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PHYSICAL AND MINERALOGICAL CHARACTERISTICS OF OVERBURDEN ON THREE COMMON BASEMENT COMPLEXES

***Abdullahi, Y. M.[1]; Alhaji, M. M.[1]; & Alhassan, M.[1]**
[1]Civil Engineering Department, Federal University of Technology, Minna, Nigeria
*Corresponding Author; ymozay@gmail.com

ABSTRACT

Disturbed soil samples taken at depths 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, and 5m/to bedrock from three (3) trial pits, of common basement complexes around Minna, of granite, gneiss and schist parent rocks, were subjected to physical tests, while X-ray diffraction (XRD) method was employed for the mineralogical analysis. Variation of physical and mineralogical properties with depth of the weathering profiles was made. Index properties results for the three (3) location shows, they are clay and silt of intermediate and low plasticity with liquid limit and plasticity index ranging between 27.80 to 50.50% and 4.74 to 40.00% respectively while percentage of fines ranging between 24.67 to 63.70%. The x-ray diffraction results show the presence of quartz in all locations, while the major minerals for each of the location were identified to be kaolinite, albite; a non-clay mineral and illite in combination with other minerals. The presence of kaolinite in combination with other clay minerals, such as montmorillonite is responsible for intermediate plasticity of samples of granite parent rock.

Keywords: *Basement Complexes, Bedrock, Index Properties, Plasticity, Weathering Profile, X-Ray Diffraction.*

1 INTRODUCTION

All soils are derived from rock by weathering process; the relationship between rock types and soil types is an integral aspect of the study of soils, especially on tropically weathered soils, this process brings about changes in chemical and mineralogical composition of parent rock (Irfan & Dearman 1978) and are dictated primarily by the minerals that constitute the soil particles and their parent rock (Braja 2010). Five factors that have an influence on the weathering of rock and the subsequent formation of soil minerals are; parent rock - composition and texture, climate - principally the variation in temperature and rainfall, topography, vegetation; in particular the products of decomposition, and time (Grim 1968), this factors are optimized in the tropics (Townsend 1985), as they affect the variation of mineralogical and engineering properties of soils with depth. Mechanical process disintegrates these rocks into smaller fragments; and chemical action which depends on temperature, surface area and amount of water (Gard 2012), reduces these small fragments, rearrange the elements into new minerals, and thus decompose them.

Chemical weathering (decomposition) can transform hard rock minerals into soft, easily erodible matter. The principal types of decomposition are hydration, oxidation, carbonation, desilication and leaching. These processes occur when oxygen and carbon dioxide which are always present in the air readily combine with the elements of rock in the presence of water (especially if it contains traces of acid or alkali) resulting to a change in the mineral form of the parent rock (Murthy 2012) and consequently resulting in some minerals disappearing partially or fully, and new compounds formed, with maximum intensity in the humid and tropical climate, (Venkatramaiah 2006).

With overburden soils of the tropics receiving relatively little attention because of their location in areas of underdeveloped economies (Lambe and Whitemen 1969), most soil workers assume weathering products are uniform with depth conducting only a single or few soil tests at the beginning of excavation to represent soils at deeper depth borrow pits. They treat weathering profile as uniform with depth, not considering different formation factors, the composite and complex nature of the weathering materials (Adekoya, 1987), but it is common to find differences in the results of investigation even within short distances and/or depth. Therefore ignoring the variability of soil properties in a weathering profile with depth is denying the different formation factors of these soils and may lead to misleading results and consequently, serious failure to engineering structures erected on them.

Soil mineralogy plays an important role in forming the character of a soil, such that the key features employed to differentiate soils at the highest level depend on mineralogy (Uehara and Gillsman, 1981), this property is responsible for all the engineering properties such as specific gravity, shear strength, Atterberg limits, petrophysical properties and soil classification (Shafique et al., 2012) and when chemical and mineralogical analysis are conducted on soils in addition to the geotechnical characteristics, it proves to be useful in understanding soil behavior for engineering construction and has assisted significantly in its utility ((Mahalinger-Iyer and Williams 1997), but unfortunately, analysis to determine the mineral composition of soils is not usually explored in soil investigation, partly because the techniques and the equipment used are beyond the resources of the ordinary soil testing laboratory in Nigeria.

Soil minerals are composed of primary and secondary minerals. Primary are of the same minerals with the parent rocks; sand and gravel, which are products of mechanical weathering, are composed of this minerals, with no cohesive and plastic characteristics, while secondary minerals are found in silts and clay, they are products of chemical weathering; they are further classified as non-clay mineral and clay minerals. Non clay minerals are amorphous and impart little or no cohesion and plasticity characteristics to soil. However, particles defined as clay on the basis of their size are not necessarily clay minerals. Clays are geological materials having particle size of less than 2 microns and the family of minerals having similar chemical compositions and common crystal structural characteristics (Velde, 1995) they are generally plastic at appropriate water contents and will harden when fired or dried. Clays are very abundant at the earth's surface; they form rocks known as shales and are a major component in nearly all sedimentary rocks. The small size of the particles and their unique crystal structures give clay materials special properties, including cation exchange capabilities, plastic behavior when wet, catalytic abilities, swelling behavior, and low permeabilities.

Clay minerals can only be seen with high power electron microscope. They are responsible for many of the soil’s most important and characteristic (Schulze, 2005), because of their tendency to develop plasticity when mixed with water, they influence basic properties, strength properties as well as chemical properties especially if they are prone to swelling (Jworchan, 2006), however the basic properties found in the clay fraction of soils that form the basis for their distinction are the constant surface charge and the constant surface potential (Uehara and Gillsman, 1981). Clay minerals can be categorized into four subgroups: (1) kaolinite; (2) smectite (montmorillonite, saponite); (3) mica (illite), and (4) chlorite (Shichi and Takagi, 2000; Nayak and Singh, 2007; Burhan et al., 2010), they are determined by their chemical composition, layered structure and size. The highest volume changing clay, exibiting high swelling and shrinkage potentials is the montmorillonite group (smectites). These volume changing clays are generally present all over the world being the cause of most natural hazards like foundation problems causing damage to structures, roads, services and rock instability causing landslides. The illite group has the same structural arrangement with the montmorillonite but presence of potassium as the bonding materials between units makes the illite minerals swell less, while the kaolinite is stable and water cannot enter between the sheets to expand the unit cells due to strong hydrogen bonding.

Basement complex rocks have been exposed to varying degrees of weathering over the years which led to the formation of clay deposits which are widely distributed in the study area (Ajayi 1981). In the north of Nigeria, these rocks are composed of gneisses, migmatites and granites, with extensive areas of schists, phylites and quartzites (Oyawoye, 1972; Rahaman, 1989). A better understanding of the nature of soils formed from these rocks and their mineralogical composition would make possible a more precise prediction of behavior, and many of the problems encountered in engineering practice would be avoided (Ademila and Adebanjo 2017). Therefore the aim of this study is to establish the variability in physical and mineralogical characteristics of overburden with depth derived from three (3) basement complexes of granite, schist and gneisss, as data from this study can aid in assessing the soils for classification and engineering performance.

2 METHODOLOGY

Basement complex weathered rocks of schist, gneiss and schist origin were identified at Tudun Fulani, dam site, and Birgi Village, along Talba Farm road, Bosso Local Government and in Kateregi Village adjacent Minning site, Katcha Local government of Niger State.

Three (3) trial pits were dogged manually to bedrock or 5m depth, during which disturbed soils samples were collected at 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, and 5.0m, with the soil profile been inspected visually. Samples were collected in polythene bags, sealed, labeled and taken to the Laboratory. Collected samples were air dried immediately after removing samples for the determination of natural moisture content

The samples were air dried and sieved, then subjected to clay mineral analysis using X-Ray Diffraction (XRD) conducted in South Africa. X-ray diffraction method is suitable for identifying and quantifying the minerals present in soils. Tests including Natural Moisture Content (NMC), washed sieved analysis, Liquid Limit (LL), Plastic Limit (PL), and Specific Gravity (SG) were carried out on each of the samples. All these tests were done in Civil Engineering Laboratory of Federal University of Technology, Minna in accordance with B. S. 8110 (1990) with modifications where necessary.

3 RESULTS AND DISCUSSION

3.1 Physical properties

Results for Natural Moisture Content (NMC), Liquid limit (LL), Plastic limit (PL), Plasticity Index (PI), Percentage passing sieve No. 200, AASHTO classification and Plasticity of all sampless are contained in table I, II and III.

The natural moisture content for samples from weathered granite increased from 10.30% at 0.5m to 24.10% at 2.0m depth, it then decreased along the profile, and then increased between 4.5m to 5m depth, while samples from weathered gneiss rock increased from 5.7% at 0.5m depth to 6.5% at 2.5m after which it finally dropped to 5.26% at 4m depth. Consequently samples obtained from weathered schist recorded values ranging between 4.4 to 8.88%. Natural moisture content is not a constant property of soils, these values are consistent with the fines contents of the clays (Ademila et al 2017), it increases with increasing clay content due to the ability of clay particles to absorb water and consequently increase with depth because of the exposure of the ground top to the sun (Asmaa 2012).

The weathered gneiss recorded the highest value of 2.92 as specific gravity at depth 0.5m. The weathered granite recorded values ranging between 2.54 to 2.77, while samples of weathered schist show an increment from 2.58 at 0.5m to 2.65 at 2m depth, it then decreased to 2.57 at 3m depth and finally increased to 2.66 at depth 3.5m. Specific gravity is an important property in the identification and evaluation of aggregate parameters for construction purposes; the higher, the better for construction purposes (Gidigasu 1976), it has also been shown to be closely linked with the mineralogy and/or the chemical composition of the soil (Ramamurthy and Sitharam 2005).

Samples of granite parent rock recorded the highest values of liquid limit, ranging between 46.02%- 50.50%, while sample from weathered gneiss recording between 29%-30.80%, consequently the liquid limit value for schist basement increased from 36% at 0.5m depth to 40% at depth 2m, and finally decreased to 39.9% at 3.5m depth. Liquid limit less than 30% indicates low plasticity, between 35% and 50% indicates intermediate plasticity, between 50% and 70% high plasticity, between 70% and 90% indicates very high plasticity and greater than 90% indicates extremely high plasticity (Whitlow, 1995). Soils with high liquid limit are generally preferable for liners because of their low hydraulic conductivity (Ige, 2010). Liquid limit of soil use for barriers lining should be less than 90% (Declan and Paul 2003) and should have a lower limit of at least 20% (Benson et al 1994). Standard for road works recommend liquid limits of 50% maximum for sub base and base materials (FMWH, 1997). Variation in the liquid limit may be due to the mineralogical composition of the samples. Thus all soils studied are can be used for sub base material and base material, because they fall below the 50% threshold of liquid limit, with improvement where necessary. The plastic limit for weathered granite recorded the highest, with values ranging between 27.75 to 37.75%, with weathered gneiss rock recording between 0 to 27.37%, while samples from weathered schist recorded no plastic limit. Soil with plastic limit ranging between 10 – 60% is recommended for use in ceramic production (Grimshaw 1971), weathered granite samples and some from the gneiss weathered rock fall within this specified limit.

Plasticity index is the range of moisture content over which a soil is in plastic condition, and is influenced by the amount clay fraction and the type of clay minerals present, since the amount of attracted water held in a soil is influenced by clay minerals. The plasticity Index for the weathered granite ranges between 9.24% to 20.66%, samples from weathered gneiss recording values between 1.63% and 30.8%, while weathered schist samples recorded the highest values, between 35.01% and 39.9%. The difference in the plasticity index may be due to the presence of montmorillonite which is responsible for great volume change potential (Ademila and Adebanjo 2017).

Low plasticity index and liquid limit could an indication of the presence of high amount of kaolinite and absence or very low content of montmorillonite (Duruojinnaka et al 2016), however small value of plasticity index such as 5% indicates that a small change in moisture content will change the soil from a semi-solid to a liquid condition, while plasticity index, such as 20% shows that considerable water can be added before the soil becomes liquid (Salome et al 2013).

According to Unified Soil Classification System (USCS), samples from granite basement, on the plasticity chart are classified as silt and clays of intermediate plasticity with percentage passing sieve No. 200(0.075mm) ranging between 35.47% to 63.70%, those taken from weathered gneiss falls into the category of silts and clays with low plasticity, with percentage passing sieve No. 200(0.075mm) between 24.67% to 34.00% while samples of schist basement origin falling under clays of intermediate plasticity with percentage passing sieve No. 200(0.075mm) between 22.17% to 40.77%. Soils with amounts of fines less than 50% are expected to possess better engineering properties while those with amounts of fines greater than 50% are expected to pose field compaction problems when used either as sub-base or sub-grade materials (Oyediran 2010), while recommended specification for general filling for highway construction should contain fines ≤ 35 % (FMWH 2000). Therefore on the basis of the recommendations almost all samples are suitable for general filling for highway construction; hence, the materials qualify as general filling materials.

TABLE I: PHYSICAL PROPERTIES WITH DEPTH OF WEATHERED GRANITE

BIRGI SAMPLES										
Depth (m)	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**
Natural moisture content (%)	10.30	16.90	20.50	24.10	22.40	21.80	22.60	22.70	25.90	26.30
Specific gravity Gs	2.71	2.64	2.77	2.68	2.54	2.59	2.66	2.69	2.68	2.66
Liquid limit "LL" (%)	46.02	49.20	49.60	50.50	46.20	46.00	48.80	46.00	48.20	46.20
Plastic limit "PL"(%)	27.76	28.54	36.5	36.07	36.07	35.02	37.75	35.71	36.93	36.96
Plasticity Index "PI" (%)	18.26	20.66	13.10	14.43	10.13	10.98	11.05	10.29	11.27	9.24
Percentage passing sieve No. 200 (0.075mm)	35.47	53.40	56.97	52.00	48.10	49.30	47.90	53.37	62.60	63.70
AASHTO classification	A-7-6	A-7-6	A-7-6	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5
Plasticity	CI	CI	CI	CI	MI	MI	MI	MI	MI	MI

TABLE II: PHYSICAL PROPERTIES WITH DEPTH OF WEATHERED GNEISS

KATEREGI SAMPLES								
Depth (m)	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
Natural moisture content (%)	5.70	4.81	4.50	6.10	6.50	5.90	5.32	5.26
Specific gravity Gs	2.92	2.68	2.62	2.58	2.69	2.68	2.71	2.71
Liquid limit "LL" (%)	29.00	30.80	30.50	30.00	29.00	27.80	28.60	30.80
Plastic limit "PL"(%)	0.00	21.12	25.76	24.19	27.37	0.00	0.00	0.00
Plasticity Index "PI" (%)	29.00	9.68	4.74	5.81	1.63	27.80	28.60	30.80
Percentage passing sieve No. 200 (0.075mm)	27.87	34.00	29.30	30.80	28.87	24.57	27.63	24.67
AASHTO classification	A-6	A-5	A-4	A-4	A-4	A-6	A-6	A-4
Plasticity	CL	ML	ML	ML	ML	CL	CL	CL

TABLE III: PHYSICAL PROPERTIES WITH DEPTH OF WEATHERED SCHIST

TUDUN FULANI							
Depth (m)	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**
Natural moisture content (%)	5.96	5.57	8.88	6.35	8.22	4.60	4.44
Specific gravity Gs	2.58	2.62	2.60	2.65	2.62	2.57	2.66
Liquid limit "LL" (%)	36.00	35.01	35.50	40.00	39.10	39.00	39.90
Plastic limit "PL"(%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plasticity Index "PI" (%)	36.00	35.01	35.50	40.00	39.10	39.00	39.90
Percentage passing seive No. 200 (0.075mm)	40.77	34.80	22.17	30.73	37.23	32.23	29.90
AASHTO classification	A-6	A-2-6	A-2-6	A-2-6	A-6	A-2-6	A-2-6
Plasticity	CI	CI	CI	CI	CI	CI	CI

3.2 Mineralogical Composition

The mineralogical compositions of the studied samples are shown in table IV, V and VI and figure 1, 2 and 3 showing the XRD diffractogram. The XRD results show the presence of clay and non-clay minerals with high presence of quartz in all the samples.

The X-Ray pattern for weathered granite indicates the presence of clay minerals of kaolinite as the dominant mineral, montmorillonite, mica called phlogopite; the trio showing presence from the top to the bottom of the profile, saponite between 2.5 to 5m depth and mica called annite occuring only at depth 5.0m, all showing a decreasing trend from the top of the profile to 4.5m depth, with with their presence increasing at 5m depth. However, Potassium Aluminum Silicate, Magnisium Silicate Hydroxide, Magnisium Aluminium Oxide, and Potassium Aluminium Hydride was introduced into the profile at 2.5m, with an increasing trend to 5.0m. Chemical weathering can results in some minerals disappearing partially or fully, and new compounds formed (Venkatramaiah 2006).

The clay mineral that is mostly responsible for expansiveness belongs to the montmorillonite group (Murthy 2002) therefore the presence of kaolinite combined with monmorilonite may be responsible for the intermediate plasticity of samples collected from this location.

TABLE IV: MINEROLOGY OF WEATHERED GRANITE

Granite										
Depth (m)	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**
Quartz	96.46	46.77	46.77	56.13	35.45	35.48	35.45	35.45	12.61	171.73
Kaolinite	37.84	37.84	37.84	37.84	26.83	22.71	16.52	16.52	24.23	131.25
Montmorillonite	11.01	11.01	11.01	11.01	11.01	11.01	11.01	11.01	11.01	50
Phlogopite	4.10	4.10	9.84	5.26	5.25	2.68	2.68	2.68	2.68	41.67
Anorthoclase	4.17	-	-	-	-	-	-	-	-	-
Saponite	-	-	-	-	2.54	2.54	2.18	2.18	2.18	9.90
Annite	-	-	-	-	-	-	-	-	-	22.92

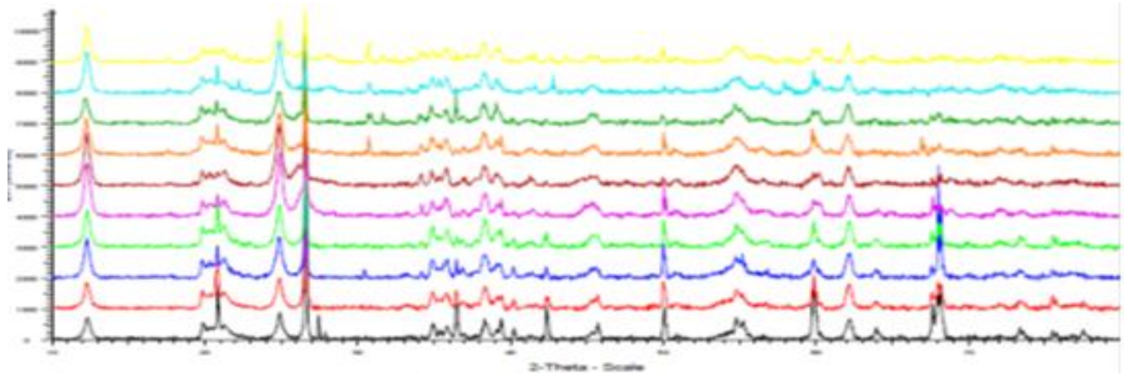

FIGURE 1: XRD DIFFRACTOGRAM OF WEATHERED GRANITE

The XRD result for weathered gneiss shows presence of non-clay mineral such as albite of the feldspar group; existing all through the profile, Magnesioarfvedsonite, and Gregoryite; identified between 0.5m to 2.5m depth, Arfvedsonite and Hydrobiotite, while clay minerals such as Phlogopit and Biotite of the mica group shows presence only at 3.0m depth. This location records the least plasticity, this may due to the dominance of non-clay minerals or as a result of the age of weathering.

TABLE V: MINEROLOGY OF WEATHERED GNEISS

Gneiss								
Depth (m)	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
Quartz	44.70	83.19	77.67	100.91	57.64	117.81	151.78	151.78
Albite	22.30	14.58	38.75	43.84	25.04	14.93	31.25	31.25
Magnesioarfvedsonite	6.92	12.89	12.03	13.82	9.72	-	-	-
Gregoryite	3.60	6.70	6.25	-	-	-	-	-
Arfvedsonite	-	6.95	4.74	-	-	8.48	6.33	6.33
Hydrobiotite	-	-	7.81	-	-	-	-	-
Carbon	-	-	-	-	-	23.17	48.50	48.50
Phlogopite	-	-	-	-	-	2.08	-	-
Biotite	-	-	-	-	-	2.08	-	-

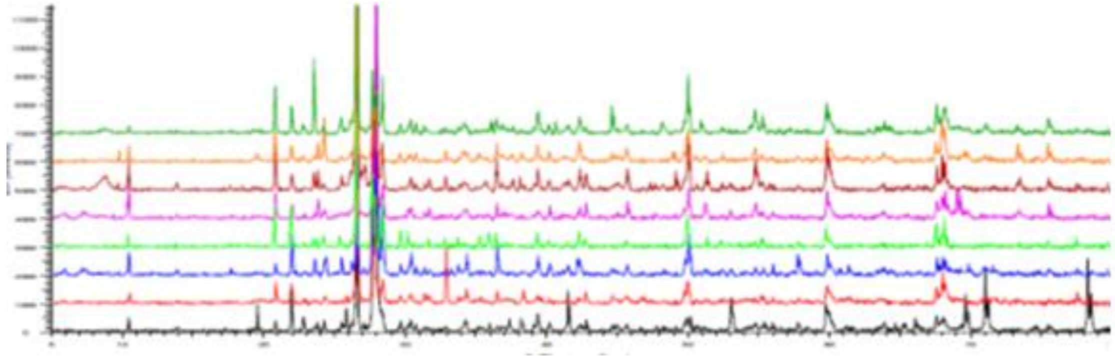

FIGURE 2: XRD DIFFRACTOGRAM OF SAMPLES FROM WEATHERED GNEISS

The XRD pattern for samples from weatherd schist, shows illite as dominant clay mineral, with other minerals such as albite; a non-clay mineral, showing presence from depth 0.5m to the bedrock at depth 3.5m, with kaolinite showing presence at depth 0.5, 1.0, 1.5, 3.0 and 3.5m, phlogopite of mica group appearing between 1.5 and 2.5m depth, biotite of mica group while nontronite of smectite group showing presence at depth 2.5m and 3.0m respectively. The presence of illite, combined with other clay minerals may be responsible for the low plasticity of samples collected from this location

TABLE VI: MINEROLOGY OF WEATHERED SCHIST

Schist							
Depth (m)	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**
Quartz	164.67	91.29	173.25	120.50	50	153.22	90.87
Illite	32.01	5.26	44.93	4.46	4.17	44.56	9.92
Albite	68.91	38.20	72.50	5.04	5.04	85.48	50.70
Kaolinite	12.82	4.74	9.00	-	-	8.94	5.30
Phlogopite	-	-	27.10	10.42	10.42	-	-
Biotite	-	-	-	-	4.17	-	-
Nontronite	-	-	-	-	-	4.17	-

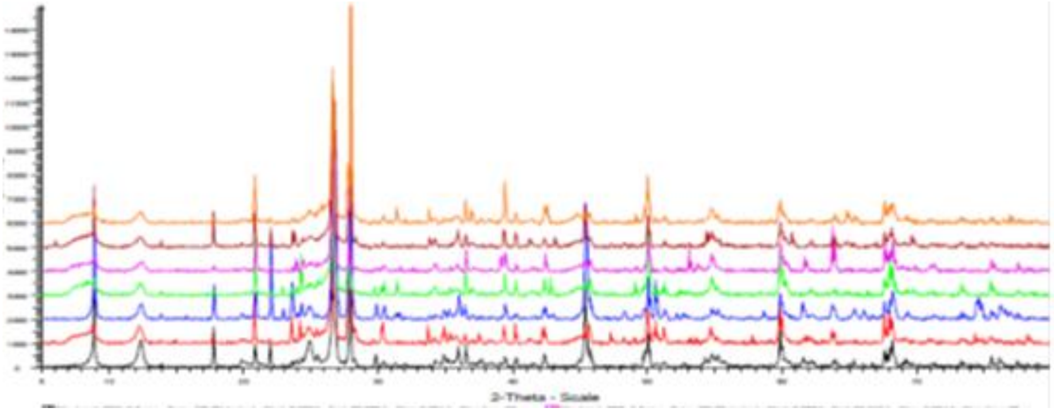

FIGURE 3: XRD DIFFRACTOGRAM OF SAMPLES FROM WEATHERED SCHIST

4 CONCLUSION

The mineralogy of soils influences its performance such that the fundamental understanding of their engineering behavior is provided by investigating their physical and mineralogical properties from different locations and depth.

The high quartz content revealed by the X-ray diffraction accounts of all locations studied is responsible for the high percentage of sand size fraction observed.

The mineralogical investigations indicate the presence high swelling clay montmorillonite on only samples from the granite basement; this location indicates the presence of clay minerals such as kaolinite, montmorillonite, phlogopite saponite and anite, while samples of weathered schist showing presence of clay minerals such as illite, kaolinite, phlogotite, biotite and nontronite which could be responsible for their intermediate plasticity, and that of weathered gneiss show the presence swelling clays of biotite and phlogotite only at 3m depth, This could also be responsible for their low plasticity of this soils. This result is in agreement with previous finding reported on minerology of lateritic soils derived from weathered granite in Minna by Alhassan and et al (2012) where kaolinite was found to be the dominant mineral.

From the foregoing, conclusion could be drawn that the presence of clay minerals derived from these basement complex weathered rocks is responsible for a major contributory factor to the behaviour of soils. The results of this project should be adopted as a basis for further studies and investigation of schist, granite and gneiss weathered rocks in the study area.

REFERENCES

Adekoya, J.A. (1987). Preliminary Geological and Geotechnical Study of Lateritic Weathering Profiles Derived from Banded Gneiss in the Ibadan Area, S.W Nigeria, *Proceedings of 9th Regional Conference for Africa on Soil Mechanics and Foundation Engineering*, Lagos, Nigeria, 21-30

Ademila, O. & Adebanjo, O. J. (2017). Geotechnical and Mineralogical Characterization of Clay Deposits in Parts of Southwestern Nigeria, *Journal of Geosciences Research*, 2(2), 127-137. doi: 10.22606/gr.2017.22006

Ajayi, J.O. & Agagu, O. K. (1981). Mineralogy of primary clay deposits in the basement complex areas of Nigeria, *Journal of Mining and Geology*, 18(1), 27-30.

Alhassan, M., Mesaiyete, E. & Mustapha, A.M. (2012). Clay Mineralogy of Lateritic Soils Derived from Granite Basement-A Case Study of Minna Lateritic Soils. *Electronic Journal of Geotechnical Engineering (EJGE*), Oklahoma, USA, 17(M), 1897-1903.

Asmaa, G.S. (2012). Review on Granitic Residual Soils Geotechnical Properties, *Electronic Journal of Geotechnical Engineering (EJGE),* Oklahoma, USA, 17(M), 2645-2658

B.S. 8110 (1990). Methods of Testing Soil for Civil Engineering Purposes, British Standard Institute, London

Benson, C.H., Zhai, H. & Wang, X. (1994). Estimating Hydraulic Conductivity of clays liners. *Journal of Geotechnical Engineering,* 120(2): 366-387.

Braja, M.D. (2008). Principle of Geotechnical Engineering (7th edition). United States: Global publishing

Burhan, D & Ciftci, E. (2010). The clay minerals observed in the building stones of Aksaray-Guzelyurt area (Central Anatolia-Turkey) and their effects. *International Journal of the Physical Sciences,* 5:1734-1743.

Craig, R. F. (2005). Soil Mechanics. (7th edition). London: Spon press 1.

Dearman, W.R, Baynes, F.J. & Irfan, T.Y. (1978). Engineering grading of weathered granite. *Engineering Geology*, 12, 345-374.

Declan, O. & Paul, Q. (2003) “Geotechnical engineering and environmental aspects of clay liners for landfill projects,” *Technical paper 3,* Fehily Timoney and Co. and IGSL limited.

Duruojinnaka, I.B., Okeke, O.C. & Amadi, C.C. (2016) Geotechnical and geochemical characterization of lateritic soil deposit derived from ajali sandstone in ihube-okigwe, southeastern Nigeria for road construction, *International Journal for Research in Social Science and Humanities Research,* 2:20-36

Federal Ministry of Works and Housing (1997). General Specifications for Roads and Bridge. Volume II. Federal Highway Department, FMWH: Lagos, Nigeria. 317

Federal Ministry of Works and Housing (2010) “Specification for roads and bridges” 2:137-275.

Garg, S.K. (2012). Soil mechanics and foundation Engineering, (8th edition). New Delhi: Khahana publishers 10-13

Gidigasu, M. D. (1976). Laterite soil engineering pedo-genesis and engineering principles, Amsterdam Elsevier Scientific, New York, 554

Grim, R.E. (1968). Clay Mineralogy, 2nd Ed, New York: McGraw Hill, 596.

Grimshaw, R. W. (1971). The Chemistry and Physics of clays and allied ceramic materials, (3rd Edition). Ernest Benn Limited, 801-802.

Ige, O.O. (2010). Assessment of geotechnical properties of migmatite-gneiss derived residual soil from Ilorin, Southwestern Nigeria, as barrier in sanitary landfills. *Continental Journal of Earth Sciences* 5(1):32-41.

Jworchan, I. (2006). Minerology and chemical properties of residual soils. *The Journal Geological Society of London.* 1,21

Lambe, T.W. & Wihtman, R.V. (1969). Soil Mechanics. New York: J. Wiley and Sons, 165.

Mahalinger-Iyer, U. & Williams, D. J. (1997). Properties and performance of lateritic soil in road pavements. *Journal of Engineering Geology.* 46:71–80

Murthy, V.N.S (2002). Geotechnical Engineering: Principle and practice of soil mechanics and foundation Engineering. New York: Marcel Dekker Inc. published by CRC press. 8.

Nayak, P. G & Singh, B. K. 2007. Instrumental characterization of clay by XRF, XRD and FTIR. *Bull. Mater. Science*, 30:235-238.

Oyawoye, M.O. (1972). The Basement Complex of Nigeria. Ibadan: Geology department, university of Ibadan, University Press, 66-102

Oyediran, I. A. & Williams, T. O. (2010). Geotechnical properties of some banded gneiss derived lateritic soils from Ibadan, Southwestern Nigeria, *Journal of Science Research*, 9(2), 62-68

Rahaman, M.A. (1989). Review of the Basement geology of South-western Nigeria. In: Geology of Nigeria, Kogbe CA (ed.), Rock View (Nigeria) Limited. 39-56.

Ramamurthy, T.N & Sitharam, T.G. (2005). Geotechnical Engineering: Basics of soil mechanics. S. Chand Publishing India, 64

Salome H.W., Abdullahi I.N., Irmiya S.A. & Yusuf, I. (2013). Geotechnical and Mineralogical Characterization of Soils Derived from Schist along Shango-Chanchaga Highway, Minna, Central Nigeria. *Journal of Minerals and Materials Characterization and Engineering,* 1:363-366

Schulze, D.G. (2005). Clay Minerals Encyclopedia of Soils in the Environment. 246-254

Shafique, U., Khan, M. S., Mustafa, A. & Arif, S. (2012). Engineering geological characterization of Lahore soil, based on geotechnical testing and mineralogical composition using X-ray diffraction, *Pakistan Journal of Science,* 64(3), 191-195.

Shichi, T & Takagi, K. 2000. Clay minerals as photochemical reaction fields. *Journal Photochem. Photobiol. C: Photochem Rev.,* 1:113.

Townsend, F.C (1985). Geotechnical characteristics of residual soils, *Journal of Geotechnical Engineering,* 111:77-92

Uehera, G. & Gillsman, G. (1981). The minerology, chemistry and physics of tropical soils with variable charge clays. Westview Tropical Agriculture Series No. 4. Published in the United States of America by, Westview Press, Inc. ISBN 0-89158-484-6

Velde, B. (1995). Composition and mineralogy of clay minerals. In: B. Velde (ed.), Origin and mineralogy of clays. New York, Springer-Verlag. 8-42.

Venkatramaiah, C. (2006). Geotechnical Engineering, Revised Third Edition, New Age International (P) Limited, Publishers, Ansari Road, Daryaganj, New Delhi – 110002, 6

Whitlow R. (1995). Basic soil mechanics (3rd Edition). Addison Wesley Longman Limited, Edinburgh gate.