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Industrial Evaluation of Kaolinite around Esa-Oke and Its Environs, Southwestern Nigeria

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Abstract

Residual clay occurrences developed over Basement Complex rocks around Esa-Oke and its environs in southwestern Nigeria were investigated to evaluate their industrial properties. Field observation on colour and texture showed that the clay bodies in the environment vary from reddish – whitish colour with gritty textural characteristics. Powdered samples of representative clay bodies were selected for routine mineralogical analysis using X-ray diffractometer while major and trace elements were determined using X-ray fluorescence withspectrometer. Mineralogical studies showed that kaolinite is the only clay mineral in the weathered clay samples analyzed while phlogopite and quartz constitute non-clay mineral.

Chemical data showed that SiO_2, Al_2O_3 and Fe_2O_3 with values 64, 27 and 5wt% respectively, constitute about 96% of the bulk chemical composition. Industrial suitability of clay bodies revealed that reddish clays in the environment could serve as raw material for brick production, ceramic wares and also good for non-bearing wall material. On other hand, whitish clay in the environment if properly processed through screening by reducing particle size, could be used in textile, plastic, paint and paper industries.

Keywords: ***Industrial suitability, Kaolinite, Residual clay***

Introduction

Psammite, being a metamorphosed impure sedimentary rock of a dominantly sandstone protolith mixed with small amount of feldspars and micas constitute a unit of the four major groups of basement complex of Nigeria; namely, the Migmatite – Gneiss – Quartzite complex, series of approximately North – South trending Schist, Pan African granitic intrusives and undeformed acid and basic dykes. Due to location of Nigeria in the tropics, characterized by high temperature, rainfall and humidity conditions that aid chemical weathering processes, these rocks are often broken down chemically resulting in formation of residual soil profile that is occasionally dominated by quartz and clay minerals.

Several publications on clays in Nigeria have revealed that kaolinite constitute the most abundant clay mineral in residual weathered material. Kaolinite, because of its physic-chemical properties as industrial raw material, its contribution to the economic, technological and industrial development remain significant. This present work is therefore aimed at evaluating the industrial applications of kaolinitic rocks in Esa-Oke and its environs.

Geology of the area

Esa – Oke and its environs falls within the eastern part of late Precambrian Okemesi fold belt of Ilesha Schist belt (fig 1) that haveNNS – SSE trending. This side of the belt consist of Quartzite and Quartz- schist. Quartzite formed the major dominant rock unit that constitute the ridge around the mapped eastern side of the belt with quart – schist occurring as a low-lying exposure forming the innermost part of Okemesi anticline (Okunlola and Okoroafor, 2009). The occurrence of clay bodies in this area is presumed to have been formed from quart-schist rock unit.

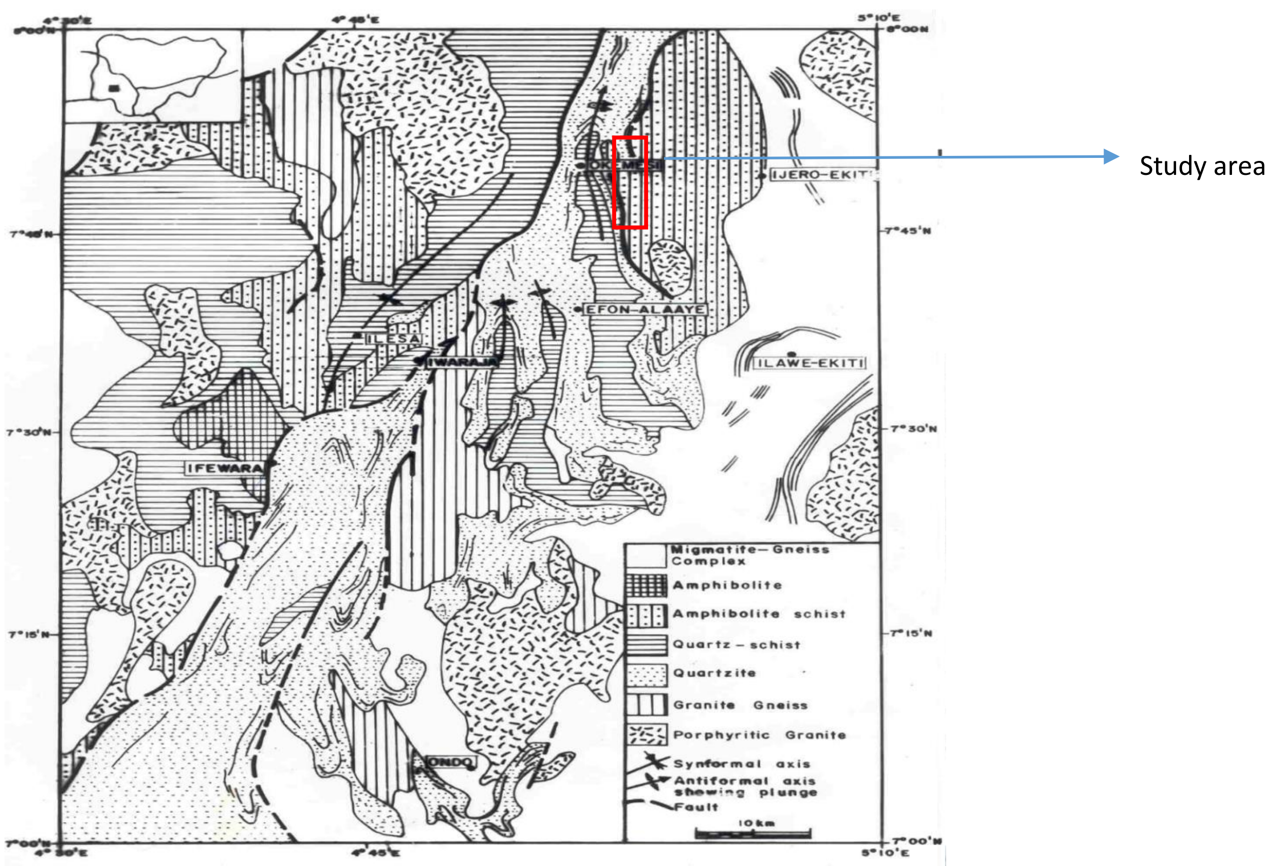


Fig 1: Geologic map of Okemesi fold belt showing the Esa – Oke and its environs (modified from Hubbard, 1975)

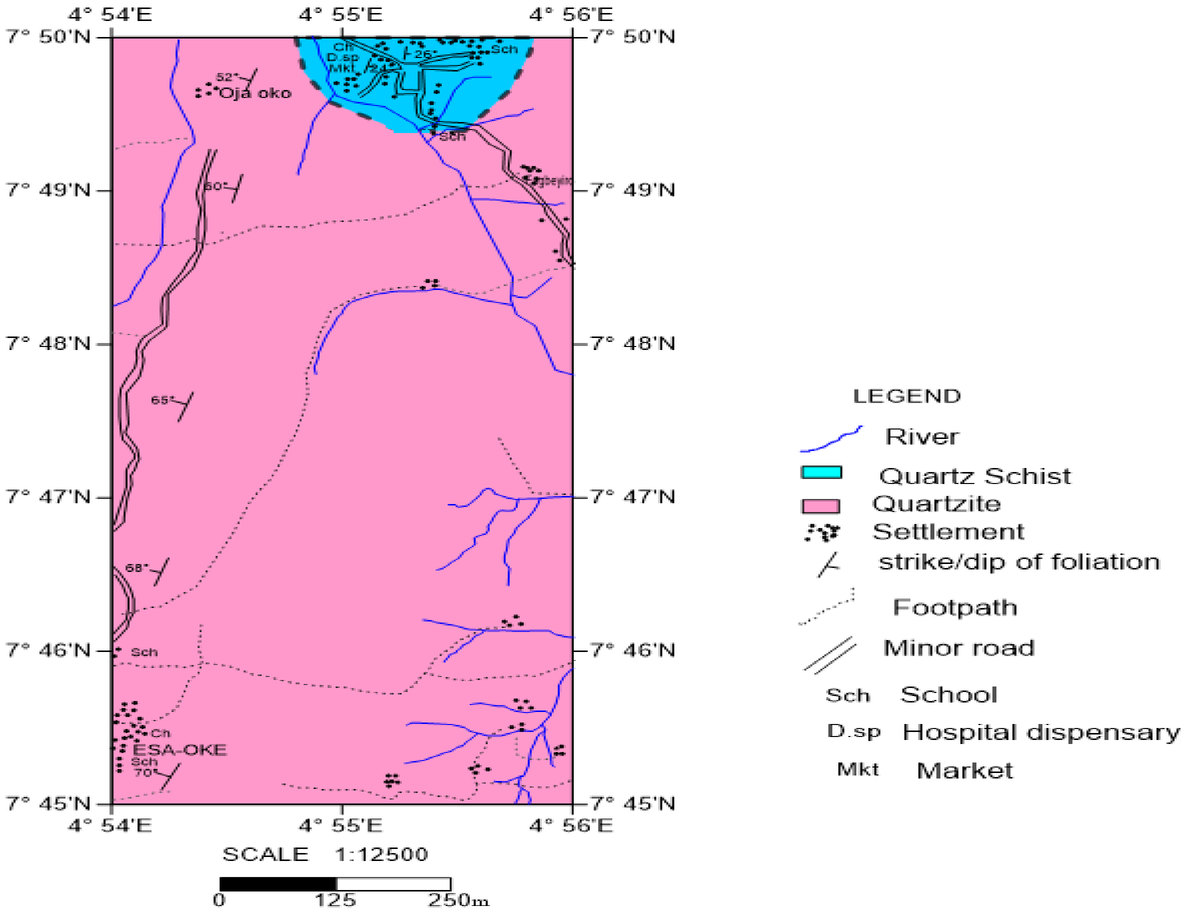


Fig 2: Geologic of Esa – Oke and its environs

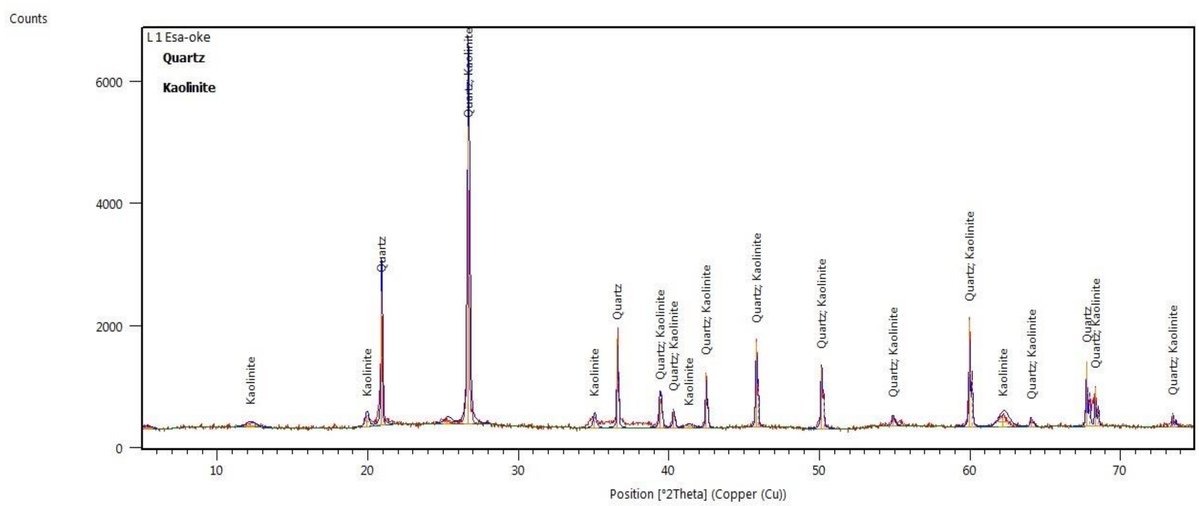
Sampling and analysis

Seventeen soil samples were collected randomly along the road cut from different locations. For physical characteristics determination of selected prepared clay samples, Atterberg limits were undertaken according to the British standard specifications as well as unconfined compressive strength and firing test. Mineralogical and Chemical analysis were carried out using X-ray diffraction (XRD) and X-ray fluorescence spectrometer (XRF) methods respectively.

Mineralogical characteristics

Powdered samples of the residual clay were analyzed using EMPYREAN X-ray diffractometer at Petrochemical engineering department, Amodu Bello University, Zaria. The diffraction pattern were recorded at the scan steep time of 29.0700(s) with Cu tube and Ni filter to produce K-alpha and K-beta radiation. The strongest diffractograms were converted from 2Ɵ angles to d-spacing values and a match of d-spacing value for unknown was done with those given in index book. Minerals were identified through relative proportion method as described by Carrol (1971). Mineralogical results as presented in table (1) shows that kaolinite is the dominant clay mineral in the analysed samples. Quartz and phlogopite constitute the major non-clay minerals that display notable intensities in the diffractograms as shown in fig (3a and b) As shown in table (1), kaolinite constitute about 45 – 48% in prepared clay samples analysed while quartz formed around 16 – 52% with phlogopite of 40% as non- clay constituent. The wide variation in percentages of quartz and presence of phlogopite in one of the samples analyzed is indicative of weathering of intrusive rock as observed in the field while mapping.

The abundant quartz and small amount of kaolinite are the major disparity between the investigated clay bodies, the china clay (Huber, 1985), National Fertilizer Company of Nigeria (NAFCON) specifications and values documented on residual clays of Imope and Kitibi Ayede, Southwestern Nigeria (Bolarinwa, 2004).



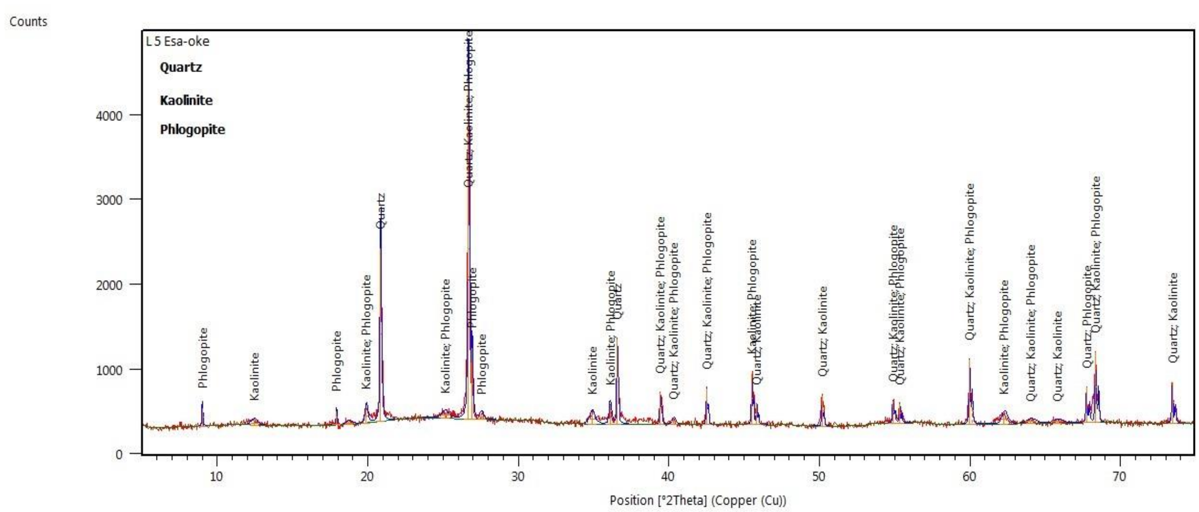


Fig 3: X-ray diffraction trace for clay samples (a- Esa- Oke reddish clay; b – Esa –Oke whitish clay).

Table 1: Average mineralogical composition of Esa- oke and its environs residual clay

Minerals	Location		Reference samples			
	L_1 (%)	**L_5 (%)**	**A (%)**	**B (%)**	**C (%)**	**D (%)**
Kaolinite	**48**	**45**	**85**	**85**	**72.5**	**73.3**
Quartz	**52**	**16**	**Trace**	**4**	**16**	**24**
Phlogopite	**-**	**40**	**-**	**-**	**-**	**-**
Illite	**-**	**-**	**-**	**-**	**1.5**	**-**
Montmorillonite	**-**	**-**	**-**	**-**	**5**	**-**
Goethite	**-**	**-**	**-**	**-**	**2.5**	**1**

(A) – China clay (Huber, 1985). Recommended values for ceramics

(B) – NAFCON (1985) recommended values for fertilizer production

(C) – Average mineralogical composition of Imope residual clay. (Bolarinwa , Elueze, and Christopher, 2004).

(D) – Average mineralogical composition of Kitibi residual clay. (Bolarinwa, Elueze, and Christopher, 2004).

Chemical composition

Prepared powder of representative clay samples were analyzed using X-ray fluorescence spectrometer. Measurement conditions were set at 40 kilovolt for Ti (22) and 15 kilovolt for elements from Mn to Zn for 300 seconds time count. Elemental concentration were calculated were calculated by comparing X-ray spectral peaks determined with X-ray intensities of those of single standards made up of oxide of the elements. Chemical data of five (5) representative samples as presented in Table (2) shows that SiO_2,Al_2O_3 and $Fe_2O_3$with abundance range 49 - 75, 19 -34 and 0.9 - 13wt% respectively constitutes about 96% of the bulk chemical composition.Na_2O appears to have occur in trace only in whitish clay bodies in the area with CaO of about 0.14 - 0.16% when compared with 0% of these oxides in lateritic bodies. However, clay bodies within the study area favourably compared with plastic fire clay of St. Louis, Florida active kaolinite and other clay deposits in southwestern Nigeria as resented in Table (2). In term of Industrial functional application of chemical compositions as shown in Table (3), clay bodies in the area are within the limits of industrial specifications for refractory bricks (Parker, 1967), ceramic (Singer and Sonja, 1967),paint (Paynes, 1964), paper (Keller, 1964) and building bricks (Murray, 1960).

Table 2: Average chemical composition of Esa- Oke and its environs residual clay in comparison with other clay deposits.

Oxides	**L_1 (%)**	**L_2 (%)**	**L_3 (%)**	**L_5 (%)**	**L_{14} (%)**	**Reference Samples**					
						A (%)	**B (%)**	**C (%)**	**D (%)**	**E (%)**	**F (%)**
Na_2O	0.000	0.046	0.000	0.064	0.000	0.21	0.03	0.20	0.45	0.14	0.77
MgO	0.396	0.647	0.340	0.705	0.404	0.13	0.08	0.30	1.26	0.71	0.10
Al_2O_3	29.596	29.761	21.691	33.622	19.371	37.63	9.42	24.00	18.20	20.62	25.11
SiO_2	52.876	64.376	74.658	55.660	72.869	46.88	52.92	57.67	57.98	61.92	54.12
P_2O_5	0.107	0.225	0.315	0.236	0.492	-	-	-	-	-	0.61
SO_3	0.203	0.526	0.392	0.537	0.426	-	-	-	-	-	-
Cl	0.055	0.027	0.015	0.022	0.025	-	-	-	-	-	-
K_2O	1.153	2.985	0.063	3.316	1.329	1.60	0.98	0.50	1.51	0.63	1.16
CaO	0.073	0.155	0.059	0.140	0.159	0.03	1.91	0.70	0.62	0.02	0.38
TiO_2	2.196	0.328	0.426	1.116	0.728	-	-	-	-	3.20	-
Cr_2O_3	0.034	0.018	0.007	0.042	0.008	-	-	-	-	-	-
Mn_2O_3	0.085	0.022	0.007	0.025	0.013	-	-	-	0.04	0.71	0.06
Fe_2O_3	13.214	0.880	2.025	4.498	3.883	0.88	3.65	2.23	9.93	5.00	4.92
ZnO	0.002	0.000	0.000	0.001	0.000	-	-	-	-	-	-
SrO	0.011	0.004	0.004	0.014	0.010	-	-	-	-	-	-

Average values for 6 samples

(A) China clay (Hubber,1985)

(B) Florida active kaolinite (Hubber, 1985)

(C) Plastic fir clay, St, Louis (Hubber 1985)

(D) Isan clay (Elueze and Bolarinwa, 1994)

(E) Abraka sedimentary clay (Emoufrieta, et al, 1994)

(F) Imope residual reddish clay (Elueze, et al, 2004)

Oxides	L_1 (%)	L_2 (%)	L_3 (%)	L_5 (%)	L_{14} (%)	Some Industrial Specifications						
						A (%)	B (%)	C (%)	D (%)	E (%)	F (%)	G (%)
Na_2O	0.000	0.046	0.000	0.064	0.000	2.76	0.20	0.8 – 3.5	0.2-0.35	0.00-0.60	-	-
MgO	0.396	0.647	0.340	0.705	0.404	8.50	0.10 – 0.19	0.2 – 0.7	0.2-0.3		-	-
Al_2O_3	29.596	29.761	21.691	33.622	19.371	9.45	26.50	25.0-44	37.3-38.4	30.5-36.1	40	38.10
SiO_2	52.876	64.376	74.658	55.660	72.869	48.67	67.50	51 -70	44.90 - 45.30	45.0 - 45.80	-	45.0
P_2O_5	0.107	0.225	0.315	0.236	0.492	-	-	-	-	-	-	-
SO_3	0.203	0.526	0.392	0.537	0.426	-	-	-	-	-	-	-
Cl	0.055	0.027	0.015	0.022	0.025	-	-	-	-	-	-	-
K_2O	1.153	2.985	0.063	3.316	1.329	2.76	1.10-3.10	-	0.04 -0.10	0.00-0.60	-	-
CaO	0.073	0.155	0.059	0.140	0.159	-	-	-	0.03 -0.25	0.00-0.50	-	-
TiO_2	2.196	0.328	0.426	1.116	0.728	-	-	-	1.35 -1.75	0.00-1.70	-	1.70
Cr_2O_3	0.034	0.018	0.007	0.042	0.008	-	-	-	-	-	-	-
Mn_2O_3	0.085	0.022	0.007	0.025	0.013	-	-	-	-	-	-	
Fe_2O_3	13.214	0.880	2.025	4.498	3.883	2.70	0.5 – 1.20	0.5 - 2.4	13.4 -13.8	0.3-0.6	47	0.60
ZnO	0.002	0.000	0.000	0.001	0.000	-	-	-	-	-	-	-
SrO	0.011	0.004	0.004	0.014	0.010	-	-	-	-	-	-	-

Table 3: Comparison of chemical composition of Esa- oke and its environs residual clay with some industrial specification

Average values for 6 samples

(A) Brick clay (Murray, 1960)

(B) Ceramics (Singer and Sonjer, 1971)

(C) Refractory Bricks (Parker, 1967)

(D) Paints (Paynes, 1964)

(E) Paper (Keller, 1964)

(F) Pharmaceutical (Todd, 1973)

(G) Textile (Keller, 1964)

Physical properties

Physical properties evaluated include linear shrinkage, Atterberge limit tests, unconfined compressive strength test on fired samples at 600˚c and firing test. Water absorption capacity was determined on some of the sample pellets fired in a furnace at 1200˚c after cooling. As presented in Table (4), water absorption capacity vary from 13.8% to 24.2% for lateritic clays while whitish clay within the area is in the range of 12% to 17%. The colours of the fired pellets range from moderate reddish orange to moderate pale brown for lateritic clays and moderate orange pink to whitish colour for whitish clay bodies. Plots of plasticity indices against liquid limits show that clay deposits in the area falls between medium to high plasticity according to Casagrande (1932) and Brumister (1949). In addition, plot of plasticity indices against plastic limits of the clays in the area according to Bain (1971) revealed that plastic clays in the area possessed low to moderate mouldability. Furthermore, results of average compressive strength of fired mould samples at 600˚c are between 163kpa to 1660kpa. These values are lower than the average value 5.6N/mm^{2}and minimum of 3.0N/mm^{2}recommended values by Nigerian Building and Road Research Institute (NBRRI) for construction of bungalows and one storey buildings (Aribisala, 1978).

Table 4: Summary of Physical Properties of Clay Deposit within the Study Area

Location	LL (%)	PL (%)	PI (%)	LS (%)	WAC (%)	Strength at 600 ˚c		Colour change after firing at 1200˚c
						kPa	N/mm^2	
1	47.20	22.50	24.70	9.80	13.80	404.30	0.40	Moderate reddish orange
2	23.20	-	-	0.00	17.90	-	-	whitish
3	23.10	-	-	0.00	24.20	163.00	0.16	Moderate reddish orange
4	21.10	-	-	0.00	17.30	-	-	Moderate reddish brown
5	42.00	27.80	14.20	5.00	12.80	339.50	0.34	Moderate orange pink
7	33.00	16.20	16.77	7.10	16.40	773.60	0.78	Moderate reddish orange
9	39.60	19.40	20.16	9.80	19.30	953.00	0.95	Moderate reddish brown
11	37.00	17.10	19.86	8.30	17.80	-	-	Moderate reddish brown
12	53.20	28.60	24.63	14.3	17.80	260.50	0.26	Moderate reddish orange
13	27.60	-	-	1.40	15.30	697.8	0.70	Moderate reddish orange
14	23.80	-	-	0.00	16.30	-	-	Moderate reddish orange
17	40.30	25.00	15.30	9.30	14.80	-	-	Moderate pale reddish brown

Conclusion and Recommendation

Mineralogical anlysis based on X-ray diffraction studies show that the clay profile developed on basement complex of Esa-Oke and its environs are dominantly made of kaolinite while phlogopite and quartz constitute non-clay constituents. Comparing mineralogy of clay deposits in the area with some industrial specifications, if properly blended with other minerals, the deposit is amendable to beneficiation to suit different industrial applications. Average abundance of major elements show that clay bodies in the study area have high percentage of SiO_2 (64%), Al_2O_3 (27%) and Fe_2O_3 (5%) constituting about 96% of the bulk chemical composition. This implies that clay bodies in this environment was chemically derived from quartz-schist rock unit in this environment except for localized pocket of clay developed from chemical weathering of an intrusive granitic rock. On basis of relevant physical parameters, the investigated clay bodies possess moderate mouldability and moderate reddish orange to whitish colour. Low values of compressive strength of samples in the present work could have been as a result of manual compaction of samples. Very high quality bricks could be produced from the clay bodies in the study area if standard brick making machine with more efficient compaction system is used.

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