Geotechnical and Mineralogical Appraisal of Shale and Claystone Facies of the Maastrichtian Patti Formation, Bida Basin, Nigeria

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Abstract- The need for construction materials in the rapidly developing areas around Federal Capital Territory, Abuja, Nigeria cannot be overemphasized and this study was undertaken in line with this need. The study area, located about 60km from Abuja, is underlain predominantly by shales and claystones of the Patti Formation. These argillaceous rocks may offer locally sourced construction material if they meet certain specifications, however to date, there has not been a geotechnical study of these rocks. The geotechnical properties and the mineralogy of the shale and claystone were investigated to evaluate their suitability for civil engineering works. Particle size distribution, Atterberg limits and X-ray diffraction analyses were performed on fifteen shale and claystone samples collected from three localities (along an approximately 25km transect) for determination of their geotechnical properties and mineralogical composition. Mineralogical data obtained show the samples are dominated by kaolinite with minor amount of montmorillonite. Quartz and minor amounts of microcline, rutile and anatase dominate the non-clay mineral fraction. Particle size data indicate high proportion of fines and they are well graded. The Atterberg limits indicate that the samples have average values of liquid limit of 51%, plastic limit of 23%, plasticity index of 29% and shrinkage limit of 13%. These indicate they are of medium compressibility, low to medium shrink/swell potential, marginal expansive rating and low permeability. High bulk specific gravity (average of 2.61) suggests the samples are inorganic and this is supported by the consistency limits values. Generally, results indicate the shale and claystone can be useful as stabilizing materials in civil engineering works. In addition, the marginally expansive nature of the shale and claystone, low permeability and intermediate to high plasticity may make them suitable as road subgrade.

Keywords- activity, Bida Basin, Gerinya, Kaolinite, plasticity, Patti Formation

1 INTRODUCTION

1.1 BACKGROUND

Shale, as used in the present study is laminated and grayish in colour while claystone is fine grained, brown to white compacted and massive clays. The study of shales and claystone in sedimentary basins have received local and international attention with diverse objectives ranging from evaluation of industrial application, geotechnical properties, provenance and hydrocarbon reservoirs (Nton and Elueze, 2005; Ojo et al., 2011). Geologic materials (soils and rocks) are very critical in engineering design and construction of buildings, landfills and roads. The mineralogical composition of clay influences geotechnical properties, particularly, swelling nature of clay (Ogunsanwo, 1995; Alao, 2011). Generally, texture and composition of soil and rock influence engineering properties in respect of the ability of material to withstand engineering structure. Hence, understanding of soil compositions, their unconfined compressive strengths as well as their structural make-up helps geotechnical engineers in their tasks (Lee et. al, 1983; Jacquelyn, 2000).

Okogbue et al. (2010) compared geotechnical properties of Abakaliki, Awgu and Enugu shale formations and their likely use for construction and suggested that Abakaliki shale may be satisfactory as fill and embankment material but may not be good as sub base material due to high liquid limit and plasticity index. Adeshina et al. (2017) studied shales (Enugu, Ameki and Imo) in Anambra Basin for use as landfill liners and suggested that high hydraulic conductivity and swelling potentials of the shales would not make them suitable for natural clay liners. These aspects of research, however, have not been extended to the shales and claystone in the southern Bida Basin despite its substantial occurrence both in the subsurface and outcrop levels. Most previous studies of shales in the Bida Basin have been on the evaluation of hydrocarbon source rock characteristics, biostratigraphy and provenance (Agyingi, 1993; Ojo and Akande, 2008; Ojo et al.2016).

The present paper is therefore designed to determine the geotechnical properties (texture, consistency limits, specific gravity) and mineralogical composition of the shales and clays which are exposed at Gerinya, Ahoko Quarry and Idu areas (Fig. 1). Their suitability as civil engineering construction materials are also examined on the basis of the outlined parameters. In recent time, shale has been applied for diverse purposes including embankment, landfill, pavement and other civil engineering works. However, shale often presents some problems such as getting weathered from a hard, rock-like material to a fine-grained soil, particularly when used as foundation or construction material. This degradation occurs over a long time, and many engineering problems such as settlements and slope failures may result several years after construction (Gomez-Gutierrez et al. 2011). Diverse construction work done globally on shale or using shales have experienced failures, hence, it is important to assess their geotechnical properties and determine their best applications.

1.2 GEOLOGICAL SETTINGS OF THE STUDY AREA

The Bida Basin is a NW-SE trending intracratonic sedimentary basin in Nigeria, West Africa which is contiguous with the Anambra Basin to the southeast and the Sokoto Basin to the northwest (Fig. 1). Authors have provided evidences such as Landsat images and

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geophysical data in support of rift hypothesis for the origin of Bida Basin (Kogbe et al., 1983; Ojo and Ajakaiye, 1989). The popular opinion is that the basin's structural evolution was associated with the mega Benue trough structure which has been proven to have evolved as a result of fragmentation and separation of African and South America plates in the mid Cretaceous times. The basin presents an oval shape with thickening of the argillaceous rocks towards the centre of the basin. Depth to basement in this area is about 3.5km and the sedimentary fills which are essentially clastics, are generally flat-lying.

1.3 STATIGRAPHY

The stratigraphic framework of southern arm of the basin which is focus of this study, presents an undeformed, parallel bedded clastic sequence of about 3.5km thick, continental to shallow marine sediments of late Cretaceous age. The oldest unit, the Lokoja Formation overlies non-conformably Pre-Cambrian crystalline rocks (consisting of schist, gneisses and granites) and it is succeeded by the Maastrichtian Patti Formation. The overlying Patti Formation, focus of this study consists of more mature sandstones, claystones, siltstones, and shales deposited in shallow marine to non-marine swamps. The Patti Formation is capped by a shallow marine Agbaja ironstone formation of late Maastrichtian age.

At the investigated sites (Gerinya, Ahoko, Idu), the lithostratigaphic sections, which are essentially roadcuts and a quarry consist of rhythmically bedded shales, claystones and ferruginised siltsones and concretionary ironstones (Figs. 2 and 3). At Ahoko Quarry and Idu Roadcut sections (about 20m thick each), the grey to dark shale is typically at the base and passes upward into claystone. At Gerinya Roadcut section (about 18m thick), the basal part of the section consists of fine-grained sandstone and it is overlain by shale. Generally, the shales in the study area are parallel laminated, grayish and carbonaceous and silty towards the top. In all the investigated sections, the shale and the claystone are friable to slightly indurated depending on the level of ferruginization. The overlying claystones are massive and brown to milky and occur at the upper part of the sections. Average thickness of the claystone and shale beds is 0.5m, though claystone beds in places may be as thick as 4m. Vertical fractures cutting through the shales and the claystone beds are common at the sites.

2 MATERIALS AND METHODS

The ridges, freshly cut along the road and the quarry, were sampled and logged along the vertical profile (Figs. 2 and 3) with the purpose of evaluating their engineering construction resource potential (e.g. liners in landfill, embarkment for dams and road subgrade. The samples were collected from the Gerinya Roadcut, Ahoko Quarry, and Idu Roadcut in the southern Bida Basin, Nigeria (Fig. 1). Sampling of the shale and claystone were made at representative intervals, between 0.3 to 1.5m, along the vertical section of the ridge (Figs. 2 and 3). Samples were selected at intervals such that the lower, middle and upper parts of the exposure were investigated particularly at Gerinya and Ahoko sites. Hammer and chisels were used to collect the samples and the samples were stored in a well labelled polymer bags prior to analysis and the friable samples were preferentially selected for the analysis. It is important to note that the shales and claystones (often referred to herein as soils) investigated in this study are friable to weakly indurated and can be analysed with routine soil techniques. Laboratory investigations were carried out on fifteen samples, which were disaggregated using mortar and pestle at the Civil Engineering Department, University of Ilorin and these include: particle size distribution, Atterberg limits, shrinkage limit and specific gravity. The particle size analysis was determined for fourteen samples using the standard ASTM D4318 hydrometer method (Gee and Bauder, 1986). This entails that the samples were treated with sodium hexametaphosphate to complex Ca^{2+}, Al^{3+}, Fe^{3+} and other cations that bind clay and silt particles into aggregates. The samples were thoroughly mixed until broken down to individual particles. The Uniformity coefficient and the coefficients of gradation were calculated using the particle size distribution curve and equations 1 and 2 below (Gee and Bauder, 1986):

$$C_u = D_{60}/D_{10} \quad (1)$$

$$C_c = (D_{30})^2/D_{60}.D_{10} \quad (2)$$

Cu= uniformity coefficient, D_{60} =largest diameter of the finest 60% of the sample, D_{30}= largest diameter of the finest 30% of the sample, D_{10}= largest diameter of the finest 10% of the sample and it is regarded as the effective size. $C_u < 3$ indicates a uniform soil; $C_u > 5$ indicates a well-graded sample. The closer the value of uniformity coefficient to one, the more uniformly graded or well sorted the sample is. When the value is high, the sample is well graded. Most well graded samples will have grading curves that are mainly flat or slightly concave, giving values of coefficient of gradation or curvature (Cc) between 0.5 and 2.0. However, 0.1 indicates a possible gap-graded soil (Ismail, 2008). Gap graded soil lacks one or more intermediate size.

For the mineralogy, eleven samples were analysed using X-ray diffraction (XRD) method at the Department of Geology, Faculty of Natural and Agricultural Sciences, University of Pretoria, South Africa. The samples were prepared for XRD analysis using a back-loading preparation method and were analysed using a PANalytical X'Pert Pro powder diffractometer with X'Celerator detector and variable divergence- and receiving slits with Fe filtered Co-Kα radiation. The Atterberg limits were determined for fifteen samples according to ASTM D4318 while the specific gravity (G_s) of the shale and claystone samples was determined using the ratio of the weights of equal volume of sample and water in air.

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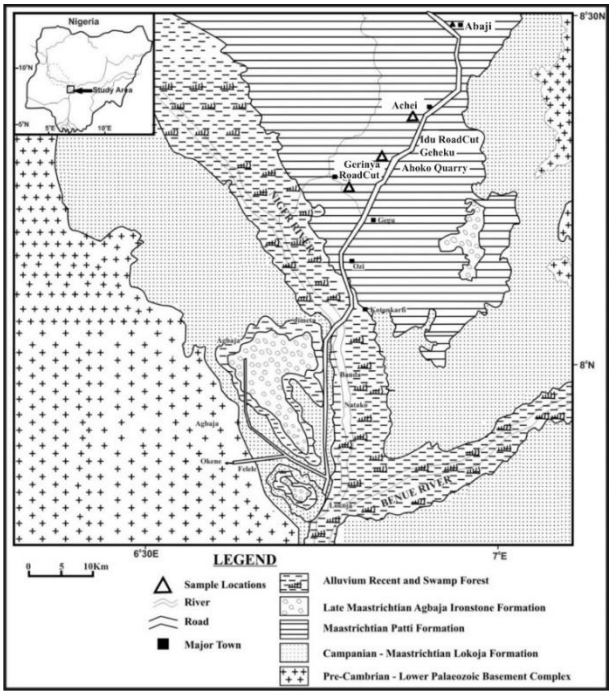


Fig. 1: Geological map of Bida Basin, Nigeria and location of investigated sites. Inset shows the location of study area in Nigeria (Ojo and Akande, 2009).

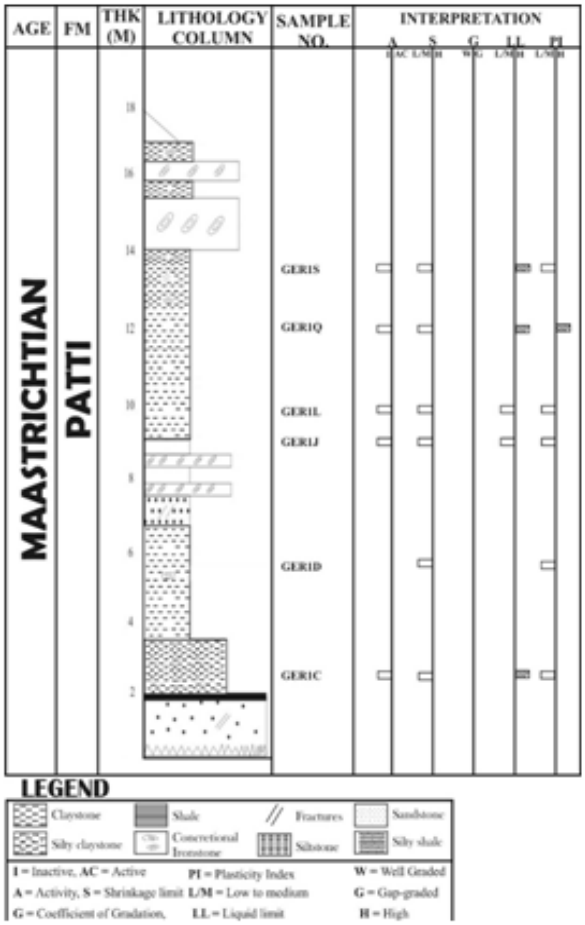


Fig. 2a: Lithostratigraphic Section of the Patti Formation at Gerinya Roadcut

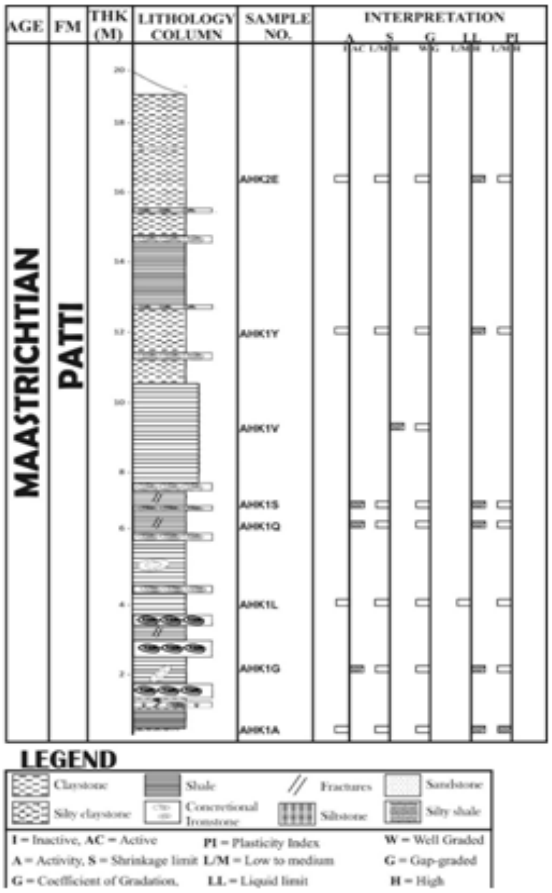


Fig. 2b: Lithostratigraphic Section of the Patti Formation at Ahoko Quarry

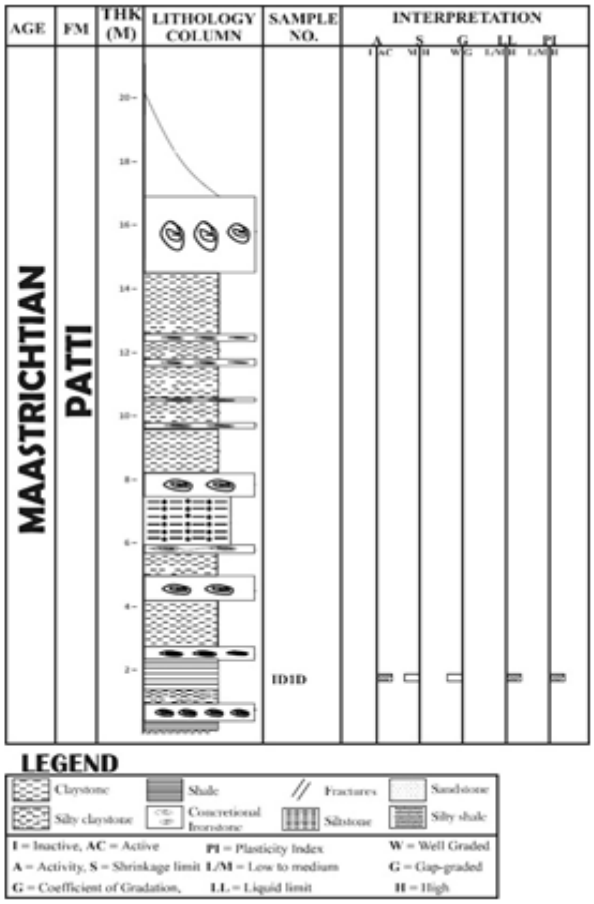


Fig. 2c. Lithostratigraphic Section of the Patti Formation at Idu Roadcut

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Fig. 3: (a) Parallel bedded claystones and fractures filled with clastic dykes (arrow) at Gerinya Roadcut. Note the clastic dykes which are perpendicular to bedding (b) Parallel bedded shale at the base and the overlying claystoneat AhokoQuarry (Average height of the Geologists at site is 1.65m).

3 Result and Discussion

3.1 Physical Properties

The physical properties of shales and claystones samples from Patti Formation exposed at Ahoko quarry (where they quarry clay and shale), Gerinya and Idu Road cuts were evaluated on the bases of grain size distribution, Atterberg limits, mineralogy and bulk specific gravity. The compressibility and permeability are inferred from related evaluated parameters. Soil techniques were applied to the disaggregated shale and claystone samples in this study.

3.2 Particle Size Distribution

The results and the interpretations are presented in Table 1 and show that the samples have high proportion of clay fraction passing 2µm except sample AHK1Q having only 10% clay. This is typical of most sedimentary claystone (Elueze and Bolarinwa, 2001). These shales and claystones are texturally classified as silty clays and clayey silts with percentage of sand sized fractions less than 20% (by weight) using a soil classification applied to disaggregated rock. The uniformity coefficient and coefficient of gradation values show that the shale and claystone samples fall within well graded soils with average values of 4.87 and 0.79 respectively (Table 2) and this is in line with the submission of Elueze and Bolarinwa (2001). Sample AHK 2E is an exception to this having coefficient of gradation value of 0.05 indicating a gap graded soil and also uniformity coefficient value of 0.70 indicating uniform soil (Table 2). Civil Engineers prefer well graded soil for road constructions (Holtz and Kovacs, 1981). However, results shown by the uniformity and gradation coefficients should not be the final verdict for engineering usages because they do not account for the mineralogical compositions of the samples which impact on engineering applications of rocks and soils.

Table 1. Particle size distribution of the samples

Location	*Lithology (Field Classification)*	*Sample No*	*Sand (wt.%) 0.05-2mm*	*Silt (wt.%) 0.002-0.05mm*	*Clay (wt. %)<0.002mm*	*Soil Texture Classification*
Ahoko	Claystone	AHK1Y	11.68	44.32	44.00	Clayey Silt
Ahoko	Shale	AHK1Q	6.32	83.68	10.00	Clayey Silt
Ahoko	Claystone	AHK2E	15.68	16.32	68.00	Silty Clay
Ahoko	Shale	AHK1A	6.32	69.68	24.00	Clayey Silt
Ahoko	Shale	AHK1S	4.32	73.68	22.00	Clayey Silt
Ahoko	Shale	AHK1V	14.32	25.68	60.00	Silty Clay
Ahoko	Shale	AHK1G	4.32	71.68	24.00	Clayey Silt
Ahoko	Shale	AHK1L	6.32	71.68	22.00	Clayey Silt
Idu	Shale	ID1D	15.68	4.00	80.32	Sandy Clay
Gerinya	Claystone	GER1C	0.8	15.2	84.0	Silty Clay
Gerinya	Claystone	GER1J	1.8	18.2	80.0	Silty Clay
Gerinya	Claystone	GER1L	4.8	15.2	80.0	Silty Clay
Gerinya	Claystone	GER1Q	5.8	25.2	69.0	Silty Clay
Gerinya	Claystone	GER1S	2.8	24.2	73.0	Silty Clay

Table 2. Summary of Soil Gradation Measurements for the Selected Disaggregated Shale and Claystone Samples

Location	Lithology	Sample ID	D10,mm	D60, mm	D30, mm	Cu	Interpretation	Cc	Interpretation
Ahoko	Clay	AHK1Y	0.15	0.85	0.35	5.70	well graded soil	0.96	well graded soil
Ahoko	Shale	AHK1Q	0.09	0.70	0.24	7.80	well graded soil	0.91	well graded soil
Ahoko	Clay	AHK2E	0.75	0.55	0.15	0.70	uniform soil	0.05	gap-graded soil
Ahoko	Shale	AHK1A	0.24	0.85	0.34	3.50	well graded soil	0.57	well graded soil
Ahoko	Shale	AHK1S	0.15	0.85	0.35	5.70	well graded soil	0.96	well graded soil
Ahoko	Shale	AHK1V	0.08	0.30	0.15	4.00	well graded soil	1.00	well graded soil
Ahoko	Shale	AHK1G	0.08	0.40	0.15	5.00	well graded soil	0.70	well graded soil
Ahoko	Shale	AHK1L	0.20	1.00	0.45	5.00	well graded soil	1.01	well graded soil
Idu	Shale	ID1D	0.14	0.90	0.35	6.40	well graded soil	0.97	well graded soil
Gerinya	Clay	GER1L	ND	ND	ND	ND	ND	ND	ND
Gerinya	Clay	GER1Q	ND	ND	ND	ND	ND	ND	ND
Gerinya	Clay	GER1S	ND	ND	ND	ND	ND	ND	ND
Statistical Summary		Average	0.21	0.71	0.28	4.87		0.79	
		Min.	0.08	0.30	0.15	0.73		0.05	
		Max.	0.75	1.00	0.45	7.78		1.01	
		S.D.	0.21	0.24	0.11	1.99		0.32	

ND= not determined, SD= standard deviation, Cu=uniformity coefficient, Cc=coefficient of gradation

3.2 Atterberg Limits

The Atterberg limits test is a common soil classification technique, here applied to disaggregated shale and claystone samples. Generally, it is a basic measure of the critical moisture contents of a fine-grained soil, such as its plastic and liquid limits. When a dry clayey soil takes on increasing amounts of water or moisture, it undergoes dramatic and distinct changes in behaviour and consistency. Depending on the moisture content of the soil, it may appear in solid, semi-solid, plastic and liquid states. In each state, the consistency and behaviour of a soil is different and consequently, its engineering properties. Thus, the boundary between each state can be defined based on a change in the soil's behaviour. The Atterberg limits tests are used widely in the preliminary stages of designing any structure to ensure that the soil will have the correct amount of shear strength and not too much change in volume as it expands and shrinks with different moisture contents.

In the present study, the liquid limit of the samples varies from 41 to 56% with an average of 51% while the plastic limit ranges from 17 to 29% with an average of 23% (Table 3). The plasticity index of the samples ranged from 16 to 34.4 % with average of 29 %. This shows they are mainly

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of medium plasticity except the Gerinya Roadcut claystone sample GER 1Q, that has high plasticity index of 36.4 % (Casagrande, 1948; Harding, 1991). According to Hick (2007), the plasticity index values of the samples suggest they are of medium compressibility and medium shrink-swell potential except samples AHK 1L and GER 1L that showed low compressibility and low shrink-swell potential (Fig. 3). Samples AHK 1S and GER 1D are interpreted to be of high compressibility based on their liquid limit which is above 55% (Seed and Woodward, 1964; Mills et al., 1980; Hick, 2007). These values together with the shrinkage limits exhibited by the samples suggest they are not expansive claystones and therefore of low failure risk when used as subgrade material in road construction (Madedor, 1983). Samples AHK 1S and GER 1D are however exception to this (Fig. 2). All the investigated samples from the study areas fall above the A-line of the Casagrande chart (Fig. 4) in the zone of medium (CI) to high plasticity clays (CH) and this suggests inorganic clay of medium plasticity. The A-line is an empirical boundary that separates inorganic clays from inorganic silts and organic soils. It has a slope expressed by the following (Eq.3):

$$\text{Plasticity index (Ip)} = 0.73\ (\text{liquid limit} - 20) \quad (3)$$

According to the Engineering use chart (Wagner, 1957), the samples are classified as impervious inorganic clays and therefore can be used in engineering construction, particularly landfills. They can also be used as a homogenous embarkment in rolled earth dams because of their good to fair workability as road construction subgrade materials. The plastic limit of the samples which is less than 40% shows the samples are kaolinite rich. Bain (1971) suggested that kaolinite mineral group typically has less than 40% plastic limit while Mitchell et al. (2005) proposed a range of 25 to 40% plastic limit for kaolinitic clay minerals. The samples therefore lack significant amount of expansive clay minerals like montmorillonite and illite. The plastic limits obtained from the samples and interpretations are consistent with the mineralogical composition determined from the XRD analysis. The medium to high plasticity as indicated by the plasticity index also suggest low permeability. According to Lambe and Whitman (1979), an increase in plasticity of soil leads to decrease in its permeability.

Table 3. Results of the Atterberg Limits and some other Geotechnical Properties

Location	Lithology	Sample No	Plasticity index IP	Plastic limit	Liquid limit	Activity(A) and Clay Type of based	Shrinkage limit	Specific gravity
Ahoko	Shale	AHK 1A	25	28	53	1.04 - normal clay	10.8	2.55
Ahoko	Shale	AHK 1G	31	19	50	1.29 - active	13.7	2.50
Ahoko	Shale	AHK 1L	16	25	41	0.73 - inactive clay	12.6	2.58
Ahoko	Shale	AHK 1Q	31	21	52	3.10 - active clay	13.0	2.60
Ahoko	Shale	AHK 1S	32	24	56	1.45 - active clay	16.2	2.65
Ahoko	Shale	AHK 1V	ND	ND	ND	ND	4.3	2.58
Ahoko	Claystone	AHK 1Y	31	19	50	0.70 - inactive clay	12.1	2.40
Ahoko	Claystone	AHK 2E	27	27	54	0.40 - inactive clay	14.1	2.62
Gerinya	Claystone	GER 1C	34	17	51	0.40 - inactive clay	12.9	2.67
Gerinya	Claystone	GER 1D	26.9	29.1	56	ND	13.5	2.66
Gerinya	Claystone	GER 1J	23.2	23.8	47	0.29 = inactive clay	14.3	2.69
Gerinya	Claystone	GER 1L	20.2	25.8	46	0.25 - inactive clay	15.1	2.55
Gerinya	Claystone	GER 1Q	36.4	18.6	55	0.53 - inactive clay	12.6	2.65
Gerinya	Claystone	GER 1S	33	21	54	0.45 - inactive clay	12.6	2.71
Idu	Shale	ID 1D	35	19	54	8.75 - active clay	15.0	2.67
Average			28.7	22.66	51.36	1.49	12.85	2.61
Minimum			16	17	41	0.25	4.30	2.40
Maximum			36.4	29.1	56	8.75	16.2	2.71
St. dev.			5.9	3.94	4.29	2.31	2.72	0.08

Table 4. Shrinkage limit and degree of expansion after Holtz and Gibbs (1956) and Seed and Woodward (1962)

Degree of expansion	Shrinkage limit (%)
Low	>13
Medium	8-18
High	6-12
Very high	<10

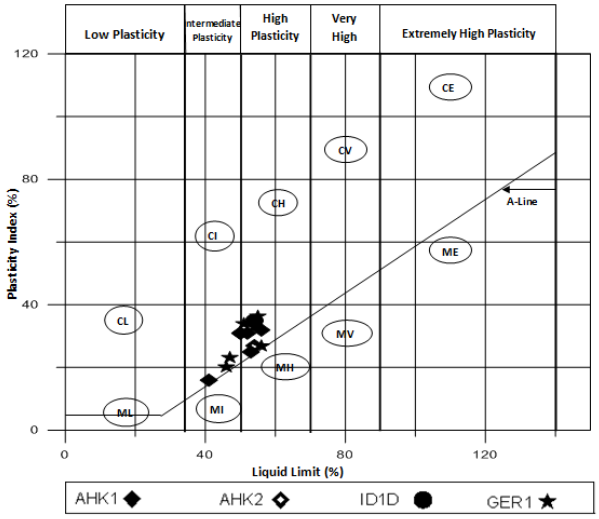


Fig. 4: Plasticity chart for the classification of clay bodies after Casagrande (1948) showing the position of the studied samples. NB: CL=low plasticity clay; OH=high plasticity organic soil; MH=high plasticity silt; ML=low plasticity silt; CH=high plasticity clay; CI= medium plasticity clay; A-Line= boundary separating inorganic clays from inorganic silts and organic soils; = limit of each plasticity field.

3.4 Activity

The activity (A) of a given soil is the ratio of plasticity index (PI) to the weight percentage of clay sized particles determined from grain size analysis and it is used as another parameter for the geotechnical characterization of the shale and claystone samples in the study area. Mathematically, it can be expressed as (Eq. 4):

$$\text{Activity, } A = \frac{\text{Plasticity Index}}{\text{Percentage by mass finer than } 0.002\text{mm}} \quad (4)$$

Values of activity are used as indicator of the dominant clay type. High activity connotes large volume change when wet and large shrinkage when dry (Mitchell, 1993; John, 2000). Moreover, soils with high activity are very reactive chemically. The activity of normal clay is between 0.75 and 1.25. When A is less than 0.75, it is inactive and considered active when A is more than 1.25 in value. The activity of the shale and claystone samples (0.25-8.75) is shown inFig.5 and Table 3.

It is important to note that most samples from the investigated sites are inactive to marginally active however two are active (AHK1Q and ID1D). The chemically active samples could swell appreciably when wet and shrink adversely when dry and this may not be appropriate for engineering construction work (Das, 2006). The quantity and type of clay mineral fraction (<2μm) in a fine soil always affect its state, particularly the swell and shrink property when wet. However, in this present study, the cross plots of activity versus % clay <2 μm (wt.%) and Atterberg limits versus clay <2 μm (wt.%) do not show the effect of clay size (Figs. 6 and 7). This may be due to the presence of some non-clay mineral like

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quartz and microcline in the samples (Velde; 1995). The non-clay minerals have their own plasticity index which may influence the plasticity of the samples (Dumbleton and West, 1966). It is also probable that certain error might have been introduced in the process of sample preparation and grain size analysis.

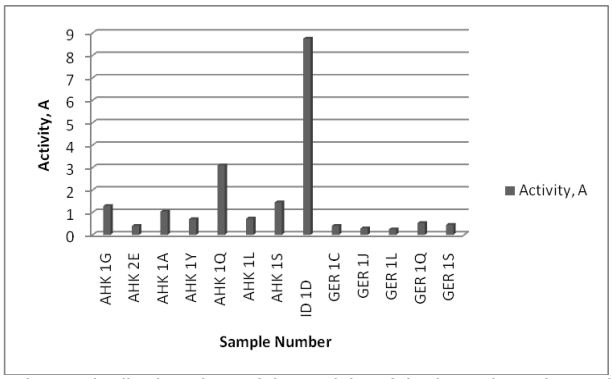


Fig. 5: Distribution chart of the Activity of the investigated samples

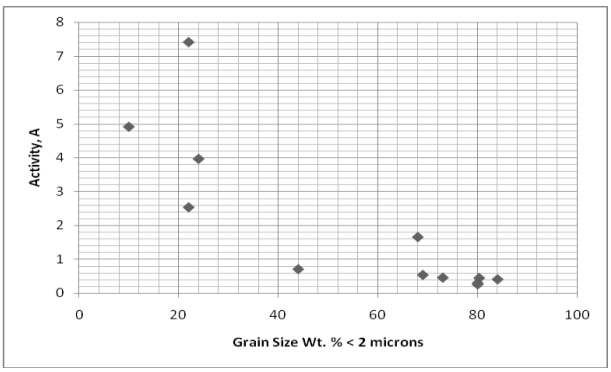


Fig. 6a: Cross plot of Activity versus clay grain size of <2 microns (wt. %)

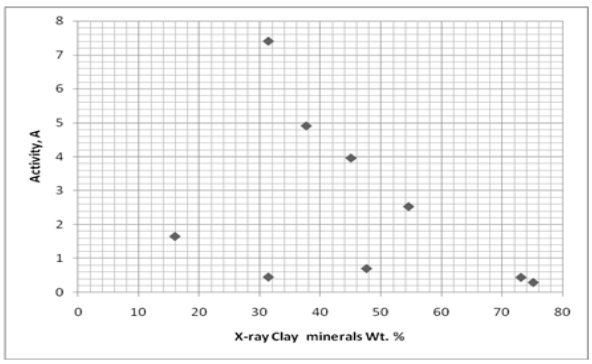


Fig. 6b Cross plot of Activity versus clay minerals (wt. %)

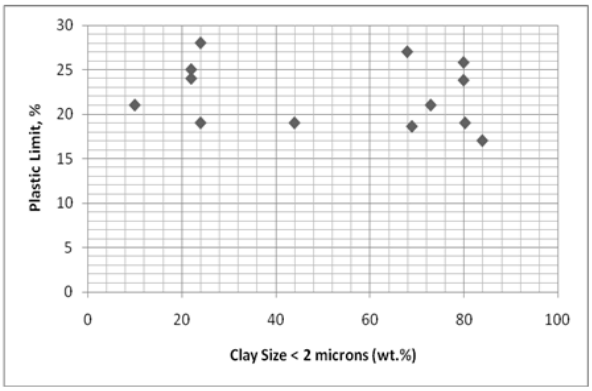


Fig. 7a. Cross plot of Plastic Limit versus clay grain size <2 microns (wt.%)

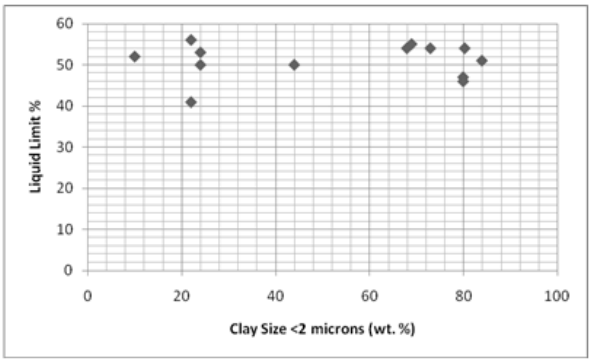


Fig. 7b: Cross plot of Liquid Limit versus clay grain size <2 microns (wt.%)

3.5 The Shrinkage Limits

The Shrinkage limit determined by DIN 18123 technique is the water content where further loss of moisture will not result in any more volume reduction. A high shrinkage indicates a large potential shrinkage of the soil mass on drying and this makes it problematic on the use of the soil as foundation for small buildings (Mills et al, 1980; Hick, 2007). The shrinkage limit of the studied samples ranges from 4.30 to 16.20% with an average of 12.9% (Table 3). The expansive rating of the soil based on shrinkage limit values which range from low to medium (Table 4) (Holtz and Gibbs, 1956; Seed et al. 1962). According to Mills et al. (1980) and Hick (2007) this implies from non-critical to marginal. In a humid climate, as it is in the present study area, the linear shrinkage potential is medium (Holland, 1981).

3.6 Specific Gravity

The values of the specific gravity of samples range from 2.40 to 2.71 with an average of 2.61. According to Day (2001), Bowles (1986), and Lambe and Whiteman (1979), soil types having specific gravity values within the range of 2.40 to 2.71 can be classified as inorganic clays. The values obtained are comparable to those obtained from claystones from Agbaja and Share, Bida Basin, respectively (Ojo et al., 2011).

3.7 Mineralogy

The mineralogical composition of the selected samples is presented in table 5. The dominant clay mineral is kaolinite (Fig. 8), which is interpreted to be a product of chemical weathering of feldspar rich rocks in humid climatic settings (Nton, 1991). The kaolinite minerals were probably derived from the older granites (Humad, 1987) in the adjoining flanks of the basin. Trace amount of montmorillonite occurred only in one of the Ahoko shales and the low amount presumably contributed to the low to medium expansive nature of the clays as suggested by Mokhtari and Dehghani (2012). Quartz is also abundant and some of the other non-clay minerals include microcline and rutile. Calcite is present in sample AHK1L at Ahoko Quarry and this may be attributed to the presence of calcareous nodules or shelly fragments in the shale due to marine water influence (Ojo and Akande, 2009). The absence of smectite and in the sediment is significant because it is probably an indication that the samples have medium swell-shrink tendency (Tripathy and Subba, 2009).

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Table 5. Mineralogical composition of the analyzed samples (Wt %)

Sample No.	Kaolinite	Quartz	Microcline	Muscovite	Anatase	Rutile	Zircon	Calcite	Montmorillonite
ID 1D	57.67	26.37	------	6.87	8.69	0.49	-----	------	-------
AHK 2E	13.10	82.08	1.91	1.65	1.27	------	------	------	-------
AHK 1Y	39.50	52.03	-------	4.19	3.96	0.33	------	-----	-------
AHK 1S	36.08	50.39	4.51	4.72	3.81	0.5	------	-----	-------
AHK 1V	15.60	73.90	5.55	2.76	1.66	-----	0.53	-----	-------
AHK 1Q	33.77	55.00	6.22	4.00	-----	-----	1.00	-----	-------
AHK 1L	45.03	41.01	3.98	4.43	5.13	0.29	-----	0.14	-------
AHK 1G	49.95	32.49	5.61	3.59	7.80	0.56	-----	-----	-------
AHK 1A	35.59	43.07	4.84	5.59	4.65	0.91	------	-----	5.59
GER 1J	67.61	21.15	-------	2.69	4.87	0.9	------	-----	-------
GER 1S	22.34	64.85	3.14	3.86	5.24	0.57	------	-----	-------

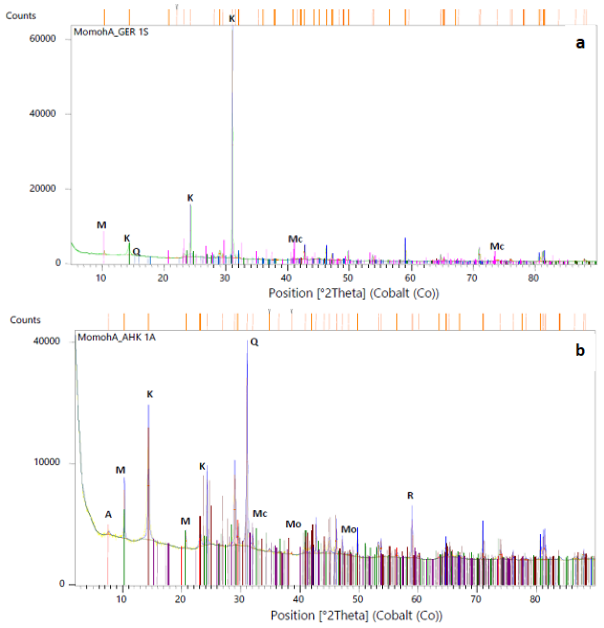


Fig. 8: X-ray diffractogram for samples (a) GER-1S (Clay at Gerinya) and (b) AHK-1A (Shale at Ahoko) showing mineralogical constituents as follows; Mv=Muscovite, A=Anatase, K=Kaolinite, R=Rutile. Mo= Montmorillonite

4 CONCLUSIONS

Particle size distribution data indicate high proportion of fines (clays and silts) in the investigated samples; however, the size of the clays does not appear to have significant effects on the geotechnical properties of the materials. This may be due to presence of some non-clay minerals in the samples. The claystones and shales in the study area are well graded. At Ahoko and Gerinya sites, horizons AHK2E, AH1Y, AHK1L, AH1A and GER1S, GER1L, GER1J, GER1C respectively are best suited for engineering construction purposes based on their acceptable values of activity, shrinkage limit (medium shrinkage/swell potential), and marginal plasticity index. Horizons GER1Q, AHK1S, AHK1Q, AHK1G and ID1D from the investigated sites are not suitable.

The plasticity index is moderate for most of the samples and they fall within the region of inorganic clay and low permeability. The clay minerals are dominated by kaolinite while smectite is rare to absent. Data obtained from the mineralogical and geotechnical analyses of the claystones and shales from the study area suggest they are suitable for use as road subgrade and embarkment in dams.

REFERENCES

Adeshina, R.B., & Tijani, M.N. (2017). Geotechnical and Geochemical Assessments of Shales in Anambra Basin, Southeastern Nigeria, as Landfill Liners. *Earth System and Environment*, 1, 1-20.

Agyingi, C.M. (1993). Palynological evidence for a late Cretaceous age for Patti Formation, Eastern Bida Basin, Nigeria. *Journal of African Earth Sciences*, 17, 513-523.

Alao, D.A., & Opaleye, S.T. (2011). Geotechnical analysis of slope failure of a kaolin quarry at Kurra, Jos, North-Central. *International Journal of Scientific Research*, 1, 87-102.

ASTM D422, (2007). Standard Test Method for Particle-Size Analysis of Soils. *Annual Book of ASTM Standards*, D422.

ASTM D4318, (2010). Standard Test Method for Liquid Limit, Plastic Limit and Plasticity Index of Soils, *Annual Book of ASTM Standards*, D4318.

Australian Standards 1726, (1993). Geotechnical site investigations, 40 pp.

Bain, J.A. (1971). A plasticity chart as an aid to the identification and assessment of industrial clays. *Clay Mineralogy*, 9, 1–17.

Bowles, J.E. (1986). Engineering Properties of Soils and their Measurement, 3rd edn. New York: *McGraw-Hill*.

Casagrande, A. (1948). Classification and identification of soils. *Proceedings of the American Society of Civil Engineers*, 73, 783–810.

Das, B.M. (2006). Principles of geotechnical engineering. Stamford, CT: *Thomson Learning College*.

Day, R.W. (2001). Soil Testing Manual. New York: *McGraw-Hill*, 618 pp.

Dumbleton, M.J., & West, G. (1966). Some factors affecting the relation between the clay minerals in soils and plasticity. *Clay minerals*, 6, 179.

Elueze, A.A., & Bolarinwa A.T. (2001). Appraisal of the residual and sedimentary clays in parts of Abeokuta area, southwestern Nigeria. *Journal of Mining and Geology*, 37, 7-14.

Gee, G.W., & Bauder, J.W. (1986). Particle Size Analysis. In A.L. Page (ed.) Methods of soil analysis Part I, Physical and mineralogical methods. 2nd edition, *Agronomy monographs 9*, American Society of Agronomy, Madison, p. 383-41.

Gomez-Gutierrez, I.C., Bryson, L.S. & Hopkins, T.C. (2011). Correlations between Geotechnical Properties and the Swell Behavior of Compacted Shales. *Geo-Frontiers*, 4119-4128.

Harding, S. (1991). Earth mover's training course Unit 7. *Soil Conservation Service of NSW*.

Hicks, R.W. (2007). Soil engineering properties. In: 'Soils-their properties and management' 3rd edn. (Eds P. E. V. Charman and B. W. Murphy.) p. 192–205, (*Oxford University Press: Melbourne*).

Holland, J.E. (1981). 'The Design, Performance and Repair of Housing Foundations' (*Swinburne College Press, Swinburne Institute of Technology: Melbourne*).

Holtz, R., & Kovacs, W. (1981). An Introduction to Geotechnical Engineering, Prentice-Hall, Inc. ISBN 0-13-484394-0

Holtz, W. G. & Gibbs, H. J., (1956). Engineering of expansive clays: *Transactions*, ASCE 121, 641-677.

Humad, S. (1987). Critical Evaluation of Foundation Practices in Black Cotton Soils towards Economy in Design. Ph.D. Thesis. Devi Ahalya Vishwavidyalaya. Indore.

Ismail, M.M. (2008). Mathematical correlations between the effective diameter of soil and other properties. *Engineering and Technology*, 26, 1274.

Jacquelyn, J. (2000). Engineering properties of soils. University of Liverpool. www.ehow.com/List 7537987 engineering-properties-soils.html.

John, A. (2000). Soil description and classification. University of the West of England; http://environment.uwe.ac.uk/geocal/SoilMech/classification/default.htm.

Kogbe, C.A., Ajakaiye, D.E. & Matheis, G. (1983). Confirmation of Rift Structure along theMid-Niger Valley, Nigeria. *Journal of African Earth Sciences*, 1, 127–131.

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http://dx.doi.org/10.46792/fuoyejet.v5i2.510 engineering.fuoye.edu.ng/journal

Lambe, T.W., & Whitman, R.Y. (1979). Soil Mechanics, SI Version. New York: *John Wiley & Sons*.

Lee, I.K., Ingles O.G., & White W. (1983). Geotechnical Engineering. *Pitman publishing Inc, USA*.

Madedor, A.O. (1983). Pavement design guidelines and practice for different geological areas in Nigeria. In Adeyemi (Ed): Geotechnical properties of lateritic soil developed over quartz schist in Ishara area southwestern Nigeria. *Journal of Mining and Geology*, 38, 65-69.

Mills, J.J., Murphy B.W., & Wickham H.G. (1980). A study of three simple laboratory tests for the prediction of shrink-swell behaviour. *Journal of Soil Conservation*, NSW, 36, 77–82.

Mitchell, J.K., & Soga, K. (2005). Fundamentals of soil behavior, Third edition, John Wiley and Sons, Inc., ISBN 978-0-471-46302-7.

Mitchell, J.K. (1993). Fundamentals of Soil Behavior, 2nd edition, *John Wiley & Sons*.

Mokhtari, M., & Dehghani, M. (2012). Swell-Shrink Behavior of Expansive Soils, Damage and Control. *Electronic Journal of Geotechnical Engineering*, 17, 2673-2682.

Nton, M.E., & Elueze, A.A. (2005). Compositional characteristics and industrial assessment of sedimentary clay bodies in part of eastern Dahomey Basin, Southern Nigeria. *Journal of Mining and Geology*, 41, 175-184.

Nton, M.E. (1991). Sedimentology and deposition environment of Awi Formation, Calabar Flank, southeastern Nigeria. *Journal of Mining and Geology*, 35, 23-36.

Ogunsanwo, O. (1995). Influence of geochemistry and mineralogy on the optimum geotechnical utilization of some laterite soils from SW Nigeria. *Journal of Mining and Geology*, 31, 183-188.

Ojo, O.J., & Akande, S.O. (2008). Microfloral assemblage, age and palaeoenvironment of the Upper Cretaceous Patti Formation, southeastern Bida basin, Nigeria. *Journal of Mining and Geology*, 44, 71-78.

Ojo, O.J., & Akande, S.O. (2009). Sedimentology and depositional environments of the Maastrichtian Patti Formation, southeastern Bida Basin, Nigeria. *Cretaceous Research*, 30, 1415-1425.

Ojo, O.J., Adepoju, S.A., Adewole, T.M., & Abiola, A.O. (2011). Sedimentological and geochemical studies of Maastrichtian clays in Bida Basin, Nigeria: Implication for resource potential. *Centrepoint Journal (Science Edition)*, 17, 79-95.

Ojo, O.J., Babatunde, F.R., Adepoju, S.A., Akande, S.O., & Momoh, A. (2016). Provenance and weathering history of the Maastrichtian shalemember of the Patti Formation, Southern Bida Basin, Nigeria. *Journal Geological Society of India*, 88, 471-480.

Ojo, S.B., & Ajakaiye, D.E. (1989). Preliminary interpretation of gravity measurements in the middle Nıger Basin area, Nigeria: In Kogbe, C.A. (Ed.), Geology of Nigeria, 2nd ed. *Elizabethan Publishing Company*, Lagos, p. 347–358.

Okogbue, C.O. &Aghamelu, O.P. (2010). Comparison of the geotechnical properties of crushed shales from Southeastern Nigeria. *Bulletin of Engineering Geology and Environment*, 69, 587–597

Seed, H,B., Woodward, R.J., & Lungren, R. (1962). Prediction of Swelling Potential for Compacted Clays, *Journal of the Soil Mechanics and Foundations Division*, Proc. of the ASCE, pp. 53-87.

Seed, H.B., & Woodward, R.J. (1964). Fundamental aspects of the Atterberg limits. *Journal of Soil Mechanical Foundation Division*, Proceedings of ASCE, 90, SM6, p. 75.

Swan, C.W., Grant, A. & Kody, A. (2013). Characteristics of Chicago blue clay subjected to a freeze-thaw cycle. Mechanical properties of frozen soils, *ASTM International*, 100 Barr Harbor Drive, West Conshohocken, PA, STP 1568, 22-32.

Tripathy, S., & Subba, R. (2009). Cyclic Swell - Shrink Behavior of a Compacted Expansive Soil, *Geotech Geol Eng*., 27, 89-103.

Velde, B. (1995). Composition and Mineralogy of Clay Minerals. In: Velde B. (eds) Origin and Mineralogy of Clays. *Springer, Berlin, Heidelberg*.

Wagner, A.A. (1957). The Use of Unified Soil Classification System by the Bureau of Reclamation. *Proceedings, 4th International conference on soil mechanics and foundation engineering (London)*, 1,125.

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