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Compositional, Geotechnical and Industrial Characteristics of Some Clay Bodies in Southern Nigeria

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Abstract

Clay occurrences at Okija, Ubiaja and Iyuku in southern Nigeria were characterized geochemically, mineralogically as well as geotechnically in order to evaluate their industrial potentials. Mineralogical analyses portray kaolinite as the dominant clay mineral with traces of illite in the transported Okija and Ubiaja samples.

Abundances of major elements show that SiO_2 (ca 50.41-64.45%) and Al_2O_3 (ca 18.62-31.62%) constitute over 80% of the bulk chemical compositions. Other constituents include Fe_2O_3, K_2O, T_iO_2, CaO, MgO and MnO. Although notable disparities exist in the S_iO_2 and Al_2O_3 contents of the clays, the Iyuku sample is more siliceous and less aluminous than the others.

Geotechnically, the in-situ derived Iyuku clay has distinctive characteristics. It is considerably less plastic, non-expansive, less hydrophilic and of low compressibility due to its lower clay fraction and higher crystallinity of available kaolinites. On the other hand, the Okija and Ubiaja clays are characterized by medium to high plasticity and compressibility. The shrinkage characteristics of the clays as well as their colloidal activities are consistent with their plasticity.

Evaluation of the industrial potential of the clays based on their physical, chemical and geotechnical characteristics revealed that they are suitable for the production of refractory bricks and ceramics. Appropriate processing/beneficiation would be mandatory if they are to qualify for other industrial applications, such as rubber, paper, paint and cosmetic industries.

Keywords: clay, geotechnical characteristics, industrial potential, kaolinitic, mineralogical characteristics, plasticity

1. Introduction

Southern Nigeria is endowed with abundant clay resources. East of the River Niger, occurrences have been reported in the old Awka, Okigwe, Umuahia and Orlu provinces. Notable clay deposits in these parts include those at Ozubulu, Enugu, Awo-Omama and Okija. Important occurrences in Southwestern Nigeria have been reported at Auchi, Ubulu-Uku, Ozanogogo, Ubiaja, and Sapele. Also, the Imo clay-shale and the Iyuku clay are some of the important argillaceous bodies of interest in Southern Nigeria.

Many of these geological materials occur as extensive cover of allochtonous units or as beds, lenses or bands within Cretaceous and Tertiary sedimentary sequences (Emofurieta et al., 1992); others e.g Iyuku are clearly authochtonous, being the product of in situ weathering of igneous rocks within the Nigerian Basement Complex (mainly granite and pegmatite). Clays are, undoubtedly, important in agriculture, ceramics, engineering and also have other industrial applications. The nature of a clay and its composition determine, not only its quality and commercial value but also, to a large extent, its engineering behaviour. Among the characteristics of clays that influence their engineering performance are clay mineral composition, physical properties such as particle size distribution, non-clay mineral composition, organic matter content and geologic history (Grim, 1968).

Interestingly, various researchers have looked at some of these clays from different angles. For example, Ajayi and Agagu (1981) carried out mineralogical analyses of primary clay deposits from seven localities representing different rocks in the Nigerian Basement Complex and found that the deposits that weathered from granites, gneisses, pegmatites and schists consisted mainly of kaolinite and trace proportions of montmorillonite and illite while deposits weathered from calc-silicate rocks contained high proportions of montmorillonite. Many sedimentary deposits have also been investigated in some detail e.g the Iguoba clay and Sokoto clay shales (Ola, 1980, 1987) and the Ubulu-Uku clay (Ola, 1987).

This paper attempts to address the nature, compositional, and basic geotechnical and physical characteristics of three clay deposits at Okija, Ubiaja and Iyuku in Southern Nigeria, with a view to predicting their engineering behavior and evaluating their economic potentials, as a contribution to the nation's industrial raw materials data base.

2. Locations and Field Occurrence

2.1 Okija Clay

Okija is a town about 45 kilometres from Onitsha, located on the banks of the Ulasi River in Anambra State (Figure 1). Here, a white or mottled-white clay of about 3 to 5 metres thickness outcrops at a road side section. The clay which is a unit of the Ameki Formation is, therefore, of variable thickness which increases southwards. It is smooth but gradually changes to a slightly gritty sandy clay of about 5 metres thickness.

2.2 Ubiaja Clay

The Ubiaja clay deposit is exposed at about one kilometre SSW of Ubiaja General Hospital in Edo State (Figure 1). Situated within the Esan Plateau, the clay is exposed along the base of an escarpment with youthful river valleys and overlapping spurs. The topography is distinctly rugged with heights reaching 250 to 320 metres above sea level. The highest parts constitute a watershed for many small streams that flow in northerly and southerly directions, the valley slopes being characterized by luxuriant growth of rain forest trees with marshy vegetation.

Lithologic log of a typical section of the Formation SSW of Ubiaja is presented in (Figure 2). It shows (from bottom to top), a light grey clay unit about 10 metres thick overlain by a dark brown lignite seam 1metre thick. A second clay unit which overlies the lignite seam is 2.5 to 3 metres thick, also light grey but with mottles/pinkish patches attributable to oxidation. This unit is succeeded by a fine to medium-grained clayey sand, while 10-12 metres of sand constitute the uppermost unit.

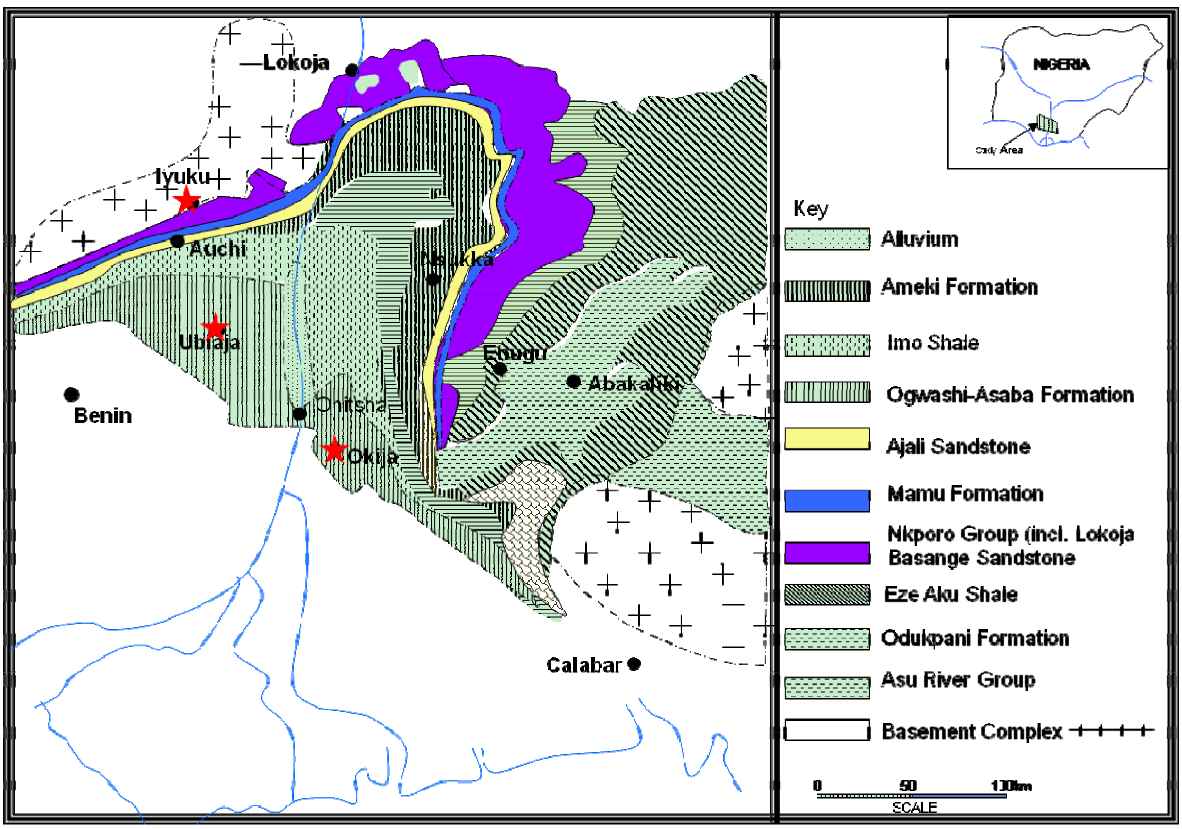

Figure 1. Geological map of parts of Southern Nigeria showing sampling locations

2.3 Iyuku Clay

Both sedimentary and crystalline Basement Complex rocks occur in the small village of Iyuku which is located NNW of Auchi in Edo State (Figure 1). The Cretaceous sandstone deposits belonging to the Lokoja-Basange Formation, form the northern limit of the southwestern Nigeria sedimentary basin and underlie about a quarter of the village while the rest of Iyuku is underlain by granitic rocks whose surface expression is circular to elliptical, and is classified as late-phase granite of the Older Granite series (Jones & Hockey, 1964).

About seven active quarries exist in the village to produce aggregates for road bases and concrete. In many parts, the granite has undergone intense in-situ chemical weathering (of mainly feldspars) down to depths ranging from 2 metres to 10 metres The weathering process has resulted in distinctly gritty white clay bodies due to the presence of relatively chemically inert quartz. The thickness of the clay body is erratic and the intensity of the chemical weathering appears to have been accentuated by the extensive gentle slope of the terrain coupled with the humid tropical climate.

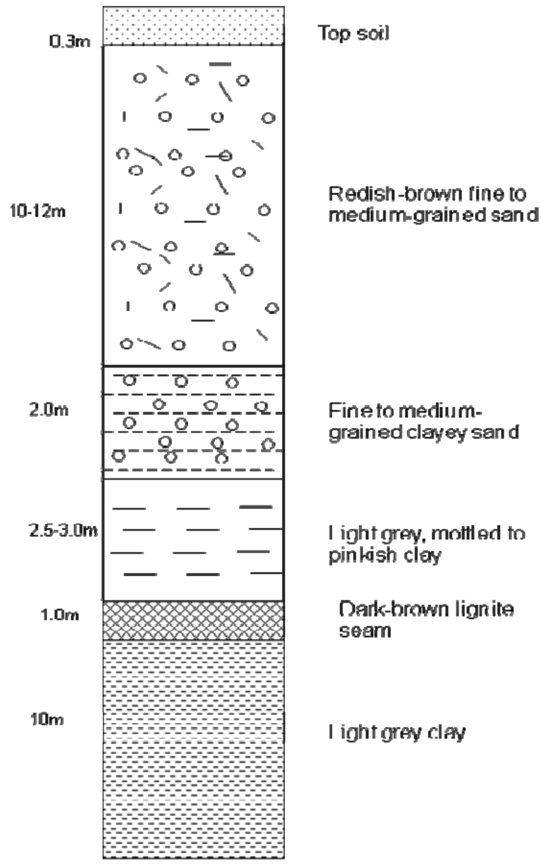

Figure 2. Litho-log of a typical section of the Ogwashi-Asaba Formation at Ubiaja

3. Sampling and Analytical Methods

Representative samples of the clay beds of the Ubiaja deposit, above and below the lignite seam were collected for this study. The bed below the lignite seam is typically grey, while the one above has a rose stained colour that is presumably a consequence of oxidation and hydration of iron bearing compounds. Samples from both beds are code-named in this study as UB_G and UB_R respectively.

Altogether, four disturbed samples representative of each clay bed, were collected in accordance with BS 1377 (1990) from freshly exposed surfaces, and then taken to the laboratory in sealed polythene bags to prevent contamination and loss of moisture. The samples were then prepared for testing by crushing using a jaw crusher, followed by milling which was accomplished by gently grinding the sample carefully, so as not to destroy the structure of the constituent minerals. Prepared samples were air-dried for 24 hours (after removing specimens for moisture content determination) before various tests were conducted on them.

3.1 Chemical and Mineralogical Analyses

The samples were analyzed for major element oxides (S_iO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, K_2O and MnO) at National Steel Raw Materials Exploration Agency (NSRMEA), Kaduna, using a Perkin Elmer Atomic Absorption Spectrophotometer (AAS). P_2O_5 and T_iO_2 were determined by a colorimetric method while loss on ignition (IL) was obtained by heating in a furnace to a temperature of 1000 ^oC for thirty minutes.

The mineralogical analyses were carried out using the x-ray diffraction (XRD) method. The analyses were conducted on randomly oriented samples with the aid of a Philips PW 1800 diffractometer with CuKα radiation. The x-ray diffraction was run from $2\theta = 2^o$ to 65^o, to produce a normal continuous scan for identification of the various major and minor peak intensities.

3.2 Geotechnical Tests

The following basic geotechnical tests were performed on representative samples of the clays following BS 1377 (1990): particle size distribution, Atterberg limits, specific gravity, natural moisture content, linear shrinkage, compaction characteristics, and free swell test. Additionally, the IL/MA (Ignition Loss/Moisture Adsorption) values were obtained according to Keeling (1961). Colloidal activity of the clay samples was computed by Skempton's (1953) formula. Analysis of the grain sizes was done by a combination of wet sieving and sedimentation under gravity using Stokes law of settling velocity. Also, liquid limits were determined by the cone penetrometer method (BS 1377, 1990).

4. Results and Discussion

4.1 Chemical Composition

Table 1 presents the results of chemical analysis showing the different oxide forms of the major elements contained in the clay samples, with a little over 85% of the materials being characterized by ten elements. The remaining 15% of the composition is ascribed to water, trace elements and, perhaps, organic matter. For comparison, typical composition of china clay (SCC), plastic fire clay (PFC), Afam Clay (AFC) and an average clay-shale (AVCS) are also shown in Table 2. For the clay bodies studied, variability of average silica content is evident, where the Ubiaja clay shows lower values (50.41-55.8%) than the Okija (60.42%) and Iyuku (64.45%) samples. However, the alumina contents, are relatively low compared to a typical china clay, the values ranging from 18.62% to 31.62%.

The Fe_2O_3 concentrations range from as low as 0.63% for the Iyuku sample to as high as 3.42% for the Okija sample reflecting the higher degree of oxidation in the latter. TiO_2 contents are less than 3% in the Ubiaja samples and less than 2% in the Okija and Iyuku clays. The alkalis (K_2O, Na_2O) as well as CaO, MgO and MnO which occur in relatively insignificant proportions are in the range 0.01 to 1.33% that is indicative of the high degree of weathering, under tropical conditions, from which the clay bodies resulted. The chemical analyses show major variations of S_iO_2 and Al_2O_3 contents between the clay samples with the Iyuku clay being the most siliceous.

Table 1. Chemical analysis of the clay samples

Oxides %	OKJ		IYU		UBJ_R		UBJ_G	
	Range (n=5)	Mean	Range (n=5)	Mean	Range (n=5)	Mean	Range (n=5)	Mean
S_iO_2	59.58-61.04	60.42	62.81-65.16	64.45	53.82-56.75	55.80	50.25-50.48	50.41
Al_2O_3	18.02-18.97	18.62	20.09-20.60	20.28	27.10-27.78	27.50	30.92-31.85	31.62
T_1O_2	0.09-1.21	1.16	0.76-0.89	0.84	2.24-2.62	2.58	2.69-2.75	2.73
Fe_2O_3	3.10-3.46	3.42	0.62-0.66	0.63	2.92-3.21	3.15	2.23-2.47	2.43
C_aO	0.29-0.41	0.38	0.24-0.31	0.28	0.07-1.03	0.09	0.09-0.14	0.11
MgO	1.25-1.30	1.28	0.09-0.24	0.12	0.08-0.15	0.12	0.14-0.19	0.17
K_2O	1.05-1.34	1.33	0.39-0.45	0.42	0.22-0.31	0.25	0.27-0.32	0.29
Na_2O	0.30-0.38	0.35	0.17-0.20	0.18	0-0.02	0.01	0-0.03	0.02
MnO	0.02-0.03	0.02	0.1-0.02	0.01	0.02-0.05	0.04	0.01-0.04	0.02
P_2O_5	0.02-0.04	0.03	-	-	0.08-0.12	0.11	0.11-0.17	0.14
LOI	11.33-11.75	11.66	11.95-12.07	12.02	9.75-9.94	9.82	10.02-10.25	10.23

Table 2. Comparison of the average chemical composition of the studied clays with average chemical composition of other types of clay

Oxides %	OKJ	IYU	UBJ_R	UBJ_G	Average clay-shale (Pettijohn, 1957) AVCS	Afam clay (Jubril & Amajor, 1991) AFC	Florida non-active kaolinite (Huber, 1985)	Florida active Kaolinite (Huber, 1985)	Plastic fire clay St Louis (Huber, 1985) PFC	China clay GTY (Huber, 1985) SCC
S_iO_2	60.42	64.45	55.80	50.41	58.10	42.20	45.57	52.92	57.67	46.88
Al_2O_3	18.62	20.28	27.50	31.62	15.40	26.20	38.45	9.42	24.00	37.65
T_iO_2	1.16	0.84	2.58	2.73	-	-	0.01	1.18	-	0.09
Fe_2O_3	3.42	0.63	3.15	2.43	4.24	5.10	0.75	3.65	3.23	0.88
C_aO	0.38	0.28	0.09	0.11	3.11	1.60	-	1.91	0.70	0.03
MgO	1.28	0.12	0.12	0.17	2.44	0.70	0.05	0.08	0.30	0.13
K_2O	1.33	0.42	0.25	0.29	3.24	8.30	0.06	0.98	0.50	1.60
Na_2O	0.35	0.18	0.01	0.02	1.30	2.90	-	0.03	0.20	0.21
MnO	0.02	0.01	0.04	0.02	-	0.03	-	-	-	-
P_2O_5	0.03	-	0.11	0.14	-	-	-	0.02	-	-
H_2O^+	11.66	12.02	9.82	10.23	-	-	-	10.19	10.50	12.45
SiO_2/AlO_3	3.24	3.18	2.03	1.59	3.77	1.61	1.19	5.62	2.40	1.25

Table 3. Major elemental oxides of the tested samples compared with chemical industrial specification

Oxides %	OKJ	IYU	UBJ_R	UBJ_G	Reference			Samples		
								Paper (ANON, 1972)		Brick clay (Murray, 1960)
					Refractory bricks (Parker, 1967)	Rubber (Keller 1964)	Ceramics (Singer and Sonja, 1971)	As coating	As Filler	
S_iO_2	60.42	64.45	55.80	50.41	51-70	44.90	67.50	47.80	48.70	38.67
Al_2O_3	18.62	20.28	27.50	31.62	25-44	32.35	26.50	37.0	36.0	9.45
T_iO_2	1.16	0.84	2.58	2.73	1.0-2.80	1.80	0.10-1.0	0.03	0.05	-
Fe_2O_3	3.42	0.63	3.15	2.43	0.5-2.40	0.43	0.5-1.20	0.58	0.82	2.70
C_aO	0.38	0.28	0.09	0.11	0.1-0.2	Tr	0.18-0.30	0.04	0.06	15.84
MgO	1.28	0.12	0.12	0.17	0.2-0.7	Tr	0.1-0.19	0.16	0.25	8.50
K_2O	1.33	0.42	0.25	0.29	-	0.28	1.10-3.10	1.10	2.12	2.76
Na_2O	0.35	0.18	0.01	0.02	0.8-3.50	0.14	0.20-1.50	0.10	0.10	2.76
MnO	0.02	0.01	0.04	0.02	-	-	-	-	-	-
S_iO_2/Al_2O_3	3.24	3.18	2.03	1.59	-	1.39	2.55	1.29	1.35	4.09
Al_2O_3/S_iO_2	0.31	0.31	0.49	0.63	-	0.72	0.39	0.77	0.74	0.24

Table 4. Physical and basic geotechnical characteristics of the studied clay samples

Clay sample	Natural moisture content %	Particle Size Distribution			Fines %	Atterberg Limits			I_L
		Clay %	Silt %	Sand %		LL%	PL%	PI%	
OKJ	8.04	61.0	26.0	13.0	87.0	54.0	22.0	32.0	-0.44
IYU	4.60	26.0	37.0	37.0	63.0	27.9	17.9	10.0	-1.53
UBJ_R	9.2	60.2	36.5	3.3	96.7	69.5	24.0	45.5	-0.33
UBJ_G	10.5	62.0	38.0	0	100	72.0	23.5	48.5	-0.7

Clay sample	G_s	Compaction characteristics		Linear Shrinkage %	Free swell %	Colloidal Activity	IL/MA ratio	USC
		Max. dry unit weight KN/m^3	Optimum moisture content %					
OKJ	2.69	17.2	24.6	6.5	10.2	0.52	6.20	CH
IYU	2.63	19.1	18.0	3.1	4.5	0.38	7.71	CL
UBJ_R	2.70	16.8	26.5	7.2	9.1	0.76	4.92	CH
UBJ_G	2.60	15.6	29.0	7.8	10.5	0.78	5.01	CH

LL = Liquid Limit

PL = Plastic Limit

IP = Plasticity Index

I_L = Liquidity Index

G_s = Particle Specific gravity

IL = Ignition Loss (Loss on Ignition)

MA = Moisture Adsorption

USC = Unified Soil Classification

CH = Inorganic clay of high compressibility and high plasticity

CL = Inorganic Silty clay of low plasticity and low compressibility.

4.2 Mineralogical Characteristics

Results of mineralogical analyses are presented in Figures 3a-3d which show that most of the material is either kaolinite ($Al_4SiO_4O_{10}(OH)_8$) or quartz (SiO_2). Although quantitative analysis was not carried out, the diffractograms indicate that kaolinite preponderates over quartz while accessory illite was recorded in both varieties of the Ubiaja clay as well as the Okija sample.

However, it is interesting to note that there is relatively more quartz and less kaolinite in the Iyuku clay than in the others, a disparity that is in consonance with their silica contents. This is attributed to the residual nature of the Iyuku clay. Also, the oxidized variety of the Ubiaja clay (UB_R) has slightly more quartz than the grey sample (UB_G). More significantly, the kaolinite peaks of the Iyuku sample are sharper and less broadened than for the other clays and that is clearly due to better crystallinity of this mineral in the Iyuku clay. Peak broadening is normally expressed in terms of the peak width at half height (Brindley & Kurtossy, 1961). It is known to be associated with disordered kaolinite.

The IL/MA test results are shown in Table 4. Based on Keeling's classification (Table 5) the predominant clay mineral in the in-situ derived Iyuku clay is well crystallized kaolinite with an IL/MA ratio of 7.71. The other samples are of intermediate crystallinity, which portrays them as slightly disordered. The results are consistent with those of qualitative mineralogical analyses by XRD and clearly depict the IL/MA ratio as an additional tool to help elucidate the nature of the clay minerals present in various types of clays. Therefore, in the absence of established instrumental techniques such as x-ray diffractometry, thermogravimetry, infra-red spectroscopy, and differential thermal analysis (DTA), so often the case in most developing countries, IL/MA certainly can provide very useful information on the type of clay minerals present which could determine industrial applications and aid in the prediction of their engineering behaviour.

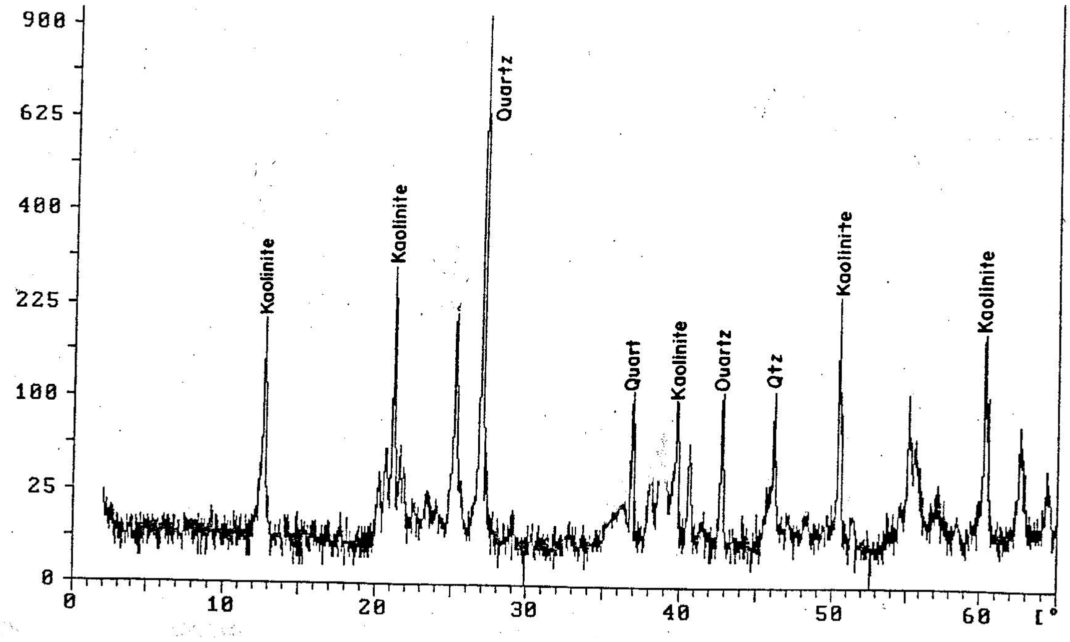

Figure 3a. X-ray diffractogram of the Iyuku Clay (IYU)

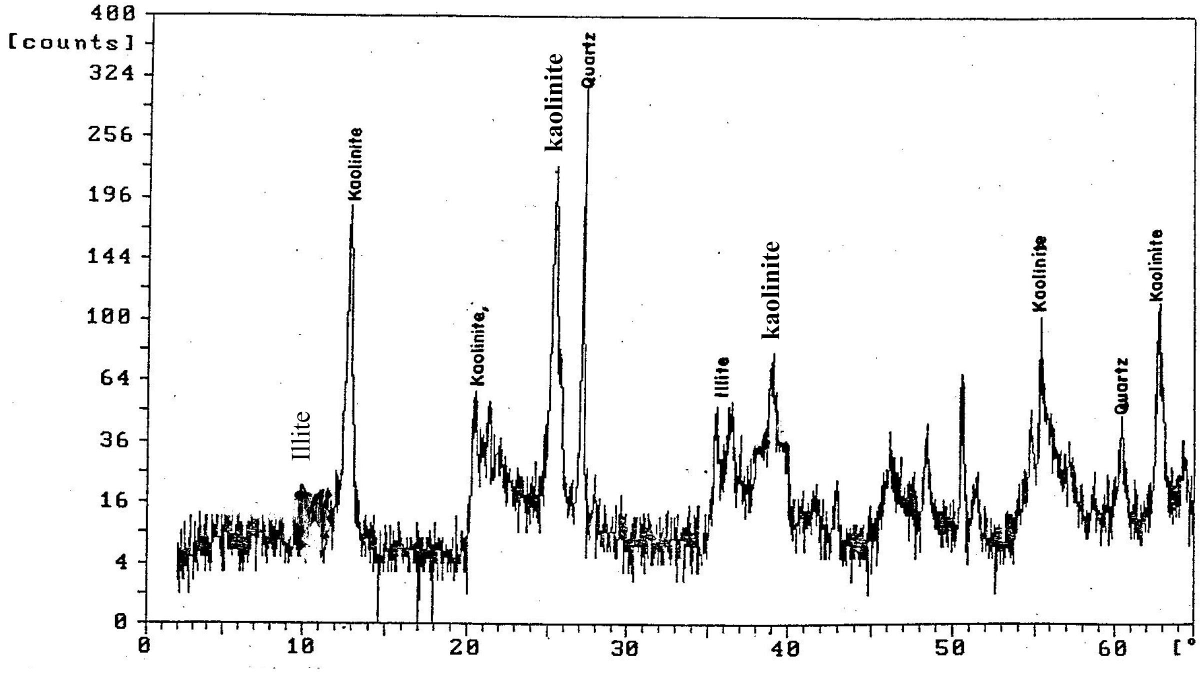

Figure 3b. X-ray diffractogram of the Okija Clay (OKJ)

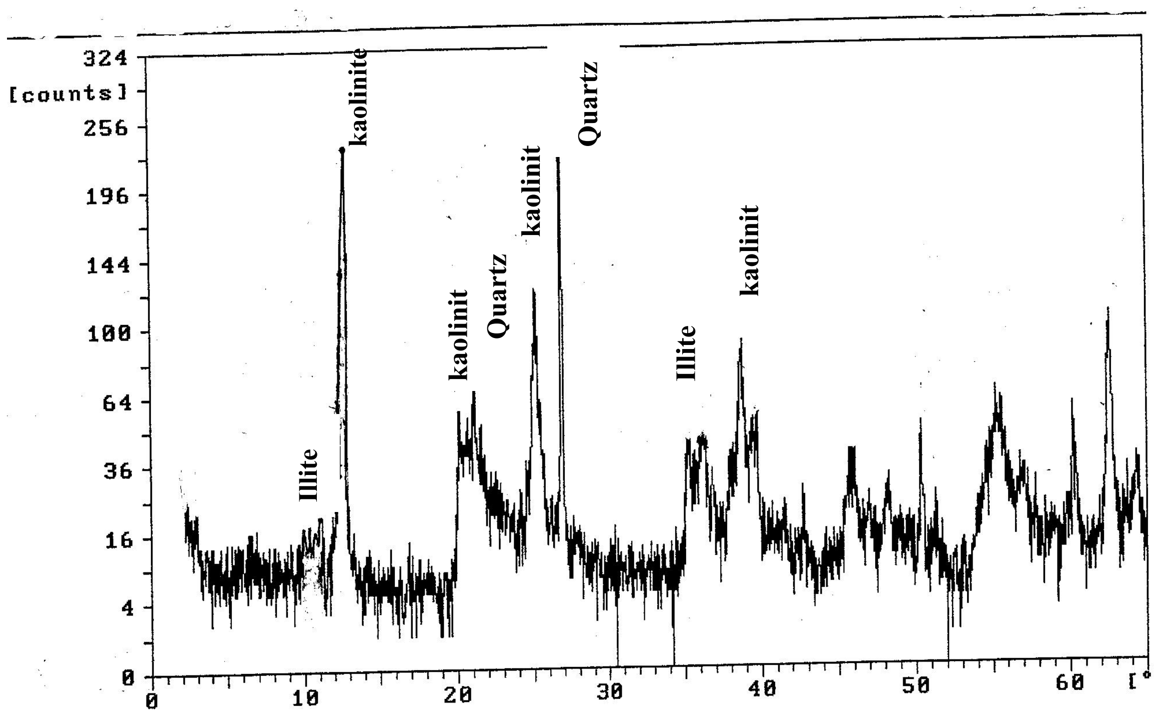

Figure 3c. X-ray diffractogram of the Ubiaja Clay (UBG)

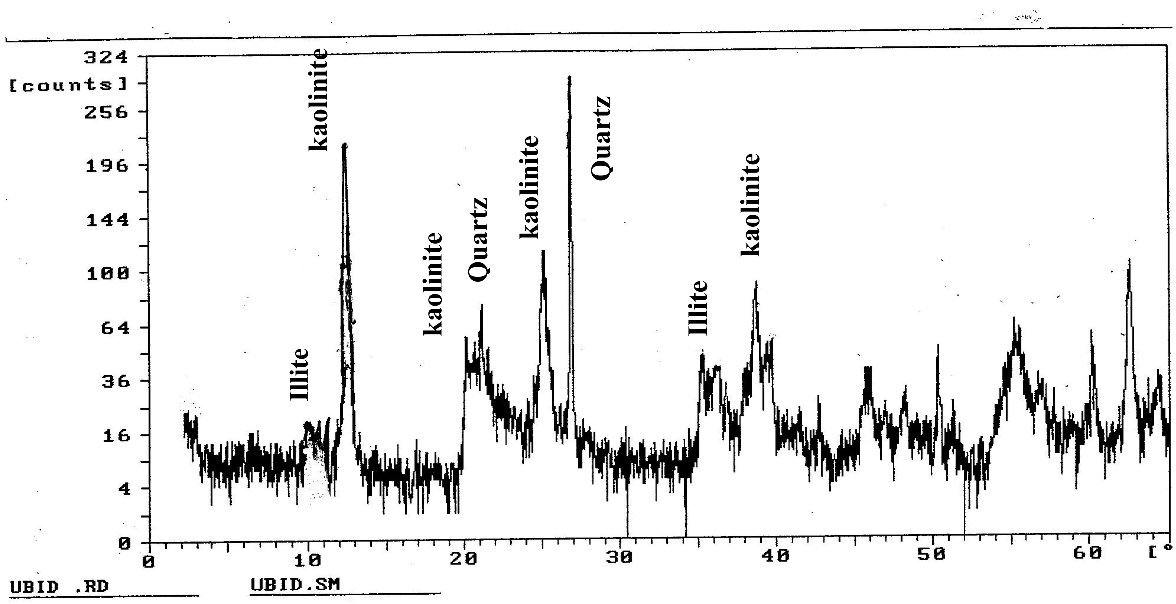

Figure 3d. X-ray diffractogram of the Ubiaja Clay (UBR)

Overall, these data corroborate earlier deductions from the mineralogical analyses based on x-ray diffraction and reinforce the argument that isomorphous substitution of Fe for Al in the octahedral layer could be responsible for crystal imperfection of kaolinite in UB_G and UB_R, a fact supported by the higher iron contents in these samples (Onyeobi & Imeokparia, 1992).

Table 5. Classification of clay minerals based on the IL/MA ratio (Keeling, 1961)

Mineral	IL/MA ratio
Well crystallized Kaolinite	> 7
Intermediate Kaolinite	3-7
b-axis disordered kaolinite	2-3
Disordered Kaolinite /Illite	1-2
Illite	0.7-1
Smectite	0.3-0.7

4.3 Geotechnical Characteristics

Geotechnical characteristics of clayey soils are often associated with their mineralogical composition, especially with clay mineralogy. It is well documented that plasticity, compressibility and swelling potential (Grim, 1968; Seed et al., 1964; Terzaghi & Peck, 1967; Gillot, 1968) increase on account of increasing amounts of smectite in a clay (e.g montmorillonite).

Particle size distribution of the studied clays, are summarized in Table 4. The granulometric data indicate that the sedimentary clays (UB_R, UB_G and OKJ) have a similar range of particle sizes with percentage fine fractions between 87% and 100% while the residual Iyuku clay is quite distinct with a high proportion (37%) of sand-size particles although, technically, it is a fine-grained soil (63% fines).

OKJ, UB_R and UB_G had natural moisture contents between 8.04% and 10.5%; a much lower value of 4.60% was recorded for the Iyuku sample. Although natural moisture content is not a constant property of soils, these values are consistent with the fines contents of the clays. The clays were generally of medium to high plasticity (32%-48.5%) except the Iyuku clay with a rather low plasticity index of 10% and an equally low liquid limit (27.9%). The liquid limit values of the other samples (54%-72%) indicate that they are clays of high compressibility (Smith, 1978). It would appear that the high plasticity of these clays is influenced not only by the mineral composition (illite and kaolinite) but also by the amorphous contents as previously suggested by Okagbue and Onyeobi (1999). The four samples plot above the A-line on the plasticity chart (Figure 4).

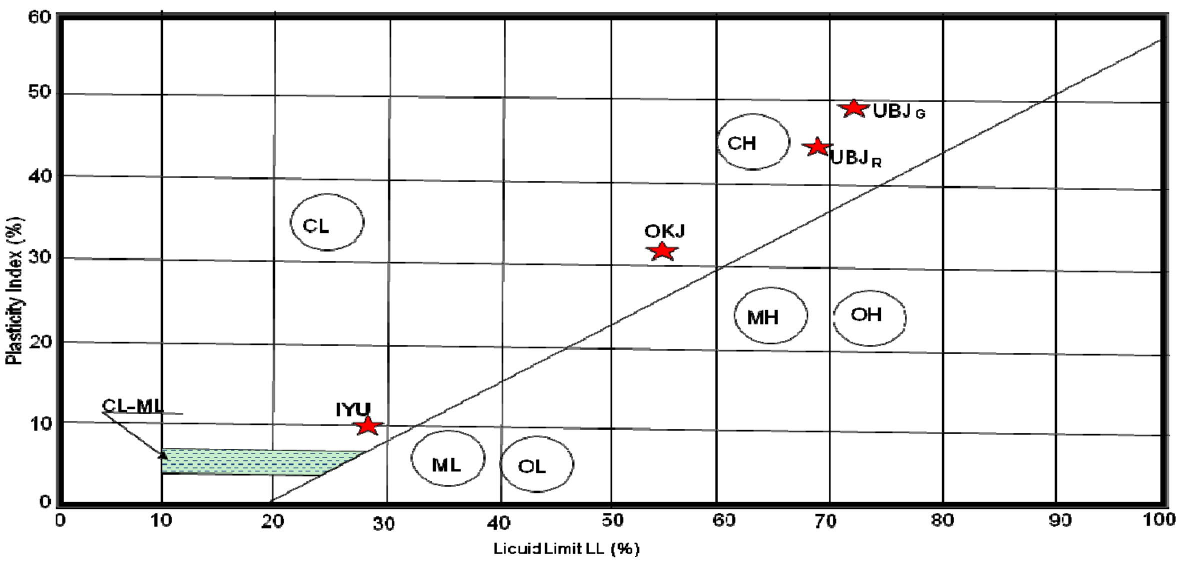

Figure 4. Plot of the samples on the Casagrande chart

However, UB_G, UB_R and OKJ are classified as CH (inorganic clay of high plasticity) while the Iyuku clay is classified in the field of CL i.e an inorganic clay of low plasticity and low compressibility. The liquidity indices (I_L) are all negative ranging from -1.53 to -0.33 which is not surprising due mainly to dry season sampling.

These negative values indicate that the clay samples as at the time of sampling, were never above the plastic limits in their natural state. Specific gravity values range from 2.63 to 2.70 and although the variability is quite narrow, the highest value associated with UB_R (red Ubiaja clay) is ascribed to its higher iron oxide content. The free swell values (4.5%-10.5%) are fairly consistent with the corresponding plasticity indices, the Iyuku clay yielding the least value and UB_G exhibiting the highest swelling potential. The linear shrinkage of the clays are likewise consistent with the plasticity index values. Altmeyer's (1955) classification of degree of expansion in terms of percentage linear shrinkage places the Ubiaja and Okija clays in the marginally expansive but not critical (5%-8%) category whereas the Iyuku clay is non-critical (< 5%). According to Chen (1975), the swelling potential should, in theory, be related to the opposite property of linear shrinkage. We note that the free swell test is rather crude with low reproducibility which makes it inferior to the potential volume change (PVC) parameter as determined in a fixed ring consolidometer. Furthermore, there is inconclusive evidence of a correlation between swelling potential and shrinkage limit. Values of colloidal activity computed with the Skempton (1953) equation are in the range 0.38 to 0.78. Although the highest values were recorded for the Ubiaja samples, the results do not quite agree with the free swell values in that they portray the clay mineral contents as normal and inactive whereas their free swell values suggest otherwise.

Compaction test results are also shown in Table 4. In all cases, optimum moisture contents are slightly above the plastic limits, varying from 18% to 29% while maximum dry unit weights are within the range 15.6KN/m^3 to 19.1KN/m^3. Significantly, the Iyuku clay with its much lower clay content recorded the highest maximum dry unit weight and the lowest optimum moisture content.

4.4 Industrial Potential

The chemical composition, mineralogical composition, and physical characteristics constitute crucial parameters in the assessment of the suitability of clays as industrial raw materials. A comparison of the chemical composition of the clays studied with the chemical specification of some industrial clays (Table 3) shows quite clearly that the Iyuku and Ubiaja clays are suitable for the production of refractory bricks (Parker, 1967) and ceramics (Singer & Sonja, 1971). In this regard, the alumina content of the Okija clay is too low. Also, the amounts of CaO, MgO, Na_2O and K_2O for all the four clays are in excess of the requirements for the production of rubber and paper (Keller, 1964). Their effect would be to lower the vitrification of the clays without necessarily detracting from their refractoriness.

In spite of their high fines contents (63%-100%) they are also composed of appreciable amounts of silt-size particles (26%-38%) which makes them unsuitable, in their raw state, for use as fillers and coating materials in the paint and cosmetic industries. The general composition of the Ubiaja clay units (UB_G and UB_R) and their proximity to a thin seam of low rank (brown) and low grade coal seem to suggest that they are underclays characterized by high plasticity as a result of high clay contents. Indeed, there is a close compositional similarity between these samples and plastic fire clay of St Louis (Huber, 1985) except for slight differences in their silica/alumina ratios. This clearly corroborates the argument that the Ubiaja clay is a fire clay. Economically, good quality fire clays are used for the production of refractories in the iron and steel industries (e.g crucibles, furnace linings etc). They are classified by their alumina content. 35% is quite good and higher amounts add to their refractory nature and plasticity.

However, the use of the Ubiaja clays in the pottery industry for the manufacture of sanitary ware, glazing tiles and acid-proof products would depend on the level of beneficiation achievable to turn them into good quality fire clays. For example, UB_R is unsuitable for glazed products on account of its objectionably high amount of Fe_2O_3 impurities which would cause undesirable brown colourations.

On the other hand, the Iyuku clay which is typically whitish in colour and which displayed much sharper kaolinite XRD peaks, low plasticity, low free swell value, low colloidal activity, low compressibility and high crystallinity (IL/MA ratio 7.71) will probably exhibit attributes analogous with those of china clay upon the removal (through filtration) of the silty/sandy quartz particles that make it gritty. This would reduce the SiO_2/Al_2O_3 ratio thereby enhancing the alumina content in relative terms. Subsequent blending with appropriate quantities of clay with high content of alumina will add to its refractory nature.

5. Conclusions

Field studies indicate that clay resources occur at Iyuku, Okija and Ubiaja in Southern Nigeria, although reserve estimates are not available. Preliminary investigation of the chemical, mineralogical and physical characteristics of these clays revealed that they are essentially kaolinitic with variable quartz content; also traces of illite were recorded in the transported Okija and Ubiaja clays. Geochemically, SiO_2 and Al_2O_3 are the predominant oxides, the in-situ derived Iyuku clay being more siliceous and less hydrophilic than the others. The kaolinites present in the transported clays are somewhat disordered compared to those in the Iyuku clay which displayed sharper XRD peaks and higher crystallinity as evidenced by a higher IL/MA value. The relatively high plasticity of the Okija and Ubiaja clays which is reflected in other geotechnical characteristics (e.g linear shrinkage) are attributable to high clay contents, occurrence of traces of illite and lower crystallinity of kaolinite. The field relationship of UB_R and UB_G with a thin lignite seam suggests that the Ubiaja clays are underclays.

Evaluation of the industrial utility of the clays based on their physical and chemical characteristics revealed that they are suitable for the production of refractory bricks and ceramics but would require processing and beneficiation to alter their silica/alumina ratios if they are to qualify for other industrial applications such as rubber, paper, paint and cosmetic industries.

Specifically, the Iyuku clay with its distinct compositional and geochemical characteristics would, with appropriate processing, be suitable for the production of water filter cartridges for filtration of drinking water.

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