates physicochemical properties of clay soils in and around sedimentary and basement complex terrains of Ondo state.

2. The Study Area

These study areas are located within Ondo State which is located in the southwestern sector of Nigeria.

It lies within latitudes 6°00′ and 7°55′N and longitudes 4°25′ and 5°59′E (Figure 2). The study area is characterized by humid tropical climate with distinct wet and dry seasons. Annual rainfall reaches mean value of about 1350mm and 2000mm for northern and southern parts respectively coupled with high temperatures reaching a peak of about 32^{o}C for the northern part and 24 ^{o}C for the southern part. The surface soils in the study area are composed largely of residual soils which are weathering products of the basement rocks. The soils are reddish to brownish in color, having fine to coarse grained. In the sedimentary, the geologic sequence is composed of the Nkporo Shale, Upper Coal Measures, Imo Shale Group, Coastal Plain Sands (Benin Formation) and F

Quarternary Coastal Alluvium (Fig. 1). The Nkporo Shale is made up of shale, sandy clay and lenses of sand. The Upper Coal Measures consists of clay/sandy clay, sand, limestone and shale. The Imo Shale Group is composed of shale while the Coastal Plain Sands has alternations of clay/sandy clay and clayey sand/sand. The Quarternary Coastal Alluvium is composed of an alternating sequence of sand and silt/clay (Jones and Hockey, 1964)

3. Material and Methods

3.1 Sampling

The samples used for the analysis were collected from twenty (10) different locations within the study area (Fig. 2). A disturbed method of sampling was employed in collecting the samples. Care was taken when collecting the samples to ensure that the analyzed samples are true representatives of the in-situ materials. Index tests were done at the laboratory of applied geology department of Federal University of Tech. FUTA and X-ray diffraction (XRD) was carried out at department of geology University of Ibadan UI., Nigeria, X-ray fluorescence (XRF) was done at the Laboratory of Environmental Science and Engineering of University of Johannbourn South Africa.

3.1. Laboratory Test

3.1.1 Particle Size Analysis

The particle size test of the soil samples was carried out on a mechanical sieve shaker. in accordance with wet sieving British Standard, BS 1377 [1990] test 7a standard. The sample materials were allowed to drain and carefully transferred to a tray and placed in the oven to dry at temperature of 105 to 110°C overnight. The dry soil was then passed through a nest of the complete range of sieves to cover the size of particles present down to 63 μm sieve. The percentage weight retained and the percentage passing in the sieves were determined. The percentage passing versus particle size distribution is plotted as shown in Figures 3a and 3b respectively.

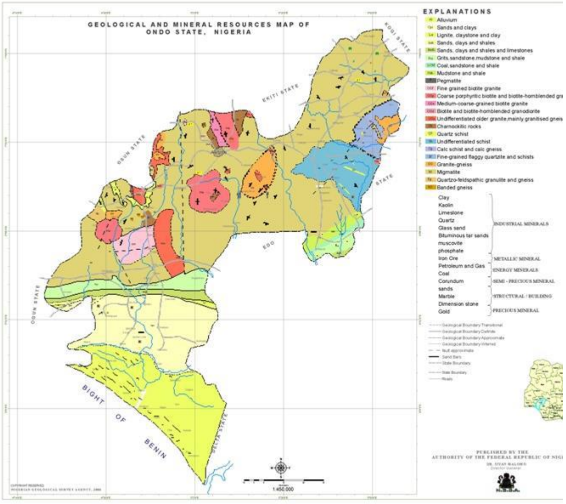

Fig 1: Geological Map of the study area

3.1.2 X-Ray Fluorescence (XRF) Analysis

A Phillips Analytical PW1480 X-Ray Fluorescence spectrometer using a Rhodium Tube as the X-ray source was used. The technique reports concentration as % oxides for major elements. Soil samples were pulverized in a milling pot to achieve particle sizes <75 μm. Major oxides determined were used for various classifications and identifications of soils engineering behaviour.

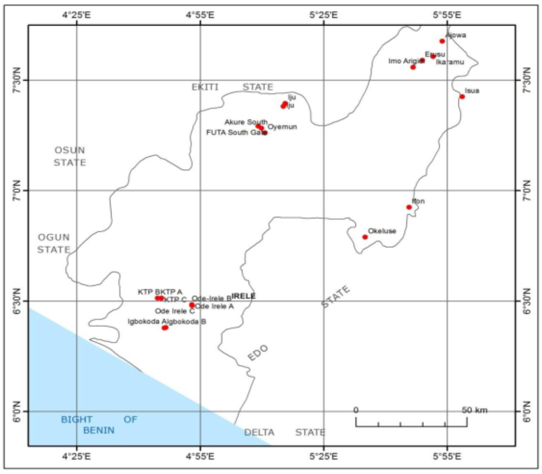

Fig 2: Map showing sample locations

Silica/sesquioxides ratios and weathering indices were also carried out using Rossiter (2004) silica-sesquioxide ratio classification and the molecular proportions of the oxides (Hanois, 1988; Fedo et al., 1995). Other geochemical quantitative analyses such as Associated Minerals (Mukherjee, 2013), Clayeyeness/ Siliceousness, Bonding property (Sridharan and Allam, 1982) and Stability after Goldberg (1989) were also carried out.

3.1.3 X-ray diffraction (XRD) analysis

The sample powder were analyzed using a Rigaku D/Max-IIIC model diffractometer, PW 1800. Diffraction diagrams were recorded using a scanning rate of

102theta/min/cm, with a Cu-filterted Fe K-alpha radiation. The area method was employed in calculating the relative proportions of the identified minerals. The XRD analysis was carried out at the University of Ibadan, Nigeria. .

4.0 Results and Discussion

4.1.1 Particle Size Analysis

Grain size distribution is one of the most important elements in the design of structures on, in, or composed of soils (Naresh and Nowatzki, 2006). The results of the grain size distribution and the fraction distribution patterns of the studied soils are presented in Table 1 and in Figures 3. The average values of sand, silt and clay contents are as follows; 25.36%, 28.94% and 45.01% for SC soil samples and 44.14% , 22.88% and 31.74% for BC ones respectively. SC samples contain higher clay content than BC; this observation may be due to higher degree of weathering which is associated with sedimentary terrain. The results showed that BC soil samples have higher amounts of sand-size particles and lower amount of clay fractions than those of SC ones. This indicates more shear strength for BC soil samples than those of SC. Hence, BC soil samples possess better engineering properties to serve as construction materials in road stabilization and in brick making due to higher shear strength properties than those of SC.

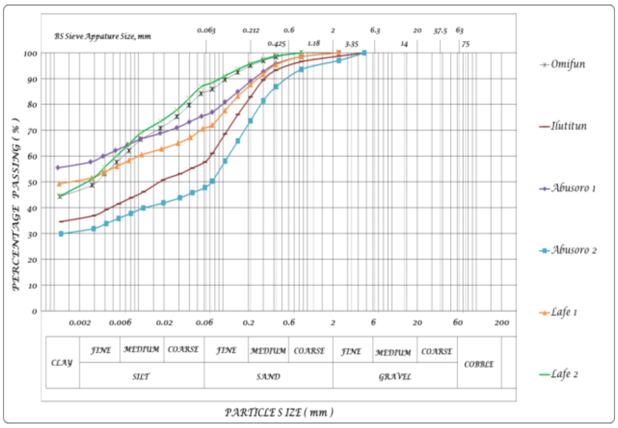

Fig. 3a. GSA Curve for Sedimentary Clay

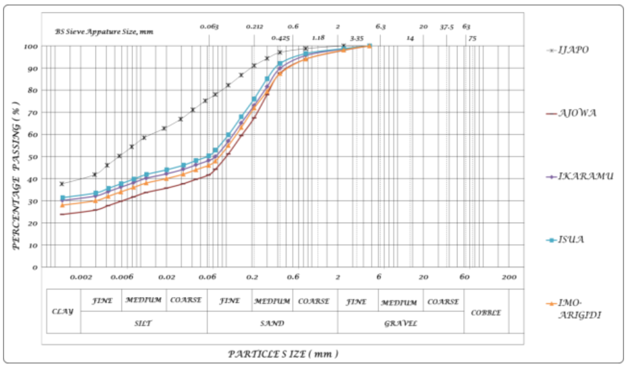

Fig.3b: GSA Curve for Basement Clay.

Table 1: *Particle Size Analysis*

Terrain	Gravel	Sand	Silts	Clay	Fines
SC 1	**0.0**	**14.2**	**39.1**	**46.8**	**86**
SC 2	**1.3**	**37.6**	**25.7**	**35.4**	**61**
SC 3	**0.0**	**23.0**	**19.9**	**57.1**	**77**
SC 4	**1.9**	**24.1**	**38.1**	**35.8**	**74**
SC 5	**0.0**	**27.9**	**21.9**	**50.2**	**72**
Ave	0.6	25.4	28.9	45.1	74
BC 1	**0.0**	**22.0**	**37.8**	**40.2**	**78**
BC2	**2.0**	**53.8**	**19.2**	**25.1**	**44**
BC3	**1.4**	**48.7**	**18.6**	**31.4**	**50**
BC4	**1.2**	**46.0**	**20.1**	**32.7**	**53**
BC5	**1.9**	**50.2**	**18.7**	**29.3**	**48**
Ave	1.3	44.2	22.9	31.7	55

4.1.2 Consistency Limits

The plasticity chart can be used to predict the compressibility of clays and silts (Cassagrande,1947).The results of the consistency limits of the studied samples and plasticity classification are presented in Table 2 .

Table 2.: Consistency Limits

Terrain	Specific gravity	LiquidLimit	Plastic Limit	Plasticity Index
SC 1	2.67	**52.3**	**31.1**	**21.2**
SC 2	2.64	**41.2**	**24.4**	**16.8**
SC 3	2.73	**64.3**	**26.8**	**37.6**
SC 4	2.68	**55.8**	**24.3**	**31.5**
SC 5	2.68	**38.8**	**22.2**	**16.6**
Average	2.68	50.5	25.8	24.7
BC 1	2.64	**42.4**	**23.0**	**19.4**
BC2	2.72	**36.3**	**19.3**	**17.0**
BC3	2.64	**42.3**	**20.8**	**21.5**
BC4	2.62	**44.2**	**19.2**	**24.5**
BC5	2.66	**46.0**	**24.3**	**21.7**
Average	2.66	42.2	21.3	20.8

The average Liquid Limits Value is 50.5% for SC soil samples and 42.2% for BC ones, this showed that SC soil samples possess more moisture content than those of BC. This attributed to more amount of clay content of SC soil samples. This reflected in the plasticity of SC soil. The average Plasticity Index Value of SC soil samples is 24.7 and that of BC ones is 20.8. In comparison, SC soil samples possess higher plasticity than those of SC. This is due to more amount of clay content. This indicates that SC soil samples fall within clay of medium-high plasticity, while the BC soil samples plot within plasticity portions (Figure 4). This suggests higher settlement properties for SC soil samples than those of BC in engineering construction works especially in road and dam construction works. Hence, BC soil sample will not pose settlement challenges in construction works like SC ones.

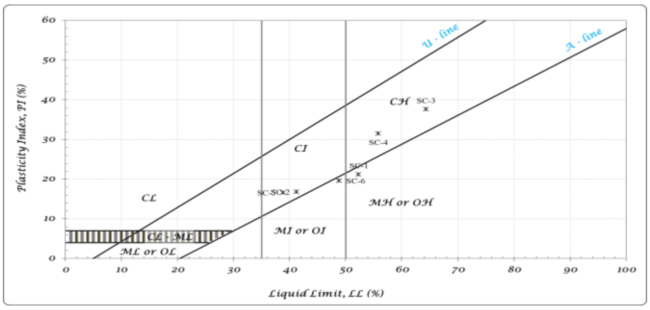

Fig. 4a: Plasticity Chart for SC Samples

Table 4: Major Oxides

	SC (%)	BC (%)
Oxides	Mean	Mean
SiO_2	57.52	50.37
Al_2O_3	34.69	27.2
Fe_2O_3	3.71	15.69
MgO	0.09	0.12
CaO	0.08	0.85
MnO	0.01	0.12
P_20_5	0.14	1.88
Na_2O	0.01	0.21
K_2O	0.44	0.21
TiO_2	2.79	2.32

4.2.0 Geochemical Analysis

4.2.1 Associated Minerals

The plasticity of clay decreases as the proportion of associated minerals increases according to Mukherjee, (2013). The results of the average oxides by wt % of the associated minerals in the studied samples are presented in Table 4. The result for SC soil samples is 7.79% and for BC ones is 21.34%. The results showed that BC soil samples possess more associated minerals than those of SC. This may be due to more degree of weathering activities in the sedimentary terrain than that of basement terrain. Owoyemi and Adeyemi (2018) reported 2500mm rainfall for Sedimentary and 2000mm rainfall Basement terrains.

This indicates that BC soil samples have lower plasticity than those of SC. This makes BC soil samples possess better engineering and more suitability as brick clay and land liner than those of SC ones.

4.2.2 Clayeyness and Siliceousness

The result of average wt% of clayeyness ($Al_2O_3/Si0_2$) and Siliceousness (SiO_2/Al_2O_3) are presented in Table 3. The results of SC soil samples are found to be 0.61% and 1.66% and those of BC were 0.54% and 1.84% respectively. In comparison the SC soil samples have more clayeyness and have less silica than those of BC. This is attributed to more amount of alumina and less silica in SC soil samples to BC ones (Table 4&5). This is also reflected in the more plasticity than those of BC. This suggests higher settlement properties for SC soil samples than those of BC in engineering construction works. Hence, BC soil sample will not pose settlement challenges in engineering construction works like SC ones.

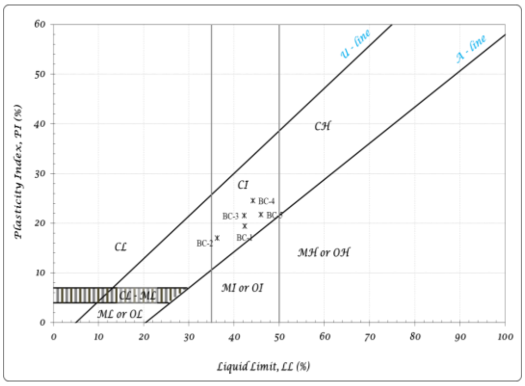

Fig. 4b: Plasticity chart for BC Samples

4.2.3 The silica–sesquioxide ratio (SSMR)

The silica–sesquioxide ratio is an indication of the degree of laterisation (Rossiter, 2004). The results of average silica-sesquioxide molar ratio (SSMR) values by w% of studied soil samples are presented in Tables 5. The value for the SC soil samples is 1•52 and for those of BC is 1.12. In comparison, BC soil samples are more lateritised than those of SC Rossiter (2004). This is due to occurence of more ferric oxide in BC soil samples (Table 4). This indicates that BC soil samples possess better crystallization of accumulated sesquioxides in the pore spaces and the formation of concretionary structure (Malomo, 1989) than those of SC. This also resulted in better engineering properties in term of shear strength, compressibility, compaction and workability (Table 3). Therefore, BC soil samples are more suitable as soil stabilizer, for bricks construction and as fill materials and than those of SC.

4.2.4 Shearing resistance Properties

Sridharan and Allam (1982) referred to total content of elements of Ca, Mg, Al and Fe in a soil as cementation compounds. The average results of the cementation compounds values are presented in Table 5. The SC soil samples is found to be 38.57% while those of BC is 44•59%. In comparison, the BC soil samples have more bonding properties than those of SC. This observation may be attributed to more amount of Fe_2O_3 and CaO concentrations in BC soil samples than those of SC. This implies that BC soil samples possess better shearing resistance than those of SC. The clay fabric as determined by inter-particle forces and manifested as shearing resistance at inter-particle contacts have a great bearing on the consistency limits, shrinkage, compressibility and shear strength characteristics (Sridharan, 2012). This accounts for more suitability of BC soil samples than those of SC as engineering construction materials especially for brick making, in road and dam constructions

Table 5.:Quantitative Analysis of the Geochemical Properties of the soil samples compared with Standard

Name	SC	BC	Kaolin	Properties
Associated Minerals	7.79	22.52	15.93	**Increases in CEC**
$Al_2O_3/Si0_2$	0.61	0.54	0.67	**Clayeyeness**
SiO_2/Al_2O_3	1.66	1.84	1.50	**Siliceousness**
CIA	98.4	89	91.02	**Weathering indices**
CIW	99.7	96	99.06	
PIA	100	95.80	99.00	
$Al_2O_3 + Fe_2O_3$	38.40	42.88	34.88	**Stabilization**
AFMC	38.57	44.59	35.30	**Shear Strength**
$SiO_2/ Al_2O_3 + Fe_2O_3$	1.52	1.19	1.47	**Laterization**
Nature of Soil	Lateritic	Lateritic	Lateritic	**Classification**

AFMC = Al2O3 + Fe2O3+ MgO+ CaO CIA = {Al2O3 / (Al2O3 + CaO* + Na2O + K2O)} x 100 CIW = {Al2O3 / (Al2O3 + CaO* + Na2O)} x 100 PIA = {(Al2O3 – K2O) / ((Al2O3 - K2O) + CaO* + Na2O)} x 100 TDS = {(Ca, Mg, Na and K). LHD = Low Heat Duty MHD = Medium Heat Duty HHD= High Heat Duty

4.2.5 Stabilization property

The combination of aluminum and iron oxides has been referred to as stabilizer in clay engineering (Goldberg, 1989). The results of the average value by wt% of the stabilization properties are presented in Table 5. The result of SC soil samples is 38.40% while that of BC is 42.88%. In comparison, BC soil samples have more stabilization properties than those of SC. This is attributed to more concentration of iron oxides in BC soil samples than those of SC (Table 5).This indicates quicker coagulation, increasing micro aggregation, less water take up and clay swelling of BC soil samples than those of SC ones according to Goldberg (1989). Therefore, BC soil samples possess better stabilizing potential when used as materials in engineering construction of earth dams, highways, embankments, airfields as well as foundation materials than those of SC.

4.2.6 Weathering Indices Properties

The greatest variation in the engineering properties of clays can be attributed to the degree of weathering that they have undergone (Bell, 2007). The result of the average of the three weathering indices of the soil samples are presented in Table 4.14. The SC soil sample has 99.4% while the BC ones is 93.6%. This shows that SC soil samples had under more kaolinization than those of BC. This is attributed to the differences in each terrain and the environmental conditions such as amount of rainfall, nearness to water table and more erosion activities. This indicates that SC soil samples had undergone more destruction of structures either micro or macro leading to development of more pore-size distribution, higher moisture contents and higher plasticity than those of BC Rahardjo et al., (2002). It is, therefore, reasonable to win soils for construction purposes from basement terrain.

4.3.0 Mineralogical Analysis (XRD)

In geotechnics, it is important to find the type of minerals present in clay, as well as their proportions in order to understand the mechanical behavior (Nazile, 2018). The result of the quantitative interpretation of patterns in Figure 5 obtained from XRD analyses are presented in Table 5. The results showed the dominance of kaolinite in all the samples and trace proportion of muscovite, hematite, anatase, smectite, albite and illite; this result is in agreement with the findings of Ajay and Agagu (1981). This is due to similarity in source rock lithology. This indicates lowest swelling and shrinkage potential, lowest base exchange capacity and low surface area properties, Grim (1968). Therefore, all the clay soil samples are useful in one area or the other as engineering construction materials. In comparison, in both SC and BC soil samples the average value of kaolinite content was 43% with traces of Muscovite, Hematite and Anatase in SC samples and traces of Smectite, Albite and Illite in BC samples. The average of 43% kaolinite content was also in agreement with the 43.64% kaolinite content in kutigi clay of Akhirevbulu et al., (2010). This indicates similarity in the predominant mineralogy composition (Table 5). The insignificant proportions difference in the trace mineral constituent may not result into significant differences in engineering properties. However, the presences of Smectite and Illite of BC samples may enhance its plasticity properties. This may account for suitability of samples in bricks making and slurry materials. While the presence of muscovite may account for more clay content and lower shear strength properties of SC soil samples.

5.0 Conclusions

The index, geochemical and mineralogical properties of natural clay soils from both sedimentary and basement areas of Ondo State were evaluated. The results revealed that the studied soil samples are inorganic clay of kaolinite clay minerals. Therefore, they are useful in one area or the other as engineering construction materials.

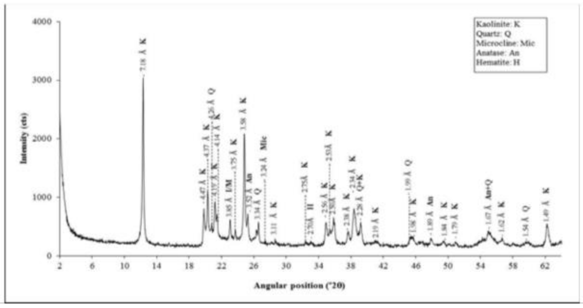

Fig 5: X-ray diffraction of the study soil

Table 5: XRD of Samples (wt. %)

Minerals	SC		BC	
Locations	SC 1	SC 2	BC 1	BC 2
Kaolinite	44	41	45	40
Quartz	50	49	40	45
Calcite				
Smectite		2	2	3
Albite			5	3
Anatase	3	3		4
Pyrite				
Chlorite				
Illite		2	4	5
Muscovite	4	2	4	
Hematite	2	1		

The mineralogy revealed that SC and BC soil samples contain different mineral constituents such as muscovite, hematite, anatase, smectite, albite and illite but in very negligible proportions which account for differences in their engineering properties and performances. The study showed that BC samples are clay with better engineering properties compared with SC ones in terms of compressibility, compaction, workability and shear strength. The SC samples, on the other hand, possess better environmental engineering properties compared with BC ones in terms of relative resistance to piping and cracking. The geochemical quantification of the soils engineering properties give insight into the missing information which the index and mineralogical analyses were not able to deduce especially in term of stability and shear strength. The differences in the respective soil samples property make it unique and suitable for different engineering applications. Basement terrain soil samples possess more associated minerals and are more lateritised than those of sedimentary terrain.

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