POTENTIAL INDUSTRIAL APPLICATIONS OF SELECTED CLAY BODIES FROM PARTS OF SOUTHERN NIGERIA

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Abstract: Scientific evaluation and refining to enhance quality for required industrial uses. Seven non-composited clays from Asaboro, Igbanke and Esan areas in southern Nigeria were mineralogically, geochemically and geotechnically tested and characterised in order to appraise their economic and industrial applications. Mineralogical analyses reveal kaolinite as the dominant clay mineral and quartz as the dominant non-clay constituent. Major element abundance show that SiO_2 (6.64 – 72.84%) and Al_2O_3 (ca. 13.63 – 30.46%) constitutes between 70 and 88% of the bulk chemical composition, while the remaining 12 – 30% of the composition is ascribed to trace elements, water and, most likely organic constituent. Although notable variability exists in the SiO_2 and Al_2O_3 contents, the Igbanke clay is less siliceous and more aluminous than the other clays. Geotechnically, the clays are characterized by medium to high compressibility and plasticity. Percentage shrinkage and colloidal activity are consistent with the plasticity. Potential industrial applications of the clays based on evaluated characteristics, revealed their suitability for the manufacture of cosmetics, paint, acid-proof products, sanitary wares and glazing tiles, rubber production and as coating material for paper production if improved upon by appropriate processing and beneficiation.

Keywords: Beneficiation, geochemical analysis, industrial clays, kaolinite

Introduction

In Nigeria, clay is widely distributed though not always found in sufficient quantity or suitable quality for modern industrial purposes. The occurrence of several clay deposits which vary from lateritic and residual profiles derived from weathering of basement lithologies in different parts of the country has been investigated by Elueze and Bolarinwa, (1995; 2001), Nton and Elueze, (2005), etc. Asidethe basement associated clay occurrences; sedimentary clay deposits in the form of alluvial bodies also occur in the different sedimentary basins across the country, (Emofurieta *et al*., 1994; Elueze *et al*., 1999; Imeokparia and Onyeobi, 2007; Obrike *et al*., 2007; Akhirevbulu *et al*., 2010). These studies revealed a dominance of kaolinite (43.64%) and high quartz percentage of about 54.55%, which imparts a gritty feel on the clays.

The quality and commercial value of clay is a function of its nature, composition and, engineering characteristics which are mainly dependent on their physical properties (such as particle size distribution), mineralogical composition, organic matter content and geologic history (Grim, 1968). Excellent review of local the use of clays deposits can be found in Obaje *et al*. (2013).

While most geological studies of the Niger Delta Basin have focused more on petroleum resources, little attention on solid minerals like clay that occur within the stratigraphic sequences of the Benin Formation is common knowledge. Although a number of studies have been done to geochemically characterize some of these clays, much has not been done to exploit their economic significance and industrial applications. This may have been due to the lack of interest in developing and using these economically important deposits.

Several authors have attempted to provide some information on the clays in the Niger Delta and southern Nigeria in general (Jubril and Amajor, 1991; Coker *et al*., 1992; Onyeobi *et al*., 2013; etc.). Aside the occurrence of clays in the Niger Delta area, more than 80 clay deposits have been reported from other parts of Nigeria (Coker *et al*., 1992).

In this article, we attempt to evaluate the bulk geochemical, mineralogical and basic geotechnical and physical properties of three clay occurrences at Asaboro, Igbanke and Esan areas in southern Nigeria with a view to evaluate their economic potential and industrial application by comparison with notable clays.

Location and field occurrence

Samples for this study were obtained from five locations which include, Asaboro, Igbanke (Ugo and Oguoguo) and Esan (Ewohimi, Atari and Ekpon) areas in Edo State (Fig. 1), located in southern Nigeria within Latitudes N06°16´32.2´´ - N06°26´29.6´´ and Longitudes E006°2´12.6´´ - E006°21´00.6’’ for the Asaboro Quarry and Latitudes N06°23´ - N6°30´ and Longitudes E006°18´ - E006°2´ for the Ewohimi area, respectively (Fig. 1). Generally, the study area is within the northern depositional belt of the Niger Delta, underlain by sediments of the Coastal Plain sands (Benin Formation) and Ogwashi-Asaba Formation of Oligocene age (Short and Stuable, 1967; Whiteman, 1982; Nwajide, 2013; Osokpor *et al*., 2019). The clay occurs as basal units at the locations studied. The base of the clay horizon in some locations grades imperceptibly into finer grain sand facies. The clays are overlain by thick intervals of reddish brown fine to coarse gained sands which range in thickness from about 9.5 to 13 meters that are in turn overlain by surficial.

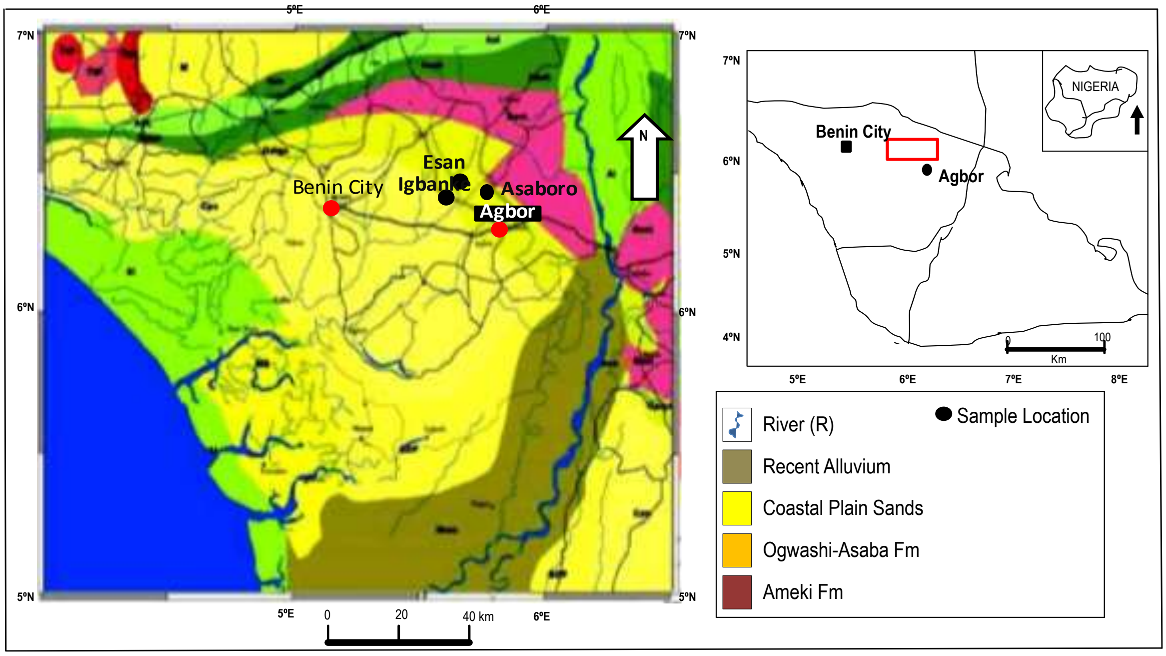

Fig. 1: Geological map of southern Nigeria showing field sampling locations sediments

Sediments (Top soil) in the area are basically weathered and slightly consolidated clayey sands, which exhibits reddish colouration impacted by long periods of weathering under humid tropical climatic condition (Fig. 2). The weathered surface sediments attain thicknesses of up to four meters in places. Although the area is largely underlain by friable sands of the Benin Formation, areas bordering river channels are characterized by recent alluvium composed of clays, silts and sands.

Thickness (m)	Lithology	Description
0.2 - 0.4		Reddish top soil
9.5 - 13		Reddish-brown, Fine to coarse, poorly sorted clayey sand
1.8 – 4.5		Light grey, mottled clay
subsurface		subsurface

Fig. 2: Representative lithological log of sampled outcrop sections

Geological setting

The Igbanke-Esan-Asaboro area is located in northern part of the Niger Delta area. The Niger Delta is situated in southern Nigeria along the West African coast at the site of a Cretaceous triple junction is the Niger Delta Basin which lies between longitudes 5° and 8°E and latitudes 3° and 6°N in the coastal area of the Gulf of Guinea,covering an area of about 75,000 km^2 with an overall regressive fill of about 12,000 m (Doust and Omatsola, 1990; Reijers, 1996) and is considered to have been built out over a crustal tract on the trailing edge of the African continent. It is bounded to the north by the Cretaceous Anambra Basin, to the east by the Calabar Flank and Abakaliki Anticlinorium and to the west by the Benin Flank, while the Atlantic Ocean forms its southern limit. It is building out into the Atlantic Ocean at the mouth of the Niger-Benue and Cross River drainage systems and extends more than 300 km from the proximal to distal ends (Reijers, 1996). It has prograded southwards from the Eocene to Recent, forming successive depositional belts that represent the most active portion of the delta at each stage of its development. Although the sedimentary wedge is dominated by prograded material, it contains major transgressive marine sequences that contribute to making its geology complex.

The tectonic evolution and setting of the Niger Delta is related to the evolution of the Benue Trough, a failed arm of a triple junction which evolved during the Early Cretaceous as a result of the separation of Africa from South American Continent in the Late Jurassic – Early Cretaceous times.

Materials and Methods

Seven non-composited clay samples obtained from outcrops exposed at Asaboro sand quarry, banks of Rivers Ugo and Oguoguo in the Igbanke area, road cut at Ekpon town and a cliff wall of River Atari, in Edo State forms the basis of this work. The area sampled fall within the topographical map sheet of Agbor N.E and NW, Nigeria on a scale of 1:50,000.

Samples were air-dried at room temperature, pulverized to obtain a minus 10 µm size fraction and sieved. Four samples (Asaboro, Ewohimi, River Oguoguo and Ekpon), were subjected to mineralogical analysis. Following pulverization procedure, the samples underwent series of treatments involving, glycolation, ion exchange and treatment with formamide.

Mineralogical analysis

Powdered samples were analysed using XRD machine (XPERT-PRO) at operating voltage of 40KV and ampere of 45mA and continuously ran at 25˚C from 5.0066 to 84.982620 with inbuilt standards, peak/width and a detector. Obtained diffraction pattern and 2θ, d-values and peak intensities patterns were used to identify the minerals. A quantitation of each mineral species present in each sample was automatically determined by software.The mineralogical analysis was carried out at the Nigerian Geological Survey Agency, Kaduna, Nigeria.

Major element analysis: X-ray fluorescence spectrometry (XRF)

25 g of air-dried and weighed samples were prepared and analysed for major, elements. Samples were dried at 60°C and pulverized to 85% passing 200 mesh (75 microns), using a mild-steel pulveriser (PUL85).

A predetermined amount of each sample was roasted to determine the Loss on Ignition (LOI) before the XRF analysis. Roasted samples were then fused in a platinum-gold crucible with a commercial Lithium Tetraborate ($LiBO_4$) flux. The molten material was cast in a platinum mould and the fused discs analysed by an X-Ray Fluorescence Spectrometer. Diorite Gneiss (SY-4) reference material was used as a standard for quality assurance (QA) and quality control (QC) of analytical results.

Geotechnical analysis

Geotechnical testing (hydrometer method) was carried out on six samples to determine grain size distribution as an initial conceptual step to characterize the sediments. Further analyses included the determination of the Atterberge Limits (liquid limit, plastic limit and plastic index) in accordance with BS 1377: Part 2 and water absorption capacity test which was done in accordance with ASTM designation C 128.

Results and Discussion

Major element oxides

The major element oxides in the clays constitutes between 70 - 88% of the clays, while the remaining 12 – 30% of the composition is ascribed to trace elements, water and, most likely organic constituent (Table 1). The constituent oxide values of the different clays were compared with the average clay-shale (AVCS) (Pettijohn, 1957), Afam Clay, (AFCS), (Jubril and Amajor, 1991), Florida non-active and active Kaolinite (Huber, 1985), Plastic Fire Clay (PFC) (Huber, 1985) and China Clay (SCC) (Huber, 1985), (Table 2). The clays display variability in the average silica content, in which the Igbanke clay shows lower average values (49.35) than the Esan clay (64.39) and the Asaboro clay (64.44) samples. However the mean alumina content of the different clays (17.85 – 23.57), is low compared to typical china clay (37.65), plastic fire clay (24.00) and Florida non-active clays (38.85) (Huber, 1985), and the Afam clay (26.20) (Jubril and Amajor, 1991)

Concentrations of Fe_2O_3 range from 1.58 for the Esan clay to 3.38 for the Igbanke clay. These values reflect a higher degree of oxidation for the Igbanke samples than the Esan and Asaboro clays. The CaO (0.02 – 0.03), MgO (0.08 – 0.09) and MnO (0.01) (refractories) as well as the Alkalis, K_2O (0.11 – 0.13) and Na_2O (0.02) occur in relatively insignificant proportions, indicative of high degree of chemical weathering under tropical humid conditions consistent with derived Chemical Index of Alteration(CIA) values obtained in this study. Major chemical variations exist between the three clays in terms of the silica and alumina contents, with the Igbanke clay being less siliceous and more aluminous than the Esan and Asaboro clays.

Table 1: Major elements concentrations in the samples

Oxide %	Detection Limit (wt. %)	Esan Clays			Asaboro Clays		Igbanke Clays		Average Esan Clay	Average Asaboro Clay	Average Igbanke Clays
		AT	EW	EK	ASI	ASII	UG	OG			
SiO_2	0.01	69.20	58.7	65.28	72.84	56.03	36.64	62.05	64.39	64.44	49.35
Al_2O_3	0.01	14.0	22.92	16.90	13.63	22.07	30.46	16.67	17.94	17.85	23.57
Fe_2O_3	0.01	0.88	2.55	1.30	1.91	1.72	1.67	5.09	1.58	1.82	3.38
CaO	0.01	0.03	0.02	0.03	0.03	0.04	0.02	0.021	0.03	0.03	0.02
MgO	0.01	0.07	0.1	0.09	0.07	0.09	0.08	0.08	0.09	0.08	0.08
Na_2O	0.01	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	0.02	0.02
K_2O	0.01	0.08	0.14	0.17	0.05	0.16	0.16	0.08	0.13	0.11	0.12
MnO	0.01	0.006	0.014	0.008	0.006	0.012	0.002	0.011	0.01	0.01	0.01
TiO_2	0.01	1.03	3.09	1.65	0.01	2.74	1.32	1.60	1.92	1.36	1.46
P_2O_5	0.01	0.045	0.079	0.055	0.03	0.06	0.09	0.04	0.06	0.04	0.07
LOI	ND	13.9	11.18	14.35	8.79	16.66	28.89	14.26	13.14	12.73	21.58
SUM	ND	99.27	98.84	99.86	97.39	99.63	99.37	99.94	99.32	98.51	99.67

AT: Atari, EW: Ewohimi, EK: Ekpon, ASI: Asaboro I, ASII: Asaboro II, OG: Oguoguo, UG: Ugo

Table 2: A comparison of the average chemical composition of the different clays with average chemical composition of other types of clays

Oxide %	Average Esan Clay	Average Asaboro Clay	Average Igbanke Clays	Average clay-shale (Pettijohn,1957) AVCS	Afam clay (Jubril & Amajor,1991) AFCS	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
SiO_2	64.39	64.44	49.35	58.10	42.20	45.57	52.92	57.67	46.88
Al_2O_3	17.94	17.85	23.57	15.40	26.20	38.45	9.42	24.00	37.65
Fe_2O_3	1.58	1.82	3.38	4.24	5.10	0.75	3.65	3.23	0.88
CaO	0.03	0.03	0.02	3.11	1.60	-	1.91	0.70	0.03
MgO	0.09	0.08	0.08	2.44	0.70	0.05	0.08	0.30	0.13
Na_2O	0.02	0.02	0.02	1.30	2.90	-	0.03	0.20	0.21
K_2O	0.13	0.11	0.12	3.24	8.30	0.06	0.98	0.50	1.60
MnO	0.01	0.01	0.01	-	0.03	-	-	-	-
TiO_2	1.92	1.36	1.46	-	-	0.01	1.18	-	0.09
P_2O_5	0.06	0.04	0.07	-	-	-	0.02	-	-
H_2O^+	13.14	12.73	21.58	-	-	-	10.19	10.50	12.45
SiO_2/Al_2O_3	3.59	3.61	2.09	3.77	1.61	1.19	5.62	2.40	1.25

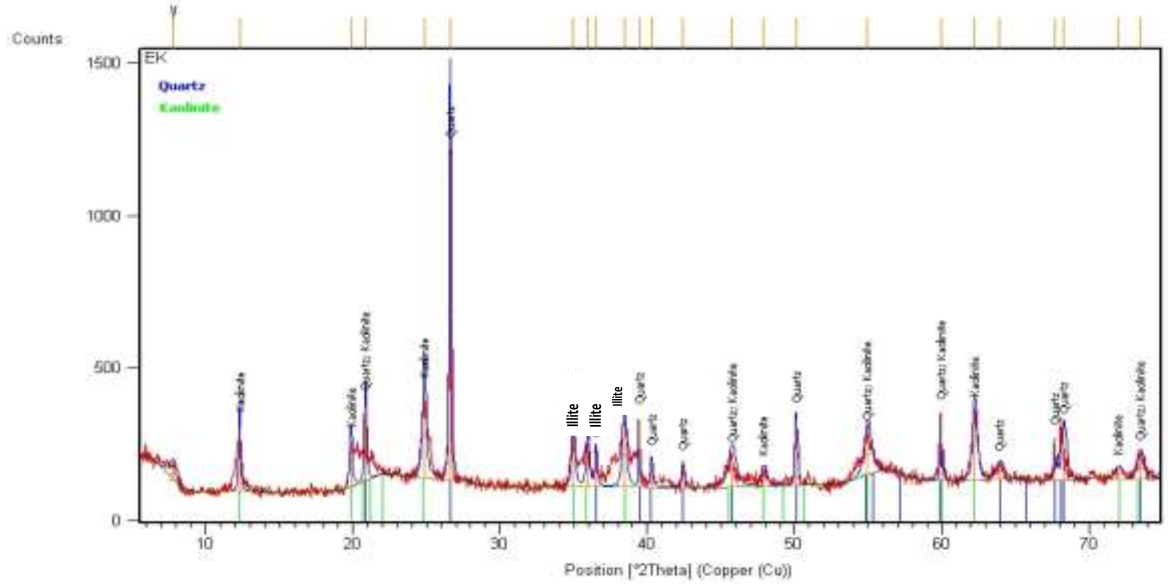

Fig. 3: X-Ray diffractograms of Ekpon (EK) clay sample showing kaolinite as the dominant mineral present in the clay sample

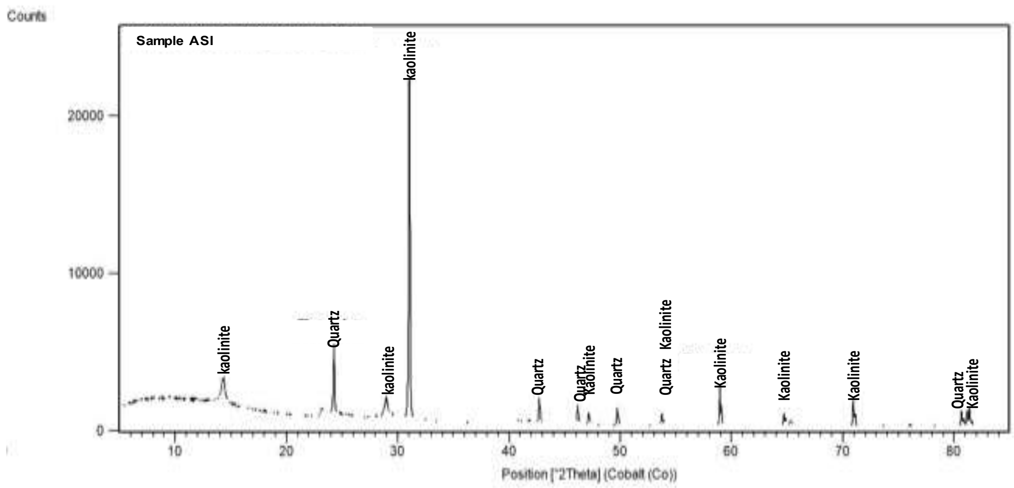

Fig. 4: X-Ray diffractograms of Asaboro (ASI) clay sample showing kaolinite as the dominant mineral present in the clay sample

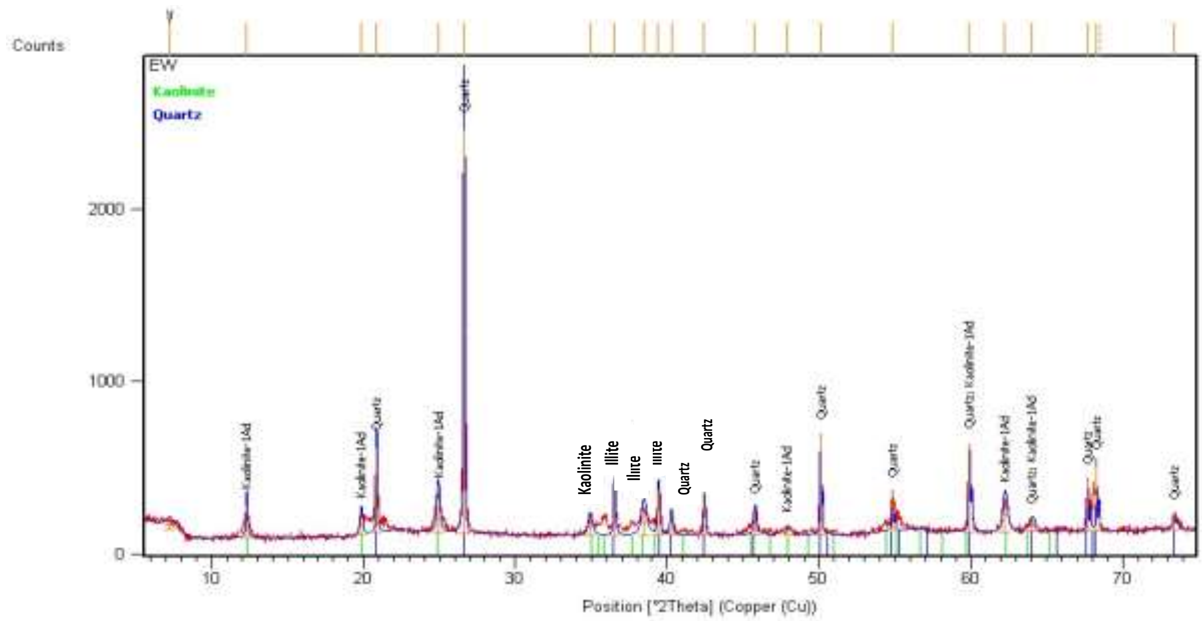

Fig. 5: X-Ray diffractogram of Ewohimi (EW) clay sample showing kaolinite as the dominant mineral present in the clay sample

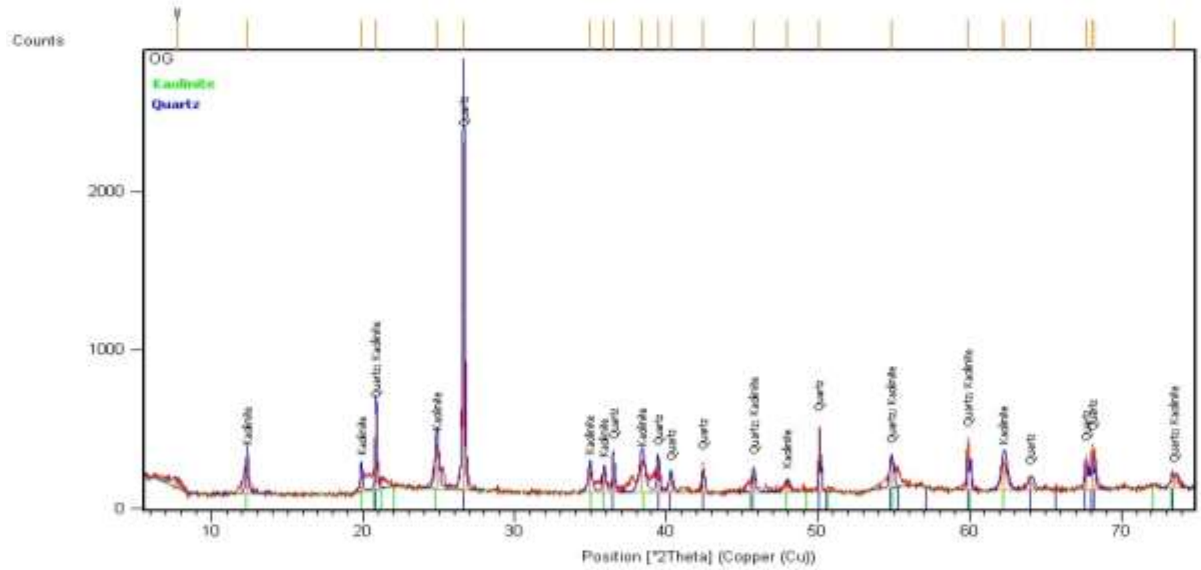

Fig. 6: X-Ray diffractogram of Oguoguo (OG) clay sample showing kaolinite as the dominant mineral present in the clay sample

Mineralogical results

Mineralogical composition ofAsaboro, Esan and Igbanke clays are shown in Figs. 3 – 6. Although quantitative analysis was not carried out, the diffractograms indicate a preponderance of kaoliniteas dominant clay mineral [$Al_4SiO_4O_{10}(OH)_8$] and subordinate quartz content (SiO_2) with a virtual absence of other clay mineral species.

A close observation of the kaolinite peaks of the three clays show broadened peaks, that is normally expressed in terms of the peak width at half height (Brindley & Kurtossy, 1961; Onyeobi *et al*., 2013). This feature is associated with disordered kaolinite and less crystallinity. A ratio of the loss on ignition (IL) and the moisture absorption (MA) as a parameter to further classify the clays based on Keeling (1961) classification, reveal the dominant clay mineral in the sample to range from disordered kaolinite to intermediate kaolinite (Table 5).

Kaolinite is believed to form by weathering or hydrothermal alteration of aluminosilicate minerals. Thus, the ultimate weathering product of rocks rich in feldspar is commonly kaolinite, indicators of detrital origin in continental sediments (Kassim, 2006).

Geotechnical properties

Atterberg Limit

Results of grain size analysis, Atterberg limits, and shrinkage and water absorption properties tested for the samples are shown in Tables 3 to 5.

Table 3: Summarized results for liquid limit, plastic limit and plasticity index of clay samples from three locations

Clay Sample	Natural moisture content %	Particle size distribution (%)			Fines %	Atterberg Limits (%)			USCS
		Clay	Silt	Sand		LL	PL	IP	
AT	6.8	45	30	25	75	50.45	16.42	34.03	CH
OG	11	62	8	30	70	51.00	20.62	30.38	CH
EW	3.5	22	11	67	33	42.00	18.74	23.26	CL
ASI	8.9	60	25	15	85	52.21	23.01	29.20	CH
ASII	8.9	60	27	13	87	51.21	21.01	30.20	CH
EK	13.4	77	11	14	88	54.60	21.7	32.90	CH

LL = Liquid Limit, PL = Plastic Limit, IP = Plasticity Index, Gs = Particle Specific gravity,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, AT: Atari, EW: Ewohimi, AS: Asaboro, OG: Oguoguo, EK: Ekpon

Atterberg Limits determined are Plastic and Liquid Limits from which the plasticity indices were computed. The Plasticity indices range from 23.26 – 34.03% (Table 3). The greater the plasticity index, the more plastic and compressible, and the greater the volume change characteristics of the clays.

Table 4: Fired shrinkage and colour change of the clays

Sample	Dry Diameter (cm)	At 950°C			At 1000°C and above			Colour	
		Fired Diameter (cm)	Linear Shrinkage (cm)	% Shrinkage	Fired Diameter (cm)	Linear Shrinkage (cm)	% Shrinkage	At 950°C	At 1000 – 1100°C
AT	3.50	3.38	0.12	3.43	3.38	0.12	3.55	Dark Grey	Brown
OG	3.50	3.39	0.11	3.14	3.39	0.12	3.53	Dark Grey	Brown
EW	3.50	3.41	0.09	2.57	3.41	0.07	2.05	Grey	Light Grey
ASI	3.50	3.48	0.02	0.57	3.48	0.06	1.72	Dark Grey	Dark Grey
ASII	3.50	3.49	0.01	0.29	3.49	0.08	2.29	Light Grey	Light Grey
EK	3.50	3.40	0.10	2.86	3.40	0.13	3.82	Light Grey	Bark Grey

AT: Atari, EW: Ewohimi, AS: Asaboro, OG: Oguoguo, EK: Ekpon

Table 5: Water absorption (Porosity) of fired clay at >1000°C and classification of clay minerals based on the IL/MA ratio (Keeling, 1961)

Sample	Original Wt. (gms.)	Soaked Wt. (gms.)	Increase in Wt. (gms.)	% Water Absorption	IL/MA
AT	11.55	12.22	0.67	5.80	2.40
OG	10.20	10.72	0.52	5.10	2.80
EW	9.77	10.65	0.88	9.00	1.24
ASI	12.35	12.94	0.59	4.76	1.85
ASII	11.55	12.10	0.55	4.76	3.50
EK	10.65	11.10	0.45	4.23	3.39

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

AT: Atari, OG: Oguoguo, EW: Ewohimi: AS: Asaboro, EK: Ekpon, LI: Loss on Ignition, MA: Moisture absoption

All the soils plot above the A-line in the Casagrande (1948) soil classification plot (Fig. 7) and are classified as inorganic claysof medium-high plasticity (LL >40)according to the Unified Soil Classification System (USCS, 1967) (Fig. 7). Generally, these values are obtainable for expandable clays; however the Geochemical and mineralogical results obtained for the samples show that the clays are Kaolinites.

Although the PI of 23.26 - 34.03% ordinarily would classify the clays as clays with medium-high swelling potential, the mineralogical attributes tells otherwise. The clays have liquid limits ranging from 42 – 51% and plasticity index between 16.42 - 20.62% (Table 3).

Depending on the amount of water present, cohesive soils can exist as liquid slurry, a plastic substance or a solid. Based on the Atterberg Limits, the Ewohimi clay is less plastic than the other studied clays (Fig. 7).

Values from the sieve analysis reveal the constituent grain size distribution in the different samples which defines in the first instance, an inherent sedimentological property of the samples (Table 3). A correlation of the grain size distribution data with the Atterberg limits of the samples shows a close correspondence in that, samples with less clay percentage exhibited low plasticity index (e.g. Ewohimi, EW, Sand = 22%, Plasticity Index = 23.38%). From the above observation, the lithologic characteristics of the Oguoguo (clay = 62%, sand = 30%) and Asaboro (Clay = 60%, av. Sand = 14%) samples shows close correspondence with the plasticity values (Table 3). Although the Ekpon (EK) and Atari (AT) samples display corresponding plasticity values related to their sand and silt percentages, a comparison of both samples on the basis of these values, presents a challenge which could be related to the presence of microcrystalline quartz. This is because the Ekpon sample with a clay content of 77% and Plasticity Index of 32.90 as against a clay content of 45% and sand content of 34.03% would ordinarily be expected to present higher plasticity values.

All of the soils plot above the A-line in the Casagrande chart (Fig. 7). The “A” line separates inorganic clays from silty and organic soils. From the plot on the chart, the clays can be described as high plasticity inorganic clays, with the exception of the Ewohimi clay which is of medium plasticity (Fig. 7). Also the cluster of the samples in the plot could be used to deduce that the soils are of same geological origin.

Table 4 shows the shrinkage value of the different clays at 950°C and 1000 -1100°C. Shrinkage at 950°C for the samples range from 0.29 – 3.43%, while shrinkage values at 1000 - 1100°C, range from 1.72 – 3.82%. The average shrinkage value of Esan clay at 950°C and 1000 - 1100°C (2.95%, 3.14%) is higher than average shrinkage values of the Auchi clay (2.49%) (Emofurieta *et al.*, 1994), but lower than the average shrinkage of Gombe (3.49%) (Emofurieta, 1994), Ewekoro (6.10%) (Nton and Elueze, 2005) and Okada shale (8.50%) (Obrika *et al.*, 2007). The average shrinkage of the Asaboro clay at 950°C and 1000 - 1100°C (1.39%, 2.87%) is lower than the Auchi Clay at 950°C, but higher than same at 1100°C. The Asaboro clay is also generally lower than the Gombe clay, Ewekoro clay and Okada shale. The Oguoguo clay with a shrinkage value of 3.41% at 950°C and 3.53% at 1100°C is also higher than the Auchi clay but lower than the Gombe and Ewekoro clays and the Okada shale.

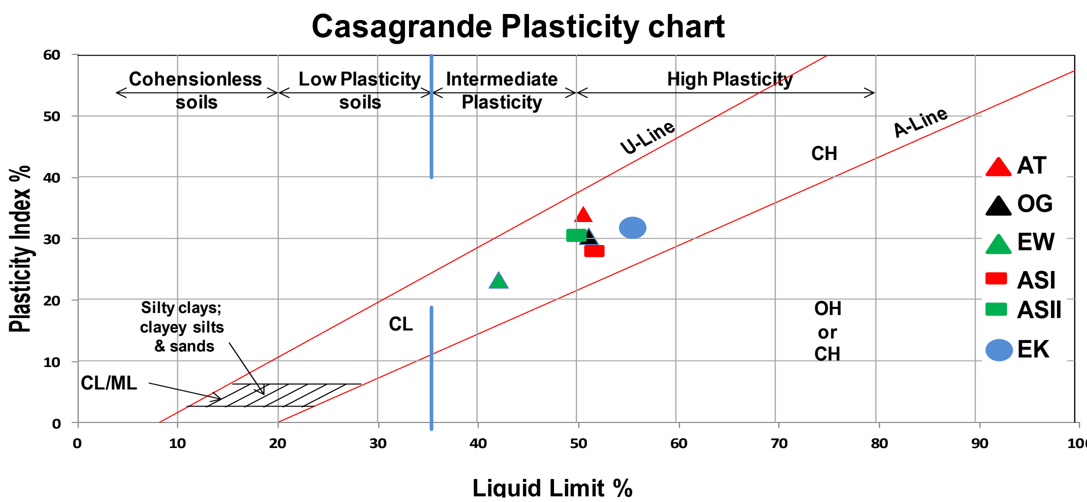

Fig. 7: Soil classification chart of some of the samples from the study area on a Casagrande soil classification plot (After Casagrande, 1948)

Table 6: Oxides of major elements in the tested samples compared with chemical industrial specification

Oxide %	Average Esan Clay	Average Asaboro Clay	Average Igbanke Clays	Reference			Paper (ANON, 1972)		Brick clay (Murray, 1960)
				Refractory bricks (Parker, 1967)	Rubber (Keller, 1964)	Ceramics (Singer and Sonja, 1971)	As Coating	As Filler	
SiO_2	64.39	64.44	49.35	51-70	44.90	67.50	47.80	48.70	38.67
Al_2O_3	17.94	17.85	23.57	25-44	32.35	26.50	37.0	36.0	9.45
Fe_2O_3	1.58	1.82	3.38	0.5-2.40	0.43	0.5-1.20	0.58	0.82	2.70
CaO	0.03	0.03	0.02	0.1-0.2	Tr	0.18-0.30	0.04	0.06	15.84
MgO	0.09	0.08	0.08	0.2-0.7	Tr	0.1-0.19	0.16	0.25	8.50
Na_2O	0.02	0.02	0.02	0.8-3.50	0.14	0.20-1.50	0.10	0.10	2.76
K_2O	0.13	0.11	0.12	-	0.28	1.10-3.10	1.10	2.12	2.76
MnO	0.01	0.01	0.01	-	-	-	-	-	-
TiO_2	1.92	1.36	1.46	1.0-2.80	1.80	0.10-1.0	0.03	0.05	-
Al_2O_3/SiO_2	0.28	0.28	0.48	-	0.72	0.39	0.77	0.74	0.24
SiO_2/Al_2O_3	3.59	3.61	2.09	-	1.39	2.55	1.29	1.35	4.09

Economic and industrial potentials of the clays

A comparison of the constituent characteristics of the clays with the industrial specification of some notable clays (Table 6) shows that the Esan and Asaboro clays are suitable for the production of refractory bricks and the production of ceramics if the alumina content of both clays are improved upon.

Although the amount of CaO, MgO, Na_2O and K_2O for the Esan and Asaboro clays meet the requirement for the production of rubber and paper if the SiO_2 content is reduced through beneficiation, and the alumina content improved by blending with appropriate quantities of clay with high content of alumina, the considerably high Fe_2O_3 content may constitute a problem to their industrial application in this regards. This problem is attributed to the colouration effect on the finished products.

The high alumina-iron ratio of 11.35 (Esan clay), 9.81 (Asaboro clay) and 6.97 (Igbanke clay), renders them less suitable for good quality cement production (Abatan *et al*., 1993).

A comparison of the chemical composition of the Igbanke clay with the industrial specification of clay meant for the production of rubber and as coating and filler in paper production (Table 6) reveal that these clays are suitable for use in the paper industry if appropriately improved upon and the iron content reduced.

Although the clays are composed of high percentages of fines (33 - 87%) which is a sedimentological attribute required for their use in the production of cosmetics and paint, a considerable amount of this fraction is silt, as high as 30% in the Atari sample. Ordinarily, the percentage silt content in the clays act as a constraint that renders these clays unsuitable in their raw state for use as coating and filler materials in the cosmetic and paint industry. Their quality can be improved by filtration to enhance their potential for use in the cosmetic and paint industries.

General compositional similarities exist between the three clays and the plastic fire clay (PFC) of St. Louis (Huber, 1985); except for slight differences in the alumina and iron content (Esan and Asaboro) and silica content (Igbanke)

Apart from the potential applications of the various clays highlighted above, the clays can also find use in the manufacture of acid-proof products, sanitary wares and glazing tiles if adequate beneficiation is done to turn them into good quality fire clays. The high amount of Fe_2O_3 impurities in the Igbanke clay (3.38%) would cause undesirable brown colouration which can pose a drawback for its industrial application in the manufacture of these materials.

Conclusion

Geochemical, mineralogical and geotechnical investigation conducted on three outcropped clays bodies in Esan, Asaboro and Igbanke areas asserts the dominance of medium to high plasticity inorganic kaolinite, with a medium to high loss on ignition values. Compositional comparison with notable clays affirms their use in the cosmetic and paint industry if appropriate beneficiation is done to reduce the coarse fraction and also in the manufacture of acid-proof products, sanitary wares and glazing tiles with adequate improvement. The Igbanke clays could find application in rubber production and as coating material for paper production if improved upon and the iron content reduced, while the high alumina-iron ratio renders them less suitable for good quality cement production.

Conflict of Interest

Authors declare that there is no conflict of interest related to this study.

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