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ARTICLE

Mineralogical and Geochemical Assessment of Clay Properties of Edda, Afikpo Sub Basin Nigeria for Possible Use in the Ceramics Industry

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ABSTRACT

Clay samples from selected part of Edda were analyzed to identify the clay mineral types present, their chemical and physical properties with a view to appraising their industrial suitability as ceramic materials. The mineralogical and geochemical analyses were done using the principles of X-Ray diffraction and X-ray fluorescence respectively. A total of seven clay samples were used for the study, other tests such as plasticity, bulk density, shrinkage, loss on ignition (LOI) and water absorption capacity was carried out to determine the amount of water absorbed under specified conditions. The basic industrial properties assessment showed that more than 70% of the clays are fine-grained. The clays exhibited low to moderate plasticity, moderate shrinkage and bulk density, low to moderate values of both loss on ignition and water absorption capacity. The clays are buff to yellowish in colour. The results of x-ray fluorescence revealed that the mean concentration of major oxide in the clays is shown as follows: SiO_2 (62.78%), Al_2O_3 (20.25%), total Fe (6.09%), CaO (0.56%), MgO (3.21%), Na_2O (0.47%), K_2O, (1.44%) and TiO_2 (0.52%). The samples have high silica content, low alumina and low oxide content. The results of x-ray diffraction revealed that kaolinite is the dominant clay mineral with illite and montmorillonite occurring in subordinate amounts, while quartz and feldspar are the non-clay components present. The characteristics of the clays for each parameter were compared with industrial standards. These properties are appropriate for the Afikpo clays to be useful in the manufacturing of ceramics. However, since the silica content of the clays is high further beneficiation is recommended.

1. Introduction

The term "clay" can be referred to as fine-grained, natural, earthy, argillaceous materials with particle size less than 0.002 mm. The term "clay mineral concept" includes the clays composed essentially of a group of extremely small crystalline particles known

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as hydrous silicate minerals. Other minerals associated with clay minerals in clays may include quartz and feldspar, as well as detrital materials that were eroded from the earth's surface. Clays are raw materials which are needed for the manufacture of a variety of industrial materials such as refractory, paint, paper, pharmaceuticals, drilling mud, and absorbents for pet litter. They find applications in the manufacture of cement, plastics, fertilizers and insecticides [1]. Therefore, adequate utilization of clay for ceramic purposes depends on its proper physio-chemical characterization. The exploitation of clays for use as raw materials in the ceramics industry has been ineffective in the Afikpo area due to scarce information on the occurrences of possible viable deposits. This has led to the under-utilization of the clays which are presently being used mostly for the production of cosmetics on a low scale and for geophagia practices. Hence, revenue generation from the ceramics industry in the state is poor. Therefore, the need for relevant information on the functional applications of the clays as ceramics materials cannot be over-emphasized, as it will contribute to the economic growth of the state and nation. This research will establish the functional application of the Edda clays and provide relevant information on the occurrence of the deposits in Edda, their viability and economic use as raw materials for the ceramics industry. This knowledge will eventually help to improve the level of small-scale mining. The characteristics of the clays will be determined by mineralogical, geochemical and geotechnical tests. The clays will be appraised by means of comparison of the physio-chemical properties with those of the various industrial specifications for ceramics. Various scholar have carried out research on suitability of clay for various purpose [2; 3; 4]. Clays have been found in huge quantities in Agwu Ndeaboh, Eze Aku, Asu River, Asata Nkporo Shales, Abakaliki anticlinorium and Lower Benue. These clays are suitable for burnt bricks and earthenware [5]. The clay deposits at Njaba, Ohiya in South Eastern Nigeria have been appraised for their suitability in white body production, also those found at Uturu and Ikpankwu were found to be potentially useful in the cement industry [6]. Field studies indicate that there are clay occurrences at Afikpo,which consists of intercalations of sandstones and shale. Preliminary investigations of the potentials of the Afikpo Clays have shown the clays to be essentially kaolinitic with differing silica amounts. Study carried out on Afikpo shale showed that the shale is useful as raw materials for pottery production. Igwe and Ezeamaku, (2010) studied the Afikpo clay to useful in paper and paint production. [8] studied the clays at Uwana to be high in refractory (SiO_2 and Al_2O_3) with corresponding low fluxes (MgO, CaO, K_2O, Na_2O, TiO_2) which makes them good and finished ceramic products materials for making of low duty refractory, vitrifying and non-vitrifying structural clay wares and finished ceramic products. The clay bodies in Nafuta, Barkin-Ladi of Plateau State were evaluated and found to be fall varies from 1,750 mm to 2,250 mm. The vegetation of the area is a mixture of eastern prototypes consisting of semi-savannah grassland with forest and swamps.

2. Geology and Stratigraphy of Southeastern Nigeria

The study area lies within Afikpo Sub-basin (Figure 2), which is one of the Upper Cretaceous sub-basins which make up the Anambra Basin [9; 10]. The Afikpo Sub-basin is considered as the southeastern depression of the Anambra Basin of [11]. The sediment fill is a succeeding post Santonian facies though to be completely accommodated within the Anambra Basin [11]. Based on the lithologic, structural and stratigraphic of the study area, three component lithostratigraphic units of the Upper Campanian-Maastrichtian were identified: the Afikpo sandstone, Nkporo and Mamu Formation (Figure 2). The Afikpo sandstone is the oldest lithostratigraphic unit, consists mainly of fine to very coarse ferruginized sandstone and shale. The Nkporo Formation overlies the Afikpo sandstone and consists of thick succession of fossiliferous dark-grey to black shales with intercalations of sandstone and ironstone. The Mamu formation is made up of coal, shale and sandstone

3. Location, Physiography, Climate and Vegetation

Table 1. Sample location and code

Sample location	Code
Ezi-Edda	EC
Nguzu Court 1	NC1
Nguzu Court 2	NC2
Afikpo South Headquarters 1	AHQ1
Afikpo South Headquarters 2	AHQ2
Letu	LC
Ebuwana	UC

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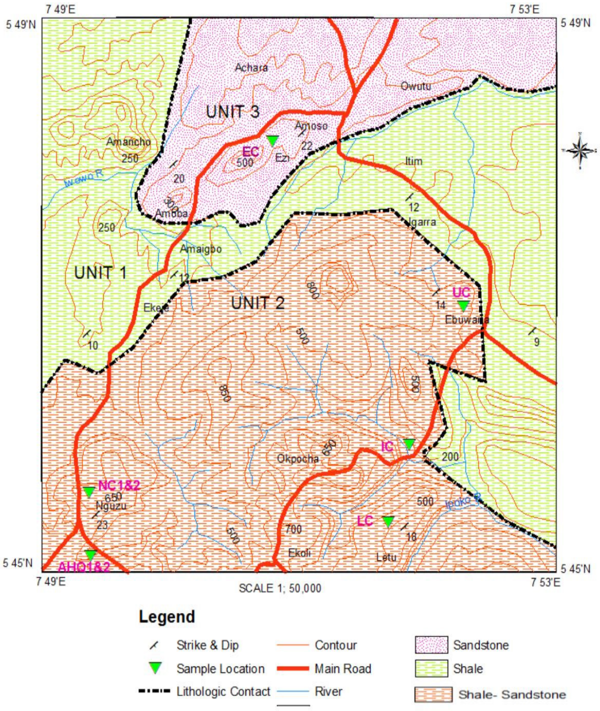

Figure 1. Geological map of the study area showing sampling points.

The area forms part of sheet 313 Afikpo NE mapped with a scale of 1:50, 000 (Figure 1). The area is accessible by means of the Afikpo-Okigwe road. The relief of the area is undulating but with isolated hillocks that rise up to 200 m above sea level. The clay deposits are surface deposits located mainly at quarry sites and along road-cuts and stream beds. The studied location is drained by the Iyere River and the tributary streams as shown below see Figure 2. The streams are intermittent streams flowing in the northwest direction. The study area has dry and wet seasons. The dry and wet seasons start and end in October/February and March/October respectively. The temperature range for the dry season is from 20 °C to 38 °C while during the wet season it spans from 16 °C to 28 °C [12; 13]. The warm and humid conditions are typical for kaolinite formations or dry seasons specific for illite and smectite formations. The average monthly raine of the Upper Cretaceous sub-basins which make up the Anambra Basin [9; 10] the Afikpo Sub-basin is considered as the southeastern depression of the Anambra Basin of [11]. The sediment fill is a succeeding post Santonian facies though to be completely accommodated within the Anambra Basin [11]. Based on the lithologic, structural and stratigraphic of the study area, three component lithostratigraphic units of the Upper Campanian-Maastrichtian were identified: the Afikpo sandstone, Nkporo and Mamu Formation (Figure 3). The Afikpo sandstone is the oldest lithostratigraphic unit, consists mainly of fine to very coarse ferruginized sandstone and shale. The Nkporo Formation overlies the Afikpo sandstone and consists of thick succession of fossiliferous dark-grey to black shales with intercalations of sandstone and ironstone. The Mamu formation is made up of coal, shale and sandstone.

Table 2. Lithostratigraphic Framework for the Southern Benue Trough, Southeast Nigeria [15]

		Lithostratigraphic Unit		Basin
		Formations	Members	
Late Cretaceous	Late Maastrichtian	Nsukka Formation		Afikpo Sub-basin
	Middle Maastrichtian	Ajali Formation		
	Early Maastrichtian	Mamu Formation		
	Late Campanian	Nkporo Formation	Nkporo Shale Afikpo Sandstone Nkporo Shale Afikpo Sandstone	
	Santonian	Angular Unconformity		
	Turonian	Ezeaku Group		Benue/Abakaliki Basin/Calabar Flank
	Cenomanian	Odukpani		
Early Cretaceous	Albian	Asu River Group		
Precambrian		Precambrian Basement Complex		

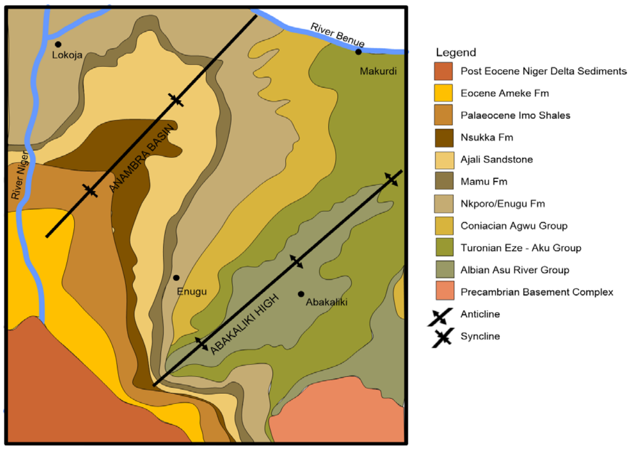

Figure 2. General geologic map of Southeastern Nigeria showing Afikpo basin in the Anambra Basin [14]

4. Materials and Methods

The clay samples were collected from two formations namely, Nkporo and Mamu formations. From the map of the study area, there are three lithologic units. The samples from Units 1 and 2 are located in Mamu formation, while those from Unit 3 belong to Nkporo formation. A total of seven (7) fresh samples were collected and preserved for analyses at depths of about 1metre. The analyses for atterberg limits, mineralogical and geochemical properties were done at Ministry of Works and Infrastructure, Enugu and Engineering Development Institute, Akure in Nigeria.The mineralogical test was done through the process of X-ray diffraction using the XRD-Philips ADP-10 automated diffractometer. For mineralogical test, the fine grained particles (less than 2 µm) were separated by centrifugation. To ensure homogenous sample throughout the study, it was done according to the procedure in Moore and Reynolds (1997). In each case, 25 grams of the sample were placed in a 600 ml polythethylene centrifuge bottle along with 500 ml of distilled water and dissolved to hydrate for 24 hours to form stable dispersions. The equipment applies the Bragg Bretano principle using a 3.0 KvA steady potential and copper K-alpha radiation generated by the x-ray machine. Identification of the constituent minerals was done by calculating the d-spacings corresponding to the Bragg angles obtained from the x-ray diffraction traces and using reference tables of diffraction spacing of standard crystalline minerals indexed according to diffraction intensity published by [16] in powder diffraction files. Approximate proportions of were established by comparing heights of specific diagnostic peak of the various minerals, with standard heights of equivalent peaks of the pure minerals established by the Joint Powder Diffraction Standards [17]. The peaks of the various minerals obtained at various d-value angles were automatically obtained with the aid of a computer program installed in the diffractometer. The bulk chemical tests was carried out with an IVT-20 computer automated X-ray Fluorescence (XRF) spectrometer. The samples were prepared following the procedure outlined in [18]. The exchangeable metallic bases (in milli-equivalents per hundred grams of dry sample) were determined by leaching 50 g of the samples with neutral ammonium acetate and the resulting aliquots were analyzed for Si, Na, Ca, Fe and Ti cations according to the method given in [16]. The liquid and plastic limits of the clay samples were determined with about 100 g of each sample passing325 µm (BS No. 36) in accordance with [19]. The shrinkage test was done with the use of pelletized round bars of dimensions 180 mm × 90 mm in accordance with [20].The bars were air-dried for 6 hours, and oven-dried at 80^0 C overnight. After 4 hours, the furnace was allowed to cool down to room temperature and the diameters of the fired pellets were measured. The difference between the dry and fired shrinkage diameters of the fired pellets gave the percentage shrinkage. The loss on ignition test was done by firing the samples for over 30 minutes for over 10 hours at four different temperatures ranging from 900-1200^0C.

$$Liquid\ limit\ (LL)\frac{Moisture\ content\ (MC)\times Number\ of\ blows\ (N)0.121}{25}$$

As proposed by [20].

$$Liquidity\ index==\frac{NM-PL}{PI} \qquad (Equation\ 2)$$

As proposed by [21].

Where NM= soil's natural moisture content (in %)

$$Plasticity\ Index = LL - PL \qquad (Equation\ 3)$$

As proposed by [22].

5. Bulk Density, Specific Gravity and Water Absorption Capacity Analyses

The bulk density was determined with about 100 g of sample using a free-fall method according to the procedure outlined in [16]. Each sample was evaluated twice and the average values of the density calculated. The water absorption capacity test was done according to [16]. It was done with the use of fired pellets placed in boiling water in a beaker which was allowed to cool down. The absorbed water was removed from the pellets surface using a moisture cloth. The weight of the pellets was then measured (Ww). The pellets were oven-dried at a temperature of 110 °C after which the dry weight was measured (Wd). The water absorption capacity (Wa) was calculated by subtracting the dry weight (Wd) from

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the wet weight (Ww). The difference was divided by the dry weight (Wd). The specific gravity test was done using a balance sensitive to 0.1 g, an Erlenmeyer flask and a spatula. Firstly, the weight of the empty flask was recorded. The samples were poured into the flask and re-weighed while necessary precaution was taken to ensure there was no spillage by the use of a spatula to scrape off any excess above the rim of the flask. The recorded weight of the flak was subtracted from the initial weight and divided by the weight of the flask to obtain the specific gravity values for each sample.

6. Results

6.1 X-Ray Diffraction (XRD)

The result of the mineralogical test is presented in Table 3. The identified clay types are kaolinite, illite, montmorillonite with_mixed layer. The Edda Clays are kaolinitic with a maximum concentration value of 75 %. However, the non-clay mineral component consists of mainly quartz and plagioclase feldspars.

Table 3. Results of Mineralogical test (% wt)

Parameters	EC	NC1	NC2	AHQ1	LC	UC
Kaolinite	70	65	75	68	70	72
Illite	16	20	15	20	18	18
Montmorillonite	+	+	+	+	5	5
Mixed layer	14	15	10	25	11	5

+nil

The diffractograms of the clays showed distinct peaks of kaolinite as seen in Figure 3-9. The prominent peaks are recorded as 2θ= 25.13, 23.99, 24.35, 26.62, 25.07, 25.20, and 22.87. The prominent peaks can be used to identify the composition of moderate to well crystalline materials [23]. The mineralogy of the Edda clays revealed that the clays are generally non-expansive. The presence of minute concentrations of montmorillonite (5 % to 10 %) in Letu and Ebuwana clays indicates they are "sensitive" clays [24]. The clays showed similarity in mineralogy which indicates that they have the same origin. The mineralogical composition revealed that the clays were formed as a result of in-situ weathering; the diffractograms indicate dominance of kaolinite while illite and quartz occur in traces. The presence of feldspars as accessory minerals also implies that the clays were formed in an acidic environment. The formation of kaolinite is favoured by an acidic condition and high leaching environments [25].

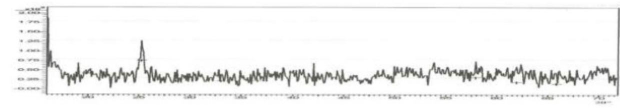

Figure 3: X-Ray Diffractogram for Ezi-Edda (EC).

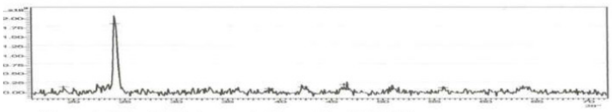

Figure 4: X-Ray Diffractogram for Nguzu Court 1 (NC 1).

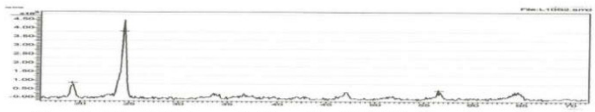

Figure 5: X-Ray Diffractogram for Nguzu Court 1 (NC 2)

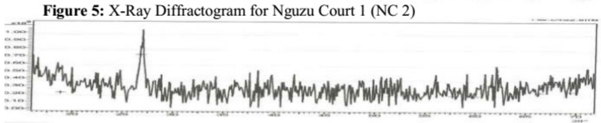

Figure 6: X-Ray Diffractogram for Ezi-Edda (EC).

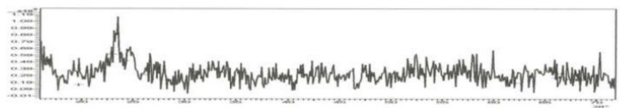

Figure 7: X-Ray Diffractogram for Afikpo South Headquarters 1 (AHQ 1).

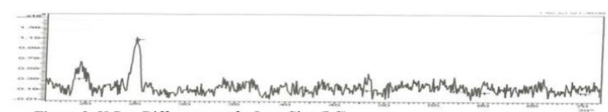

Figure 8: X-Ray Diffractogram for Letu Clay (LC).

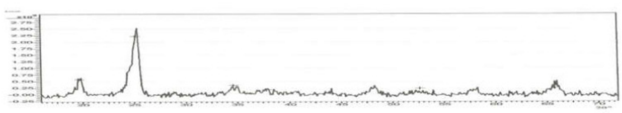

Figure 9: X-Ray Diffractogram for Ebuwana Clay

6.2 Chemical Composition of Edda Clays

Major oxide analysis showed that the clay bodies have high silica and low alumina content (see Table 4). Earlier works on various Nigerian clay deposits have shown many of them to be rather high in silica and low alumina content [26]. The table indicates that the studied clays exhibit fair consistency in the concentrations of SiO_2, Al_2O_3, Fe_2O_3, and alkali oxides which may generally imply that there are similarities in the mineralogy. The high silica content shows that the source rocks are rich in quartz and silica-rich bearing minerals confirming the grittiness of the clay [27]. Letu clay has the highest silica content of 73.14 % and alumina content of 17.24 %. The clays found at Ezi-Edda, Nguzu Court and Afikpo South Head-Quarters have a significant content of Fe_2O_3. This is indicated by the observance of reddish colouration. The iron-oxide content usually imparts a reddish colour

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to clay when fired and is possibly due to superficial oxidation and contamination by Fe-rich percolating water [28] .From the study of the Pugu kaolin of Tanzania, the iron oxide content in the clay is high (above ~ 1.43 %) could adversely affect the translucency of white wares [29]. The studied clays in the natural state could be suitable for ceramics that do not require high brightness specifications, such as stone ware and sanitary ware. The clays generally have low ($CaO + Na_2O$) content with values of 0.12-1.48 % and 0.20-0.87 %. The Ezi-Edda and Nguzu Court clays have low ($K_2O + MgO$) values. Relatively low abundance of MgO and K O (less than 0.30 %), indicate lack of expandable clay mineral in the samples. The concentrations of K_2O and Na_2O is relatively higher for clays from AHQ1 than those from AHQ2 suggesting more compositional maturity in the clays found in the latter [30]. It is also necessary to note that high SiO_2 but low CaO, MgO, and Na_2O revealed that the clays in both locations are amenable to beneficiation to achieve appropriate grade for manufacture of sanitary hardware [31]. The low earth-alkaline oxides ($CaO + Na_2O$) content indicates that the clays are poor in carbonates [32]. The Afikpo South Head-Quarters clays have significant concentration of potassium oxide (K_2O) of 8.07 %. Due to the relatively high value of K_2O in the clays it can be deduced that there is presence of illite. The relatively high K+ may be attributed to abundant K- feldspar consequent on albtitization process [33]. The high K_2O content may indicate chemical decomposition of K-rich minerals like augite and other ferromagnesian minerals [33]. However, the low value of Na O simply indicates the minimal amount of the mineral [34]. The clays have low titanium oxide content, which aids its use and meet the requirements of 0.3 % for ceramic materials [35]. The losses on ignition (LOI) values of the clays are relatively low to moderate indicating that a small amount of water was lost on firing. The losses on ignition (LOI) values are lower than 18 % specified for upper limit for refractory clays [36]. The temperature obtained on firing is 1200^0 C which indicates relatively moderate firing strength. This is reflected in the result of the loss on ignition as seen in Table 4. The moderate level of firing (7.25-9.32 %) could be due to relatively high SiO_2 percentage present in the clays. The implication is that the viability and usefulness of the clays is limited to the formation of materials, which melting points are not more than 1,200 ^{0}C hence enhancing its use earthenware [28]. Allowable values for ceramic sanitary wares on sale, states that the maximum value for total shrinkage should not exceed 15% [37].

6.3 Atterberg Limit and Shrinkage

The results of the Atterberg limit and shrinkage tests were calculated using equation 1 to 3. Result obtained from the studied clays are presented in Table 5. The results indicate that the clays in their natural states have moderate plasticity. They all plot below the B-line and above the A-line in the Cassagrande plasticity chart (see Figure 10). The clustering of the samples especially for Ezi-Edda and Afikpo South Headquarters (AHQ 2), buttresses the similarity in the studied clays. The Edda clays are mouldable

Table 4. Results of Geochemical Test (% wt)

Oxides	EC	NC1	NC2	AHQ1	AHQ2	LC	UC
SiO_2	72.89	62.53	68.69	57.14	69.24	73.34	69.24
Al_2O_3	12.05	28.72	22.92	18.67	16.90	17.24	25.22
Fe_2O_3	7.29	0.18	4.61	4.60	10.42	9.32	6.20
MgO	0.14	0.11	0.13	3.16	10.12	8.64	0.18
CaO	0.12	0.08	0.32	0.87	0.64	1.48	0.42
Na_2O	0.20	0.35	0.31	0.61	0.62	0.87	0.34
K_2O	0.10	0.15	0.16	7.26	0.81	1.22	0.30
TiO_2	0.74	0.41	0.24	0.03	0.95	0.81	0.47
***LOI**	8.20	7.40	6.95	5.30	3.80	5.65	6.20

**LOI Loss on ignition*

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Table 5. Results of Plasticity and Shrinkage Tests (% wt)

Parameters	EC	NC1	NC2	AHQ1	AHQ2	LC	UC
Plastic limit	18	24	24	24	21	25	18
Liquid limit	38	52	42	45	40	49	39
Plasticity Index	20	25	18	21	19	24	21
Shrinkage	10	10	9.2	3.9	3.3	3.8	7.7

Table 6. Results of bulk density, specific gravity and water absorption capacity tests

Parameters	EC	NC1	NC2	AHQ1	LC	UC
Bulk density (Kg/m^3)	1313	1328	1309	1312	1316	1313
Water absorption capacity (%)	0.28	0.24	1.32	1.58	1.58	3.20
Specific gravity	2.0	2.2	2.2	2.1	2.1	2.3

which is an estimation of their workability, due to the fact that they plot within the field of medium compressibility and toughness. The clays can be classified as low to moderately plastic since they fall under the designated CL and within the line of moderation (B-line). According to [38], the medium plasticity is influenced by the mineral composition (particularly kaolinite and illite). The plastic limit values of the studied clays range from 18 % to 27 %. Plastic limit values less than 30 % indicates that the clays are kaolinitic [30]. The liquid limit values range from 38 % - 52 %. The plasticity index values range from 18 %-25 % with mean concentration of 21 %. Liquid limit values in this study are less than 100 %, classifying the clays as inorganic; while average plasticity of 18 % indicates moderate plasticity [39].

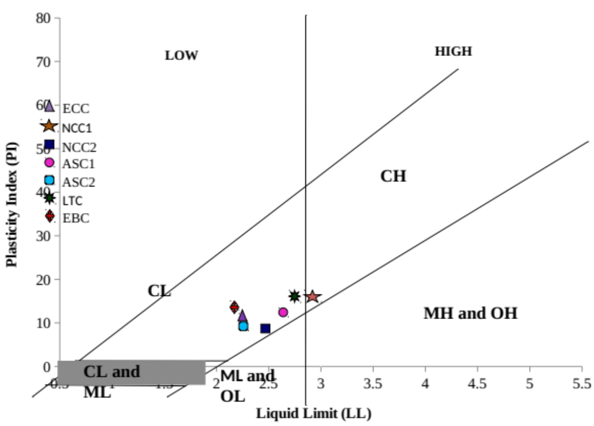

Figure 10. Plots of the studied clays in the Cassagrande Plasticity Chart.

6.4 Bulk Density, Specific Gravity and Water Absorption Capacity

The results of these tests are summarized in Table 6. There is fair consistency in the results of the bulk density of the studied clays, suggesting similarity in the material type; a situation already reflected in the results of the mineralogical and chemical analyses. The clays exhibit moderates bulk density values (1309-1328 kg/m^3). The water absorption capacity values are low due to the limited substitution associated with clays dominated by kaolinite. The lime and magnesia content is low, which influences the absorptive properties of the clays [35]. The Afikpo South Headquarters has higher values of water absorption capacity (6.20 %) which is probably due to the presence of abundant K+. Allowable values for ceramic sanitary wares, states that the maximum value for percentage water absorption capacity should not exceed 16 % [37]. The specific gravity values are consistent and fall with the range of 2.0 % to 2.5 %. The average value of the specific gravity is 2.2 % supports the fact that the deposit is kaolin based on the classification of mineral (Gary, 2008).

7. Discussion

Appraisal of the Edda clays as raw materials for the ceramics industry

Detailed comparisons of the characteristics of the Edda clays with the characteristics of various clays which have served well as industrial specifications for ceramics are presented in Tables 8-10 below. The stud-

Table 7. Comparison of the mineralogical properties of Edda clays with industrial standards (% wt)

Parameters	Industrial standard						Studied clay					Remarks
	*1	*2	*3	*4	*5	*6	EC	NC	AHQ	LC	UC	
Kaolinite	85	85	48.27	61.60	64	91	70	70	61.5	70	72	C
Illite	15	+	4.68	2.30	8	3.16	17	5	30	18	18	H
***Smectite**	+	+	+	0.50	+	+	+	+	+	5	5	H
Mixed layer	+	+	+	+	+	+	14	12.5	18.5	11	5	H

*+ nil *1- China Clay [49] *2- [44] *3- Ara Clay [41] *4- Itakpe Clay [42] *5- Ikerre Clay [45] *6- Ibadan Kaolinite [46] C-Generally Comparable H- Generally Higher *Smectite- Montmorillonite*

Table 8. Comparison of the geochemical properties of Edda clays with industrial specifications (% wt.)

Oxides	Industrial specification						**Edda Clays**					
	*1	*2	*3	*4	*5	*6	EC	NC	AHQ	LC	UC	Remarks
SiO_2	48.50	44.98	52.65	46.60	52.92	67.50	72.89	65.61	63.19	73.14	69.22	C
Al_2O_3	28.82	37.54	27.24	37.80	9.42	26.50	12.05	25.82	17.79	17.24	25.22	L
Fe_2O_3	9.84	2.35	3.01	3.97	3.65	0.5-1.20	7.29	2.40	7.51	9.32	6.20	H
MgO	0.96	1.72	0.38	0.33	0.08	0.10-0.19	0.14	0.12	6.65	8.64	0.18	H
CaO	0.58	0.09	0.19	0.16	1.90	0.18-0.30	0.12	0.20	0.76	1.48	0.42	C
Na_2O	0.23	0.19	0.37	3.03	0.03	0.20-1.50	0.20	0.33	0.62	0.87	0.34	C
K_2O	2.49	1.01	1.44	0.66	0.98	1.10-3.10	0.10	0.16	4.04	1.22	0.38	H
TiO2	1.02	1.42	+	0.45	1.18	0.10-1.00	0.74	0.33	0.49	0.81	0.47	C
*LOI	4.16	12.60	13.80	+	+	+	8.20	7.18	4.55	5.65	6.20	C

*+ nil *LOI- Loss on Ignition *1- Ara Clay [41] *2- Ibadan Kaolinite [47] *3- Itakpe Clay [42] *4- Jos Kaolin [43] *5- Florida Active Kaolinite [48] *6-Ceramics [44] C-Generally Comparable H- Generally Higher L- Generally Lower*

ied clays have a high concentration of kaolinite which is favourable for the manufacture of ceramic materials. From Table 7, it can be deduced that the mineralogical properties of the clays compare well with the industrial specifications. However, the mixed layer components consist mainly of feldspar and quartz which could serve well as fluxing agents. The presence of feldspars is important for the production of liquid phase during sintering which accelerates the densification of ceramics [40]. The combination of feldspars with kaolin and quartz generates porcelain. The values for illite and montmorillonite are marginally higher than those of the industrial specifications.

The clay of the study area was compared to industrial specification as shown in Table 8. It was observed that oxides were below industrial specification except for Fe_2O_3, MgO and K_2O that were slightly at some sampling locations see Table 8. However it is advised that oxide content in clay should be reduced. In the same viein, the alumina content of the Edda clays is lower which has to

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Table 9. Comparison of index properties of Edda clays with industrial specifications

Parameters	Industrial specification						Studied Clays		Remarks
	*1	*2	*3	*4	EC	NC	AHQ	LC	UC	
Specific gravity	2.78	+	2.61	2.56	2.0	2.2	2.4	2.1	2.3	C
***WAC (%)**	6.14	13.58	+	_+	0.28	0.68	3.10	1.58	3.2	L
Liquid limit (%)	47.80	26.88	33.0	56.11	38	47	42.5	49	39	C
Plastic limit (%)	26.24	15.51	17.5	+	18	22.5	22.5	25	18	C
Plasticity index (%)	21.48	10.38	14.5	+	20	21.5	20	24	21	H

*+ nil *W.A.C- Water Absorption Capacity *1- Ara Clay [41] *2- Itakpe Clay [42] *3- Ikerre Clay [46] *4- Ilukuno Clay [30]*

Table 10. Comparison of bulk density and shrinkage properties of Edda clays with Industrial Specifications

Parameter	Industrial specifications			Studied class			Remarks
	***Oboburu clay**	**EC**	**NC**	**AHQ**	**LC**	**UC**	
Bulk density (Kg/m^2)	1333	1333	1319	1319	1316	1313	C
	*Abraka-Amai Clay	EC	NC	AHQ	LC	UC	Remarks
Shrinkage (%)	0.25-1.23	10	9.6	3.6	3.8	7.7	H

**Oboburu Clay [50] *Abraka-Amai Clay [47].*

be enhanced.

Table 9 above showed comparison between index properties and industrial specifications. The comparison was based on the following parameters specific gravity, liquid limit and plastic limit. The plasticity index content of the clays is marginally higher than the value for the industrial specifications. The water absorption capacity value of the Edda clays is lower on comparison with the industrial specifications. However, this observed variation in comparison does not have any critical effect on the performance of the studied clays as ceramic materials. From Table 10, the bulk density values of the studied clays compare well with the industrial specification, while the shrinkage content is marginally higher than the value for the industrial specification.

From the study, it was observed that Edda clays can perform well as raw materials for the manufacture of ceramics. However, the silica oxide content of the clays could be beneficiated to reduce the quartz content which will prevent grittiness and reduce abrasiveness in the finished products. To ensure the use of the clays as ceramic materials, the alumina content of the clays can be improved upon. The clays can be used for the production of porcelain, stoneware and sanitary ware even in the natural state. However, in order to improve the appearance of the earthen wares; the iron oxide content has to be reduced to a minimal level [51; 52].

8. Conclusions

This study evaluated the physical and chemical properties of the Edda clays in southeastern Nigeria with a view to assess their suitability as raw materials for the manufacture of ceramics. X-Ray Diffraction test revealed that the clays obtained from Nkporo and Mamu Formations are mainly kaolinites with subordinate amounts of illite, montmorillonite and mixed layer The major oxide analysis which was done by means of X-Ray Fluorescence showed that the clays have significant concentration of silica oxide which in combination with the low alkali oxide content could yield good materials for the manufacture of ceramics. The clays indicated higher iron oxide content which is favourable for the manufacture of stone wares and sanitary wares. The physical test showed that the clays exhibited low to moderate plasticity as they fall within the designated lines of CL and ML according to Unified Soil Classification System. The index properties are favourable for the application of the clays as raw materials for the ceramics industry. The Edda clays based on comparison with various industrial specifications for ceramics have been proven to be useful raw materials for the manufacture of ceramics.

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