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Geotechnical and Mineralogical Evaluation of Clay Deposits in Efiwo-Itobe and its Environs, Anambra Basin, Nigeria

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Abstract
Mineralogical and geotechnical studies of exposed clay deposits of the Mamu Formation at Efiwo-Itobe on Abejukolo-Ankpa road, Northern Anambra Basin, has been undertaken with the aim of investigating their suitability for engineering works. The study area lies within Longitudes 7°45' 00" N to 7°46' 00" N and Latitudes 7°32' 00" E to 7° 33' 00" E part of sheet 249 Soko SW. The clay deposits are brown at the base and whitish at the top usually with lateritic overburden. Sedimentary structures include burrows and laminations. The liquid limit and plasticity index values of 22.50%, 21.20%, 21.25%, 21.50%, 20.95%, 21.00% and 10.13%, 6.85%, 5.55%, 4.95%, 3.72%, 3.10%, respectively, when compared to recommended standards show that the soils exhibit properties that make them suitable for their applications as liners in landfill construction, subgrade and subbase fill materials in road construction and as foundation material for building. The X-ray Diffraction studies of the clay deposits indicate that the samples contain kaolinite, quartz, muscovite, microcline and goethite in the upper layer and kaolinite, quartz, muscovite, microcline at the bottom layer. The relatively high content of quartz in the studied samples makes them impure for pharmaceutical, paint, plastics, and fertilizer. The depositional environment of the study area is interpreted to be a nearshore depositional system suggestive of continental provenance in humid climates and high leaching environment of deposition.

Keywords: *Mamu Formation, Atterberg limits, Geotechnical test, X-ray Diffraction, Clay, Provenance.*

Introduction

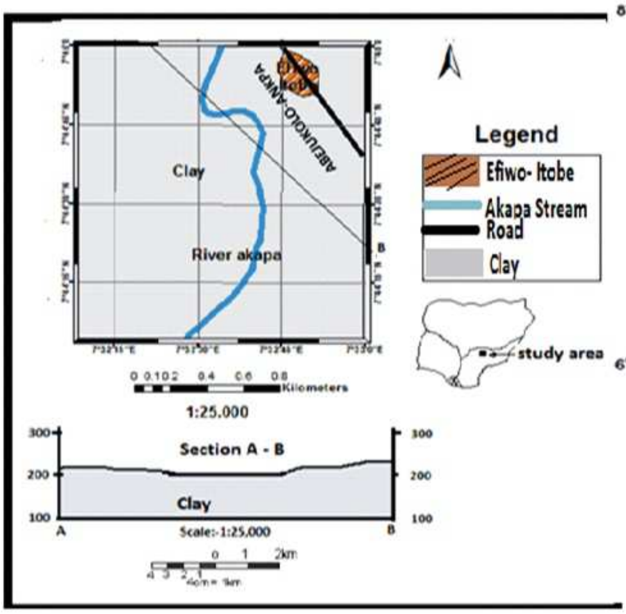
Clays are naturally occurring hydrous alluminosilicates that are products of extensive periods of chemical weathering of primary crystalline rocks. They are typically associated with very low energy depositional areas. Clay is a very important material in geotechnical engineering because it is often encountered in geotechnical engineering practice. Generally, this soil type has numerous problems due to its low strength, high compressibility and high level of volumetric changes. Clay needs to be improved upon before it can be used in construction of roads, dams, slurry walls, airports and waste landfills. Improved gradation, reduction in plasticity and swelling potential, as well as increase in strength and workability, generally improve the stability of clay (Nazile, 2018).

In the Efiwo-Itobe area, the exposed clay deposits belong to the Lower Coal Measures of Mamu Formation (Murat, 1972). Clay is the predominant lithology and is mostly utilized as subgrade (i.e., in-situ) and as aggregates in most road constructions in the area. This paper aims at conducting XRD and geotechnical studies to investigate the relationship between the provenances of these materials and how they affect their performance of the roads.

Location and Geology of the Study Area

Efiwo Itobe lies within latitude N7^0 45' 00" - 7^0 46' 00" and Longitude E 07^0 32' 00"- 7^0 33' 20" (Fig. 1). The area is drained by streams that exhibits linear drainage pattern. The climatic condition of the area is characterized by dry season of averagely four and half (4.5) months starting in November - March while the raining season lasts for seven and half (7.5) months from April to November. The average annual temperature of the area is around 26^{0}c and increases to a about 32^{0}c during the dry season. The average annual rainfall is 870 mm. The studied lithostratigraphic unit is a member of the Mamu Formation of Northern Anambra Basin. The Anambra basin is one of the seven sedimentary domains in Nigeria and covers an area of about 40,000 Km^2 (Murat, 1972). It is located at the south western extreme end of the Benue Trough with which it is genetically related in origin. The basin is bounded on the west by the Precambrian basement complex rocks of western Nigeria and on the east by the Abakaliki Anticlinorium (Fig.2). Sediment deposition in the basin started in the Campanian- Maastrichtian with a short marine transgression followed by a regression.

The Nkporo shale constitutes the basal formation of the basin and is predominantly made up of shale and mudstone occasioned by thin beds of sandy shale, sandstone and rare occurrence of shelly limestone (Kogbe, 1976). Gradual subsidence of the basin initiated by a regression during the Maastrichtian deposited the sediments of the Mamu Formation underlain by the Nkporo Shale and overlain by the Ajali Sandstone (Reyment, 1965). The formation has an approximate thickness of 1000m and consists of sandstones, clay/shale and sandy shale with coal seams. The clay units of the Mamu Formation is the focus of this study. Bounded at the top is the Ajali Formation (False-Bedded Sandstone) consisting of thick friable, poorly sorted sandstones with typical white colour and occasionally iron-stained. The Nsukka Formation lies conformably on the Ajali Sandstone and occupies a broad stretch of Country West of the Udi Plateau (Reyment, 1965). The Nsukka Formation is similar to the Mamu Formation in lithology and the rocks consist of an alternating succession of sandstone, dark shale, and sandy shale with thin coal seams at various horizons (Simpson, 1954). Thin limestone beds also occur towards the top of the Formation (Agagu *et al*., 1985).



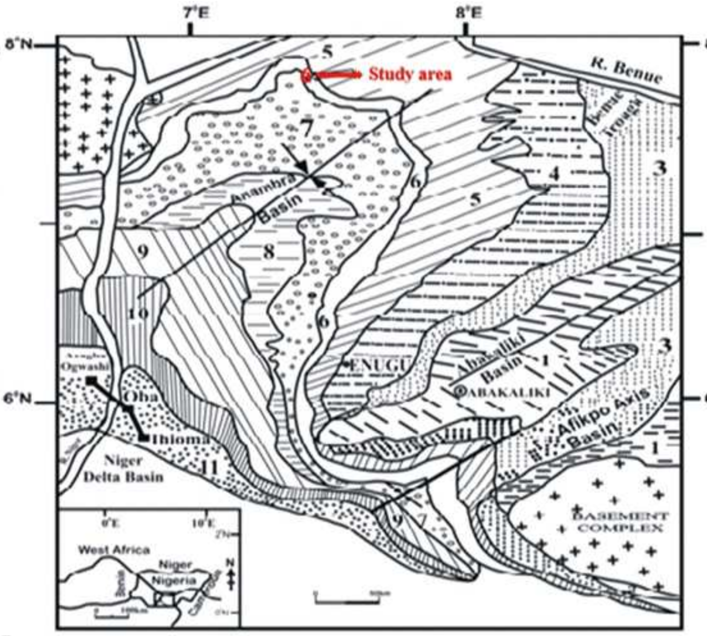


Fig. 1: (Left) Superimposed Geological Map on Topographical Map of the study area

Fig. 2: (Right) Generalized geological map of Southeastern Nigeria (red arrow; study area) showing the location of Cretaceous to Tertiary sequences north of the Niger Delta Basin. Numbers of the Formations are as follow: *1.* Asu River Group; *2.* Odukpani Fm.; *3.* Eze-Aku Shale; *4.* Awgu Shale; *5.* Enugu/Nkporo Shale; *6.* Mamu Formation; *7.* Ajali Sandstone; *8.* Nsukka Formation; *9.* Imo Shale; *10.* Ameki Formation; *11.* Ogwashi-Asaba Formation (After Akande et al., 2007).

Materials and Methods

Field Study and Sample Collection

Detailed geological mapping was carried out by traversing the area along road-cuts and footpaths to locate and study the exposed sections. These exposures were observed and described based on their colours, textures and mode of occurrences. The thickness of the beds were measured, while elevations and GPS readings were also taken. The descriptions of the exposures are summarized in Figs (3a and 3b).

Geotechnical Studies

The clay samples were subjected to geotechnical tests (Atterberg's limits) and mineralogical tests (X-ray diffraction). The shrinkage limit test, plastic limit, liquid limit and engineering tests were undertaken as outlined by Casagrande (1948). The geotechnical tests were conducted at the Petrology Laboratory, Kogi State University, Anyigba.

X-Ray Diffraction (XRD) Test

A quantitative determination of the mineralogical properties of the clay samples using Empyrean X-ray diffractogram (2010) was carried out at the National Geosciences Research Laboratory (NGRL), Kaduna. The clay samples were broken down and a representative quarter obtained with a clean mortar and pestle. The pulverized powdered sample was weighed and tested using an Empyrean Powder Diffraction equipped with a Cu – K radiation source (30Kv, 55mA)

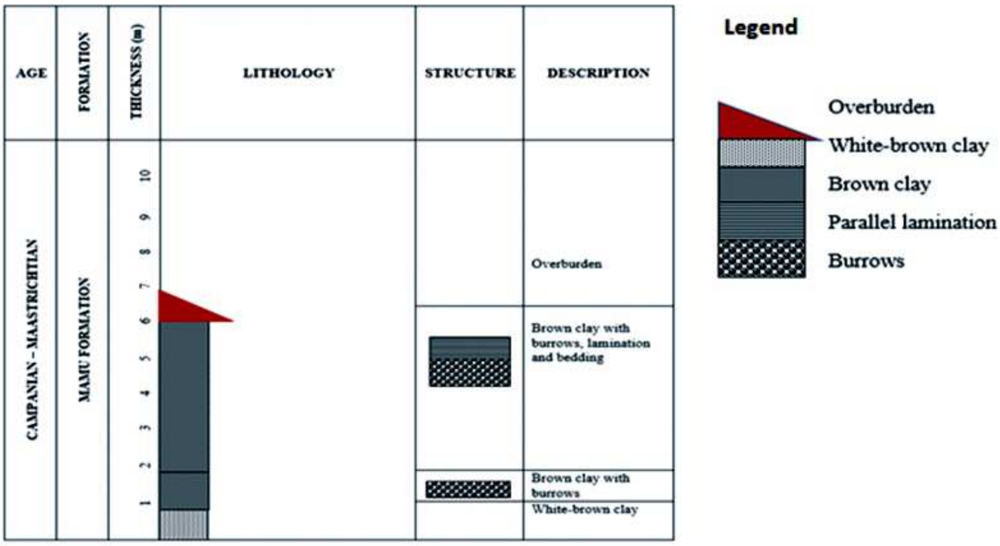


Fig. 3a: Lithologic section of location 1

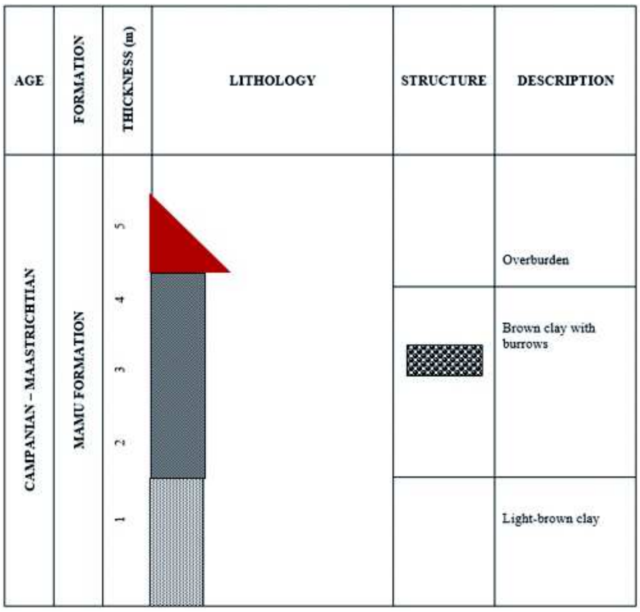


Fig. 3b: Lithologic section of location 2

inbuilt standards. The diffraction pattern was obtained with the aid of a computer, while the 2θ, d-spacing values and peak intensities yielded by the powder patterns were used to identify the minerals.

Results and Discussion

Results

Geotechnical Analysis Results

The results of geotechnical analysis consisting of liquid limit, plastic limit and plastic index are presented in Tables 1 and 2:

Table 1: Results of Plasticity Index

Locations	Liquid Limit	Plastic Limit	Plasticity Index
1a	22.50	12.37	10.13
1b	21.20	14.34	6.86
1c	21.25	15.70	5.55
2a	21.50	16.55	4.95
2b	20.95	17.23	3.72
2c	21.00	17.85	3.10

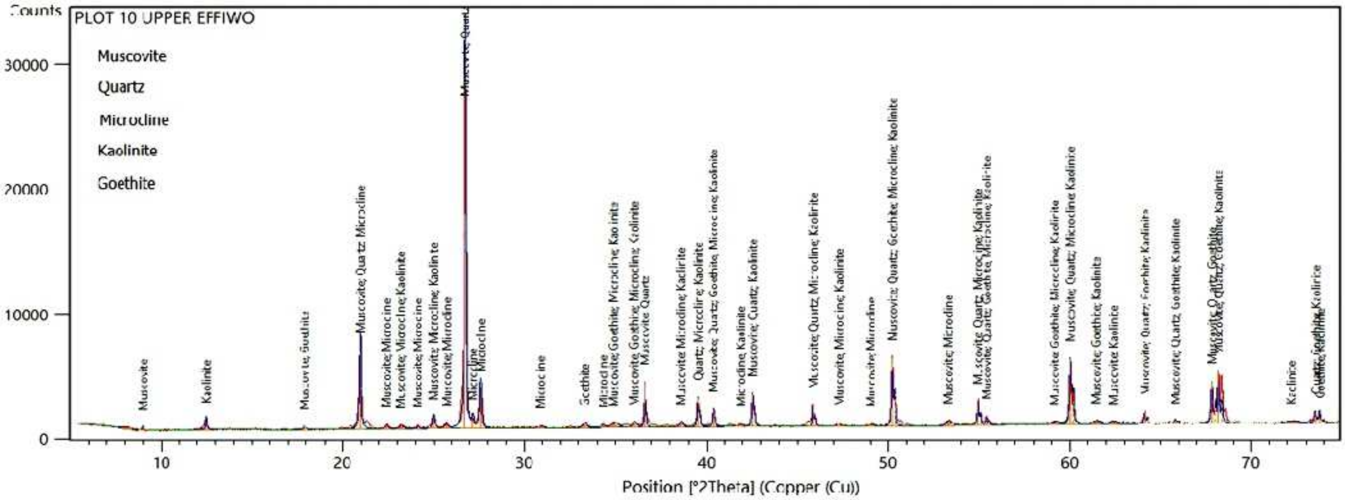
X-ray Diffraction Analysis Results

The diffraction patterns obtained from the two (2) representative samples are shown in Figs 11 and 12. The

Table 2: Showing general characterization and Engineering Implications of analysed samples

Sample	Liquid Limit	Plasticity Index	Plasticity (Sower and George 1979)	Engineering Implications
Sample 1a	22.50	10.37	Moderately plastic	Good for engineering works
Sample 1b	21.20	6.85	Slightly plastic	Good for engineering works
Sample 1c	21.25	5.55	Slightly plastic	Good for engineering works
Sample 2a	21.50	4.95	Slightly plastic	Good for engineering works
Sample 2b	20.95	3.72	Slightly plastic	Good for engineering works
Sample 2c	21.00	3.10	Slightly plastic	Good for engineering works

minerals identified and their respective concentrations are presented in Table 3, followed by the discussion of results.



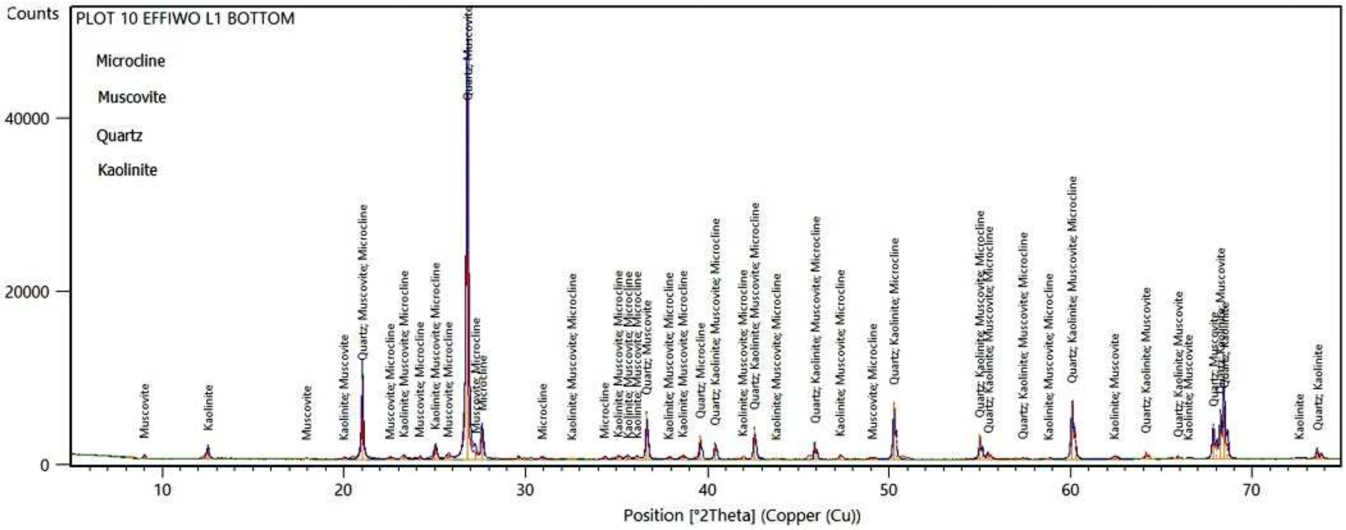


Fig. 12: X-ray Diffraction Pattern of Location 1 (bottom layer)

Discussion

Geotechnical Properties

The plasticity index of clay samples from the six sampled locations (1a, 1b, 1c, 2a, 2b and 2c) (Table 1) indicate that there are positive differences between the liquid and plastic limits of each sample. The plasticity index for samples 1a, 1b, 1c, 2a, 2b and 2c are 10, 13, 6.85, 5.55, 4.95, 3.72 and 3.10, respectively. According to Sower and George (1979) classification method, clay sample from location 1a is moderately plastic, while samples from location 1b, 1c, 2a, 2b and 2c are slightly plastic (Table 1). Furthermore, based on Casagrande (1948) classification chart for clay, all the clay samples are inorganic clays with low plasticity compressibility.

From laboratory analysis carried out on 6 samples, the soil samples from Efiwo-Itobe revealed that Sample 1, 2, 3, 4 and 5 are of medium plasticity, while sample 6 is of low plasticity. The Federal Government of Nigeria specifies that values of plasticity index of soil should be less than 20% and liquid limit should be less than 30% for soil to be used for engineering work (table 2).

The liquid limit and plasticity index values: (22.50% and 10.13%), (21.20% and 6.85%), (21.25% and 5.55%), (21.50% and 4.95%), (20.95% and 3.72%) and (21.00% and 3.10%) calculated for sample 1, 2, 3, 4, 5 and 6 respectively within the study reveal that samples 1, 2, 3, 4, 5 and 6 are ideal for engineering work because they meet the Federal Government of Nigeria's specification for engineering purpose. According to

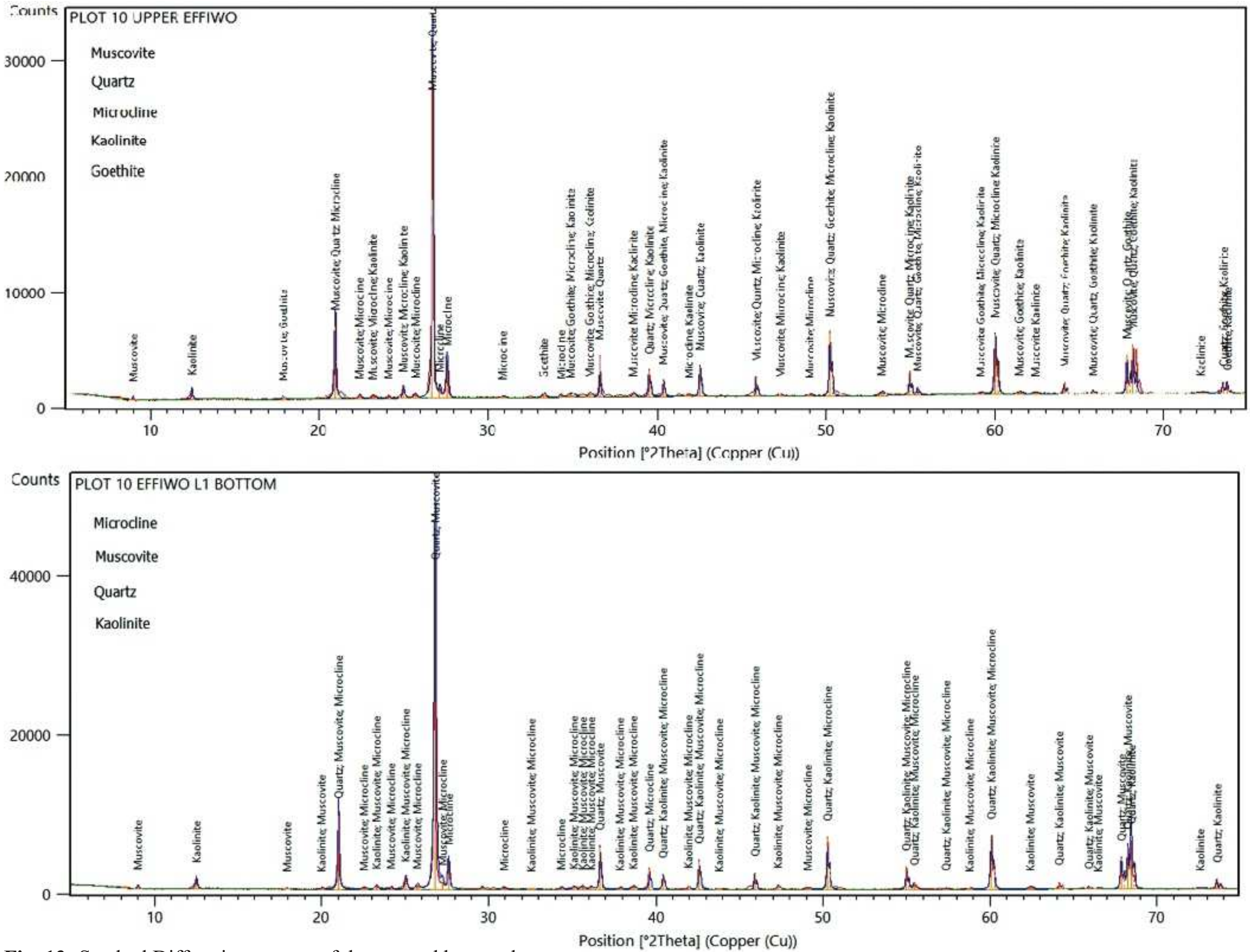


Fig. 13: Stacked Diffraction pattern of the top and bottom layer.

Seed *et al*., (1962), the plasticity index values indicate that the samples exhibit a low swelling capacity, thus, buildings or roads set up in this environment may not likely to develop cracks. All the samples fall under the liquid limit with low compressibility. Liquid limit is an important index property since it is correlated with various engineering properties (Ige, 2017). All the samples meet the 20% minimum liquid limit requirement recommended by Benson *et al*. (1994) to be considered for liner materials in a landfill. Soils with high shrinking and swelling potential can pose a hazard when used as a support for buildings and other engineering structures. The tested samples having low compressibility from the Casagrande chart are therefore predicted to have good volume stability with low swell potentials and show potential suitability as supports for building. Plasticity value higher than 7% (Daniel 1993; Benson *et al*., 1994; Rowe et al., 1995) but less than 65% is recommended to avoid excessive shrinkage. Although most samples have PI less than 7%, they are well below 65% and will therefore not undergo excessive shrinkage if considered as a barrier in a sanitary landfill. They will, however, need some improvement in order to satisfy the PI requirement of 7% as most of them are below this recommended value. Evaluating the applicability of the samples for pavement construction, the Federal Ministry of Works and Housing (FMWH, 1997), recommends subgrade/fill liquid limit of ≤50% and plasticity index ≤ 30%. Thus, all the samples satisfy these requirements. Also, for sub-base, FMWH recommends liquid limit ≤ 30% and plasticity index ≤ 12% and all the samples satisfy these requirements. Thus, samples from this locality specifies good potentials as subgrade and sub-base in pavement construction.

X-ray Diffraction (XRD) Mineralogy

The result of the XRD analysis of the clay samples presented in Table 3 indicate that the clay samples are dominated by kaolinite, quartz, muscovite, microcline and goethite with varied abundance between the lower and upper layers of the deposit. For example, kaolinite constitutes 23.40% in the upper layer and 24.77% in the bottom layer, quartz constitutes 14.95% in the upper layer and 16.51% in the bottom layer, muscovite constitutes 27.10% in the upper layer and 33.03% in the bottom layer, and microcline constitutes 22.42% and 25.69% in the bottom layer. Goethite only occurs in the upper layer as constituent of 12.14% by volume. This analysis indicates an increase in the amount of kaolinite, quartz, muscovite and microcline in the clay deposit from the upper to bottom layers. The abundance of muscovite in the clay indicate that the sediments have not been subjected to severe chemical weathering. The relatively high content of quartz in the studied samples makes it impure for pharmaceutical, paint, plastics, and fertilizer use (NAFCON- 1985). Similarly, the absence of Montmorillonite from the studied sample increases its suitability as barrier landfills. The peak patterns match and almost all the minerals follow the same pattern (Fig. 13) in the two layers of the clay. The presence of goethite in the upper layer is related to weathering.

Depositional Environment and Paleoclimate

The clay mineral of the Efiwo-Itobe clay is dominantly kaolinites with large constituents of non-clay minerals such as quartz, muscovite, microcline, and goethite (Table 3). This result suggests a dominant percentage of continentally derived clay. According to Parham (1966), kaolinite minerals decreases with increasing distance from the shoreline, while montmorillonite and illite increases with increasing distance. Therefore, kaolinite mineral abundance in the study area gives credence to deposition in a near-shore/shallow marine environment (Odoma *et al*., 2015) with deceasing clay mineral abundance away from the shoreline. The grittiness of the clay further affirms its residual origin (Alege et al, 2014). Likewise, the large quantity of the non-clay minerals is suggestive of continental provenance in humid climates and high leaching environment with low pH conditions.

Conclusions

Field mapping have shown that the clay deposits at Efiwo-Itobe exhibit sedimentary features such as parallel lamination and burrows which are associated with two lithological units of Mamu Formation exposed at Efiwo- Itobe in the Northern Anambra Basin. Geotechnical studies have shown that they are inorganic materials that have not been chemically weathered. The clay samples exhibit low, moderate to high plasticity, Mineralogical analysis using XRD reveals the presence of kaolinite as the dominant clay mineral, with other non-clay minerals such as quartz, microcline, muscovite and goethite. Kaolinite constitutes between 23.40 to 24.77%, quartz varies from 14.95 to 16.51%, muscovite ranged from 27.10 to 33.03%, and microcline ranged from 22.42 to 25.69%, goethite found only in the upper layer constitutes 12.14%. Among the two (2) layers of clay samples studied, it was observed that the clay samples have a moderate amount of kaolinite. Since muscovite is not especially resistant to chemical weathering, it can be deduced from its abundance in the analysed sample that the sediments have not been subjected to severe chemical weathering.

Kaolinite abundance gives credence to deposition in a nearshore environment with deceasing clay mineral abundance away from the shoreline. Likewise, the large quantity of the non-clay minerals is suggestive of continental provenance in humid climates and high leaching environment.

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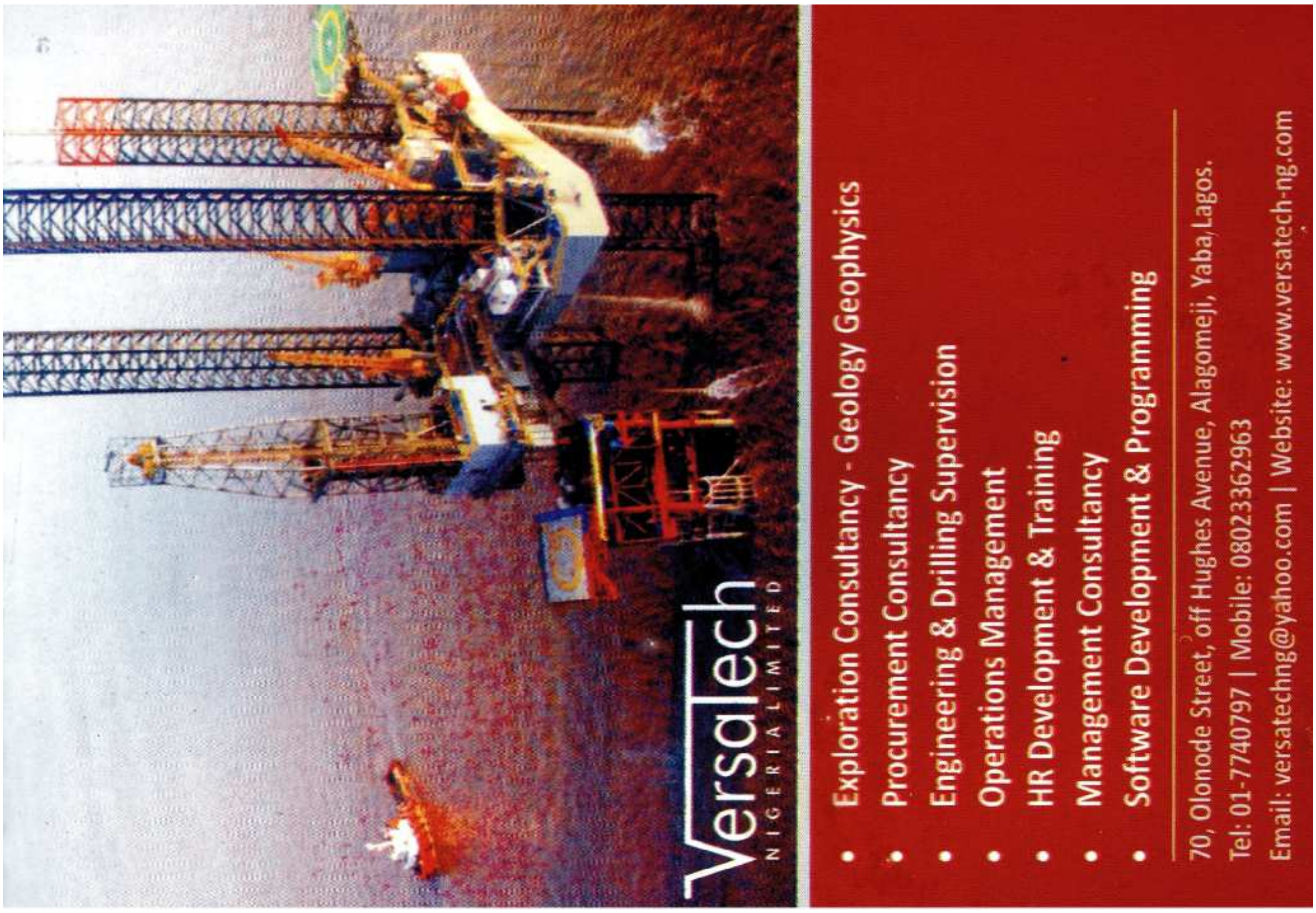

Pictorial view of the new NMGS House under construction at Abuja.