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Geology and Geotechnical Appraisal of Some Clay Deposits Around Ijero-Ekiti Southwestern Nigeria: Implication for Industrial Uses

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Abstract. The geotechnical appraisal of the clay deposits around Ijero-Ekiti, southwestern Nigeria, indicated that Ara and Ijero clays have 49.2% and 24.1% clay fractions, respectively, while Ilukuno variety has 32.8% clay fraction. The range of Atterberg liquid limits of Ara and Ijero clays was 41.8-48.0% and 25.6-36.5%, respectively, and those of plastic limits, 19.5-24.0% and 22.0-23.2%, respectively. XRD analyses showed kaolinite as the most prominent clay mineral present in the clays. Ara and Ijero clays were geochemically similar having SiO_2, Al_2O_3, Fe_2O_3 concentrations, which reflect derivation from the underlying basement rocks. Thus, these clay deposits are suitable for the manufacture of paints, ceramics, refractories, agro-chemical and pharmaceutical products.

Keywords: Ara clay deposits, Ijero clay deposits, geochemistry, clay deposits, Nigeria

Introduction

Ijero-Ekiti is about 35 km NW of Ado-Ekiti in the southwestern Nigeria. The geology of the area has been well studied and reported as part of the southwestern Nigerian basement complex (Oyinloye, 1997; Rahaman, 1988; Turner, 1983; Matheis, 1978; McCurry, 1976). According to Grant (1970), Ijero, a component of the southwestern Nigerian basement complex, is considered an Archaean-Early Proterozoic terrain. The area is described as being composed of migmatite-gneiss-quartzite complex with supracrustal rocks (Oversby, 1975; Grant *et al.*, 1972). Oyinloye (1997) comparing lithologies, considered Ijero an extension of the Ilesha schist belt. According to Oyinloye and Adebayo (2005), the migmatite-gneiss complex in the area is composed of a mafic portion made up of biotite, hornblende, quartz and opaque minerals, while the felsic portion is quartzo-feldsparthic. Other rocks identified by these authors are metasediments composed of amphibolites schist, mica schist and quarzites. The pegmatites of the area are dykelike, sheet-like , and associated with gemstones. Rocks in Ijero area have been subjected to varying degrees of weathering which led to the formation of clay deposits.

Several industries, using clay as a resource, either manufacture products directly from clay or utilize clay in their processing. Bricks and common clays are suitable for the manufacture of heavy clay products, such as building and paving bricks, drain tiles and sewer pipes. Kaolin, ball clay and fire clay are suitable for heavy clay products. The most important properties of clay are its plasticity, little shrinkage during drying and firing and good strength. The fired colour of the clay is important to both the consumer and manufacturer. Building-brick clay that fires white may be developed commercially by addition of minerals; the colour may be modified to meet whatever is popular among consumers. Fuller's earth clay, otherwise called natural bleaching clay refers to any natural or treated clay that, when used as filter, effectively removes colour and clarifies various mineral and organic oils. Mineralogically, fuller's earth is predominantly smectite (calcium montmorillonite) but typically includes some kaolinite and attapulgite. The importance of fuller's earth to industry is due to its bleaching properties. Pottery clay used for pottery and stone wares are principally kaolin and /or ball clay. For successful working and drying, such clay must be plastic when wet, shrink little while drying and resist warping and breaking after drying before firing. The final products after firing harden, become strong and non-porous and attain suitable colour. Some of the household items manufactured using pottery clays include porcelain, sinks and water closets, some chinawares, various types of ovenproof cookware, stoneware, other kitchen and dinnerware, ceramic, floor and wall tiles, decorative items and various types of refractories.

The present study focuses on three clay deposits in Ijero area (Fig. 1, 2 and 3). Two of these deposits had been mentioned in regional studies. The third deposit at Ilukuno had not been reported in literature. These three clay deposits are, therefore, studied together with a view to establishing their physical and chemical properties and implication of these for the possible industrial utilization.

Geological setting. Fieldwork carried out in the present study revealed that the area is underlain by the precambrian rocks

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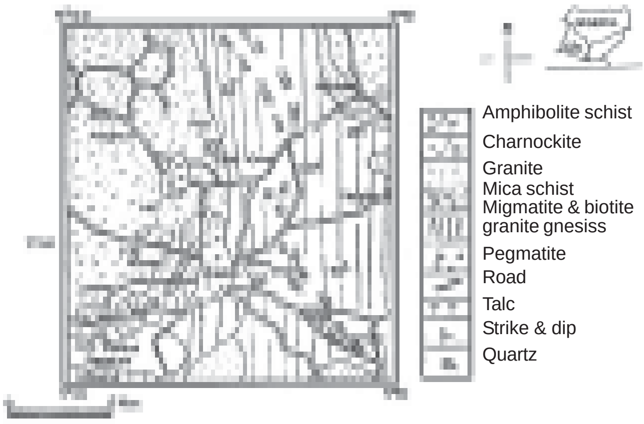


Fig. 1. Goeological map of Ijero-Ekiti and its environs.

Fig. 2. Goeological map of Ara Ijero clay site (adapted from Elueze and Bolarinwa, 1995).

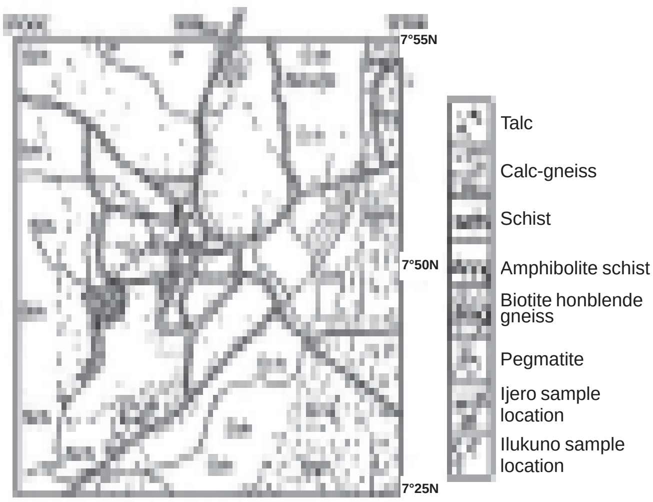


Fig. 3. Goeological map of Ijero area showing Ijero & Ilukuno clay sites (adapted from Oyinloye and Adebayo, 2005).

of the basement which are migmatite-gneiss, gneisses, metasediments-mica-schists, quartzites, calc-silicates, pegmatites and Pan African granites. In the area covered by this study, low-lying mica-schist is found to the west and the migmatites and the gneisses occur to the east. The granites occur in the south and the charnockites, in the northeastern sector of the area (Fig. 1). The schist and the intruding pegmatites have been highly weathered to the low-lying terrain and in some places are rubbles and boulders. Exposure of schists is however noticeable within some built-up areas. The charnockites occur as spherical boulders; in some places, they form large inselbergs with discrete exfoliation surfaces. Two varieties were observed: coarse-grained and fine-grained. The two sometimes occur within the same vicinity. Fresh samples are bluish to dark-green in colour while the weathered ones, show dark brown stains of chemical weathering process. Granites form prominent outcrops in the southern area.

Materials and Methods

Thirty representative samples were collected from different pits and vertical sections of the clay deposits. Samples were air dried for about two weeks and later disaggregated to increase the surface area. Sieve and hydrometer analyses and the Atterberg limits were determined in accordance with the British specifications. Firing tests to determine thermal characteristics using Gallenkamp muffle furnace were carried out on sample pellets. Specific gravity, shrinkage limits (linear), bleaching test, pH and water absorption capacity values were also determined. X-ray diffraction method is a good method that can give non-destructive structural analysis of different clay types in soils by utilizing characteristic angular values of diffracted X-ray beams. Hence, this method was used to determine the mineralogical composition of the clay samples. Air-dried powder of the clay fractions was first heated to a temperature of 600 °C and then subjected to: cobalt K.alpha radiation 40 kV, 20 mA, chart sp = 1200 mn/hc and count rate $= 1 \times 10^3$cps. The most intensive peaks of the curves were used to identify the minerals and the first order peaks were assigned to the appropriate mineral. Initial clay samples were prepared in Nigeria for chemical analyses by the first author. Pulverized clay fractions sealed in polythene bags were sent to Canada for analyses. Chemical analyses were carried out in Activation Laboratories, Ancaster Ontario, Canada, using fusion-XRF method. The fusion-XRF method applies lithium metaborate/tetraborate fusion in oxides analysis with 0.001% detection limit. Percentages of the following major element oxides were determined: SiO_2, Al_2O_3, MnO, MgO, CaO, Na_2O, K_2O, TiO_2, P_2O_5, Cr_2O_3 and total iron as Fe_2O_3; loss on ignition (H_2O^+) was also determined.

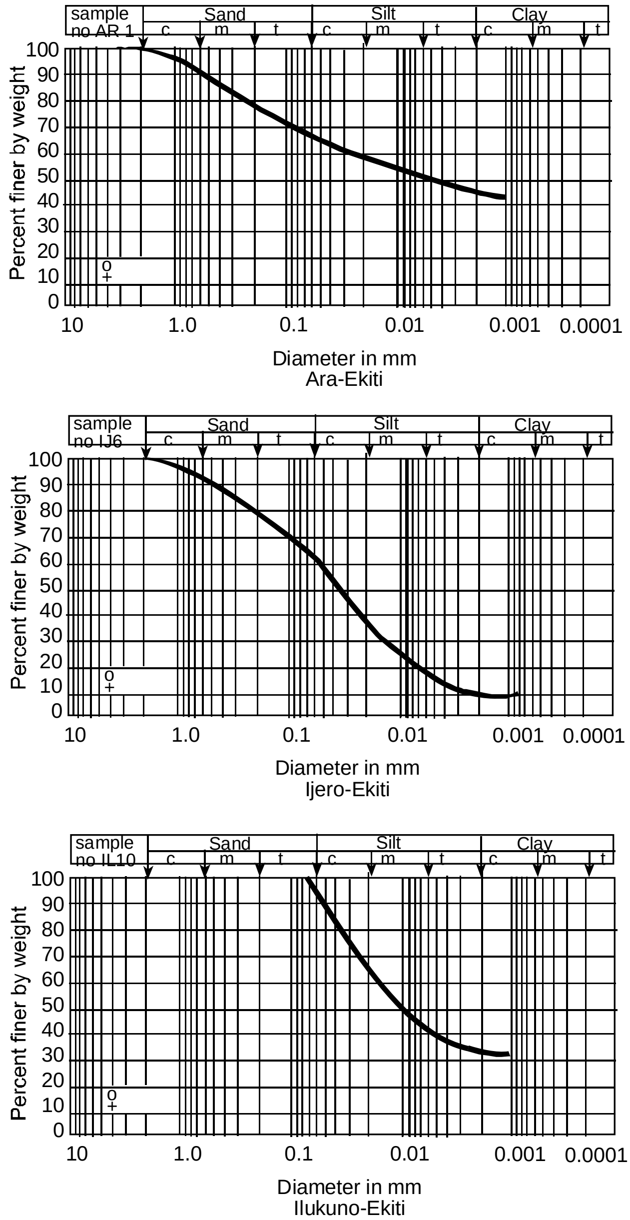
Results and Discussion

Among other properties, the particle size distribution study of clay deposits is fundamental to the determination of its industrial applications. Most of the properties of clay are function of the size of its clay fraction; for example, plasticity of clay depends on the particle size as finer particles induce higher plasticity. Hydrometer method was used to analyse the clay fraction of the clay and representative size distribution curves of the results are presented in Fig. 4. The interpretation of the curves is summarized in Table 1.

Liquid and plastic limits as well as plasticity indices, shrinkage limit values and specific gravity values are presented in Table 2. Firing characteristics as well as water absorption capacity values (WAC) are presented in Table 3. The plasticity chart for clay classification is shown in Fig. 5. The clay identification chart drawn in accordance with Bain (1971) is presented in Fig. 6. The X-ray diffractograms showing the mineral composition for the clay samples are shown in Fig. 7(a,b,c), while the quantitative implication of the curves, expressed in percentages (Carrol, 1970), is presented in Table 4. The average chemical compositions of the clays compared with those of some notable references and some industrial specifications are shown in Table 5.

Results of the sieve analyses for particle size greater than 0.002 mm and those of hydrometer tests of clay, fractions (<0.002 mm) for Ara, Ijero and Ilukuno clays as summarized in Table 1, indicate average values of clay fraction (<0.002 mm), 49.7%, 24.1% and 32.8% the range being 43-56%, 21-28% and 28-46%, those of silt fractions (0.002-0.06 mm) 16.6% (range 10-25%), 22.8% (range 17-29%) and 65.2% (range 54-70%), those of the sand quantity 31.5% (range 25-37%), 51.6 % (range 33-61%) and 2.0 % (range 2-6%) all in the same order for Ara, Ijero and Ilukuno clays, respectively. The gravel percentage of clays are relatively low i.e. 2.2% for Ara (range 1-4%), 1.5% for Ijero (range 1-5%) and non existent in Ilukuno clay samples. From Table 1 and Fig. 4, it is established that the Ara and Ijero clays are fairly well graded while Ilukuno clay is poorly graded. The disparity in the curves can be attributed to the differences in the texture of the parent rocks as well as to different degree of weathering. The shape of the grain size distribution curves and the plasticity chart also depict that the clays are silty-clays as overall average concentrations of silt and clay fractions are 34.8% and 35.5%, respectively, and according to Krynine and Judd (1957), clays that plot very close to the A-line, as shown on the chart (Fig. 5) are silty-clays. Sand and gravel fractions have extremely low average values of 2.8% and 1.2%, respectively.

Further implication of the data (Table 1 and Fig. 4) is that the clays are at different stages of maturity. The samples from Ara are probably more mature than others with higher percentage of clay fraction (49.7%) followed by Ilukuno (32.8%) and Ijero clay (24.1%). The plot of the plasticity indices against the liquid limits values (Fig. 5), according to Casagrande (1948), classify the Ara clay as an inorganic clay of medium compressibility and moderate toughness. Ijero clay is classified also as inorganic clay of low-medium compressibility and of moderate toughness, but Ilukuno clay is completely non-cohesive and subsequently non-plastic. The plot implies that Ara clay is highly plastic and of medium swelling potential (plastic index falls between 15-25%). Ijero clay is moderate



c = coarse; m = medium; f = fine; o = by sieve; + = by hydrometer

Fig. 4. Typical grain size distribution curves of the clays.

Table 1. Summary of grain size distribution of the clays

Grain size	Ara		Ijero		Ilukuno	
	Mean	Range	Mean	Range	Mean	Range
Clay	49.7	43-56	24.1	21-28	32.8	28-46
Silt	16.6	10-25	22.8	17-29	65.2	54-70
Sand	31.5	25-37	51.6	33-61	2.0	2-6
Gravel	2.2	1-4	1.5	1-4	-	-

Table 2. Values of liquid limit (LL), plastic limit (PL), plasticity index (PI), shrinkage limit (SH) and specific gravity (SG)

Ara					Ijero					Ilukuno				
LL	PL	PI	SH	SG	LL	PL	PI	SH	SG	LL	PL	PI	SH	SG
41.5	22.0	19.5	10.0	2.63	25.6	ND	ND	4.3	2.54	57.5	ND	ND	ND	2.54
45.5	24.2	21.3	10.0	2.69	28.0	ND	ND	4.3	2.63	55.0	ND	ND	ND	2.55
46.0	23.1	22.9	10.0	2.68	30.0	ND	ND	2.9	2.69	53.5	ND	ND	ND	2.54
46.5	23.2	23.3	10.0	2.69	26.0	ND	ND	2.9	2.64	57.5	ND	ND	ND	2.54
47.0	24.0	23.0	10.7	2.63	28.5	ND	ND	3.6	2.59	58.2	ND	ND	ND	2.55
45.0	23.1	21.9	10.0	2.62	25.5	ND	ND	1.4	2.57	56.5	ND	ND	ND	2.60
48.0	24.0	24.0	11.4	2.64	34.5	22.1	12.4	9.3	2.62	55.2	ND	ND	ND	2.57
42.8	22.0	20.8	9.3	2.62	35.0	22.0	13.0	9.3	2.62	53.9	ND	ND	ND	2.58
45.0	23.2	21.8	10.0	2.63	36.5	23.2	13.3	8.6	2.67	56.4	ND	ND	ND	2.56
44.0	23.1	20.9	10.0	2.68	28.0	ND	ND	3.6	2.59	57.4	ND	ND	ND	2.59
Ave		21.9	10.14	2.65			12.9	5.02	2.62					2.56

ND = not determinable.

Table 3. Results of firing and water absorption capacity (WAC) tests

Sample	Initial colour	Colour after firing	WAC range (ave.)
Ara	Yellow brown	Reddish brown	3-13(6.6)
Ijero	Brown	Light brown	3-4(3.3)
Ilukuno	White	Brittle white	-

in plasticity and swelling potential (average, 12.9%). According to classification of soils by Bain (1971), Ara and Ijero clays are kaolinitic clays (Fig. 6).

The shrinkage limit of Ara clay found in the present study (Table 2) was 10.4% in the range of 9.3-11.4%, that of Ijero 5.02% in the range of 1.4-9.3% and that of Ilukuno was not determinable. According to Bain (1971) standard, the shrinkage limit for Ara clay indicates that the degree of expansion is critical because of its average value of 10% and those of Ijero and Ilukuno clays are marginal with average values of 5% and 0%, respectively. Water absorption tests (Table 3) reveal that the Ara clay (in the range of 3-13%) has a higher average water absorption capacity of 6.6% than Ijero clay of 3.3% in the range of 3-4%) while Ilukuno clay is cohesionless. Determination of the specific gravity and /or the density of clays is made to enable appropriate design of the beneficiating equipment for removal of the non-clay fractions. The results indicate that the Ara clay of the highest specific gravity (2) and most dense of the clays while Ilukuno clay is light and of lower density.

Kaolinite was the dominant clay mineral in the samples and represented about 97% overall. (Fig.7(a,b,c) and Table 4) Illite and montmorillonite occured in traces in Ijero samples but were completely absent in Ilukuno whitish clay. Of the clay minerals, kaolinite alone constituted a range of values between 54.2% and 91.3% in the samples. The investigation shows that the average kaolinite contents were higher in Ilukuno (91.3%) and Ara (86.1%) than in Ijero (54.2%). However, montmorillonite had a 6.4% abundance in Ara samples while illite was absent. K-feldspar and quartz were the major non-clay constituents identified in the diffractograms. K-feldspar was present in the range of 5.7% - 38% while quartz was present in the range of 3.0% - 7.8%. The amount of K-feldspar was higher in Ijero (38.0%) than in Ilukuno (5.7%) whereas it was completely absent in Ara samples. The

Table 4. Mineralogical composition of the clay samples (** = representative values for 10 samples from each location)

Minerals	Ijero*	Ara*	Ilukuno*	Reference samples**				
				i	ii	iii	iv	v
Kaolinite	54.2	86.1	91.3	91	95	85	85	50
Quartz	7.8	7.1	3.0	6	2	tr	4	40
K-feldspar	38.0	-	5.7	-	-	-	3	8
Illite	tr	-	-	3	3	15	-	2
Montmorillonite	tr	6.4	-	-	-	-	-	-
Others	-	0.4	-	-	-	-	8	-

(i) Ibadan kaolinite(Emofurieta and Salami,1988), (ii) Kankara-Kaduna kaolinite (Emofurieta and Salami, 1988); (iii) China clay (Huber, 1985), (iv) ref: NAFCON (1985); (v) Isan brown clay (Elueze and Bolarinwa, 1995);***** = adapted from Emofurieta *et al.* (1992)

Table 5. Chemical composition of clays compared with references and industrial specifications

				References (A)					Industrial specifications (B)					
Oxides	Ijero*	Ara*	lluno*	i	ii	iii	iv	v	i	ii	iii	iv	v	vi
SiO_2	50.97	51.95	44.63	44.98	55.49	45.47	49.88	57.67	49.88	47.00	44.90	45.00	67.50	46.07
Al_2O_3	23.19	22.42	40.38	37.54	18.63	38.45	37.65	24.00	37.65	40.00	32.35	38.10	26.50	38.07
Fe_2O_3 (F)	7.29	7.718	0.26	2.35	9.67	0.75	0.88	3.23	0.88	-	0.43	0.60	0.50	0.33
MnO (M)	0.116	0.042	0.014	0.007	0.04	-	-	-	-	-	tr	-	1.20	-
MgO	1.464	0.763	0.205	1.72	1.25	0.05	0.13	0.30	0.13	-	tr	-	0.19	0.01
CaO	0.24	0.234	0.073	0.09	0.77	-	0.03	0.70	0.03	-	tr	-	0.30	0.38
Na_2O	0.669	0.186	0.036	0.19	0.46	-	0.21	0.20	0.21	-	0.14	-	1.50	0.27
K_2O	3.197	2.86	0.523	1.01	1.84	0.06	1.60	0.50	1.60	-	0.28	-	3.10	0.43
TiO_2 (T)	0.987	1.246	0.13	1.42	-	0.10	0.09	-	0.09	-	1.80	1.70	-	0.50
P_2O_5	0.123	0.085	0.039	-	-	-	-	-	-	-	-	-	-	-
Cr_2O_3	0.011	0.024	0.01	-	-	-	-	-	-	-	-	-	-	-
LOl	11.47	12.3	14.1	12.60	10.18	-	12.45	10.50	12.45	13.00	14.20	14.70	12.51	13.47
Total	**99.74**	**99.82**	**100**	**99.91**	**98.33**	**84.98**	**99.92**	**-97.10**	**99.92**	**-**	**-**	**-**	**-**	**99.93**
K_2O\Na_2O	3.87	3.05	0.56	1.20		0.60	1.81	0.70	7.6		0.02		2.06	1.59
F+M+T	9.74	9.72	1.36			0.90	1.10	3.53	0.97		2.23	2.30	1.70	0.83
pH	5.9	6.2	6.7		6.5									

* = average values for 10 samples; A: i. Ibadan kaolin (Emofurieta and Salami, 1988); ii. Isan brown clay (Elueze and Bolarinwa, 1995); iii. Florida non-active kaolinite; iv. China clay GTY; v. Plastic fire clay. (iii-v, Huber, 1985); B: 1, i. agricultural (Huber, 1985); ii. pharmaceutical (Todd, 1975); iii. rubber (Keller, 1964); iv. textile (Keller, 1964); 2. v. ceramics (Singer and Sonja, 1971); vi. fertilizer, (NAFCON, 1985); B: adapted from Emofurieta *et al.* (1992).

occurrence of K-feldspar in Ijero and Ilukuno samples was indicative of incomplete weathering process. This is evident in the non-determinability of plasticity for some Ijero and all Ilukuno samples.

Concentration of quartz was 7.8% in Ijero and 7.1% in Ara clays while Ilukuno recorded a lower value of 3.0%.

A simple comparison of the mineralogical compositions of the clays with those of some well-known kaolin deposits, indicate that the investigated clay deposits are somewhat similar to some notable ones (Table 5). For example, the Ilukuno clay is similar to the Ibadan and Kaduna (Kankara) clays except K-feldspar content of 5.7%. The Ijero sample is similar to Isan brown clay and with higher kaolinite value, though the latter has higher quartz (40%) value but the former also has relatively high K-feldspar (38%) content. The Ara samples compare favourably with the China clay and the specifications of NAFCON (1985), except for a little deviation in montmorillonite (6.4%) and quartz contents (7.1%).

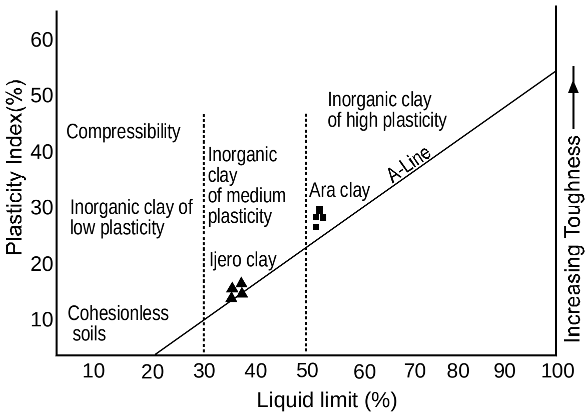


Fig. 5. Plasticity chart for the classification of clay deposits (Casagrande, 1948).

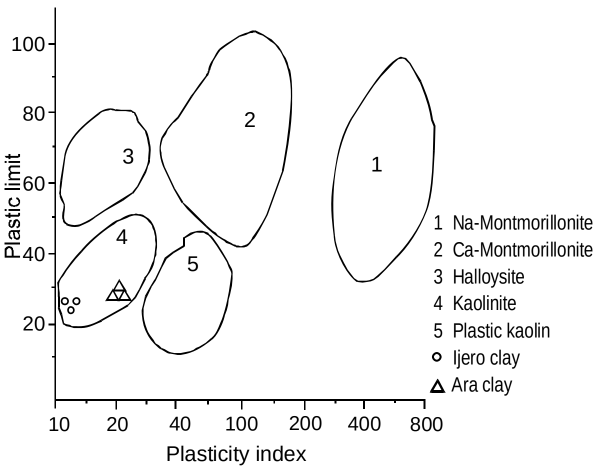


Fig. 6. Clay identification chart using plastic limit and plasticity index as parameter (Bain, 1971).

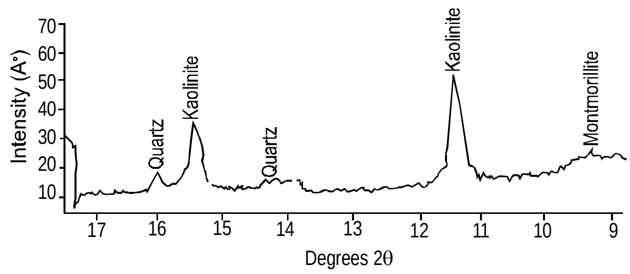


Fig. 7a. X-ray traces for Ara clay sample.

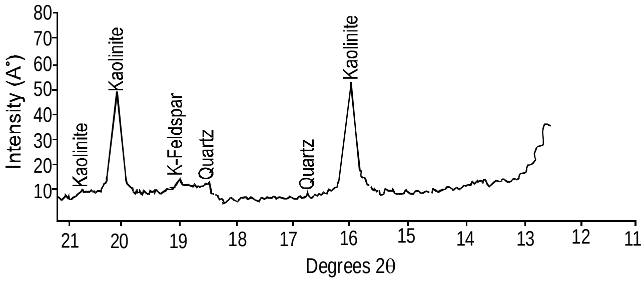


Fig. 7b. X-ray traces for Ilukuno clay sample.

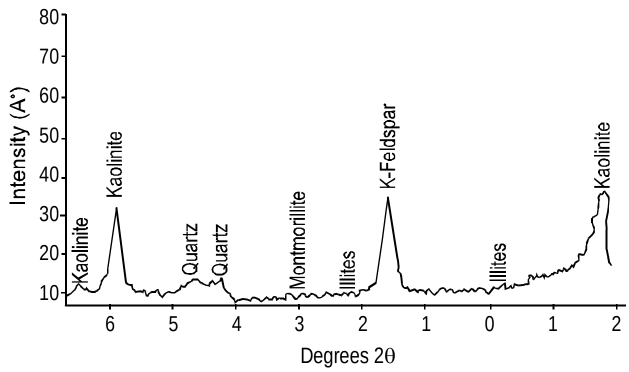


Fig. 7c. X-ray traces for Ijero clay sample.

The dominance of SiO_2, Al_2O_3 and H_2O^+ Loss on igtition (LOI) of the clay samples clearly define them as hydrated alumino-silicates. An overview of the chemical analyses shows, for example, that the Ijero clay sample has an average SiO_2, Al_2O_3 and H_2O^+ contents of 50.97%, 23.19% and 11.47%, respectively; of Ara sample has corresponding average values of 51.95%, 22.42% and 12.30%, while IIukuno sample has 44.63% silica, 40.38% alumina and 14.39% (Loi) on ignition. A close observation of these compositions reveals that the Ijero deposit is geochemically similar to Ara deposit. The mean pH values of 6.7 (Ilukuno) and 6.2 (Ara) suggest a slightly acidic environment of formation. The Ilukuno variety, which is more aluminous and slightly less siliceous, has an average pH value of 6.7, geochemically signifying almost neutral environment. An essentially neutral to acidic environment suggests low concentration of the oxides: CaO, Na_2O and MgO in the clay compositions due to leaching away of bases. The notable disparities between the chemistry of Ijero and Ara clays on one hand and that of Ilukuno whitish clay on the other are attributable to the differences in their environment of formation and deposition as is evident by their pH values.

A cursory overview of the chemical and mineralogical compositions of the surrounding basement rocks e.g., the pegmatised schists at Ijero, the granite gneiss at Ara and the pegmatites at Ilukuno show a striking similarity to those of the clay deposits. Moreover, the residual clay deposits are found resting as a mantle on fresh basement rocks. This implies that they originated from such underlying basement rocks, through chemical weathering *in situ.*

The average iron oxide content of Ijero was 7.29% and that of Ara was 7.72%. The duo is significantly higher in values than that of Ilukuno (0.26%). The iron oxide in these samples can be attributed to the possible breakdown of biotite, augite and other ferromagnesium minerals of the precursor rocks. There is also a significant difference in MgO content in Ijero clay (1.46%) whose average value is almost double that of Ara clay (0.76%) while that of Ilukuno clay lag behind with an average of 0.21%. Other oxides like Cr_2O_3 and P_2O_5 are generally low, more or less in traces in the three deposits with less than 0.1% on an average. The potash grades in abundance from Ilukuno (0.52%) to Ara (2.86%) and Ijero (3.19%) deposits. The average SiO_2: Al_2O_3 ratio of 1.1 for Ilukuno is significantly low as compared to 2.3 and 3.9 for Ijero and Ara deposits, respectively. The ratio of silica:alumina in clays in relation to bleaching has been studied and was applied by Amozie *et al.* (1993), who they established that kaolinitic clays whose silica:alumina ratio is 3 and above are fairly good bleaching agents while those with ratio between 2.0 and 2.7 bleach poorly, and those with 2.0 and below bleach very poorly. The ratio of SiO_2: Al_2O_3 of some samples from Ara clay are more than 3 while some from Ijero clay have value of 2 and above. This ratio in Ilukuno clay is < 2. Consequently, only Ara and Ijero clays in their natural state could serve as bleaching agents for treating palm oil and other similar products that require bleaching.

Furthermore, the average values for the sum of (K_2O + Na_2O) and (Fe_2O_3 + MgO +TiO_2) for Ara (3.1 % and 9.7%) and Ijero (3.9% and 9.7%) clays, respectively, are high while that of the Ilukuno (0.55 and 1.36) whitish kaolinite compares very well with China clay and the Florida non-active kaolinite. The implication of this is that the clays are chemically inert and non-corrosive (Emofurieta and Salami, 1988).

In view of the physical, chemical and mineralogical investigations of these clays, their use in manufacture of high-temperature general-purpose porcelain products is recommended. The Ilukuno clay lacks montmorillonite and illite that often contain alkali and alkaline earth ions capable of reducing refractory property. At very high temperature, kaolinite is converted to mullite and cristobalite which are very good refractory minerals. In view of the characteristics of Ilukuno clay, a good blend of a raw mix of Ilukuno, Ara and Ijero clays will be suitable for refractory products which are used for lining furnaces and kilns to withstand high temperatures. Oyinloye (1997) had reiterated the need to produce refractories in large quantities to meet the robust demand of Nigerian Steel Industries in order to reduce importation of refractories and thereby conserve foreign exchange earnings. This will in turn encourage the development of local industries. Other products for which the whitish Ilukuno clay could serve as raw material are electronic appliances such as switch base, spark plug, cup, jug and toilet wares etc.

Abundance of kaolinite in the samples indicates dominant contribution of Al_2O_3 as the presence of alumina and silica contents is the direct reflection of general purity of the clay deposits. The general low contents of TiO_2 (average 0.3% - 1.24%), MgO (average 0.21-1.47%), Na_2O (average 0.04-0.62%), P_2O_5 (average 0.04-0.1%), Cr_2O_3 (average 0.01-0.02%) and K_2O (average 0.52-3.2%) are further indications of the purity of clays; these values fall within reasonable limits of those of China clay. On the whole, the mineralogical compositions of the investigated clay deposits satisfy agricultural specifications (NAFCON, 1985). The kaolinitic clays possess certain specific properties: plasticity (where present), appropriate shrinkage to avoid cracks during drying and green strength to permit handling which make them suitable for ceramic products. A raw mix with right proportion of the three clays can fulfil specific requirements i.e., Ilukuno clay may provide aesthetic colouration, Ara clay the desired plasticity, drying strength and shrinkage quality and Ijero clay may provide the feldspar quantity needed for fluxing and vitreous binding effect often required in ceramics.

Murray (2002) observed that 45% of the world production of kaolin goes into paper filling and coating. According to Murray (2002), kaolin which consists mainly of the mineral kaolinite, is uniquely suited for this use because of its fine particle size, good viscosity, low abrasion, good opacity, white colour, high brightness and good print quality. The Ilukuno white clay is obviously suitable for this application considering, among other qualities its high percentage of kaolinite, purity (iron content<1.50%) and all other oxides in less than 0.1% concentration plus its low specific gravity. For this purpose, Ilukuno whitish clay simply requires a minimum beneficiation process to remove the non-clayey and coarse fractions. Kaolinitic clay, in particular, forms slurry when added to water because it distributes itself evenly throughout the water. The paint industry adopts the advantage of this property of clay to disperse pigment (colour) evenly throughout the paint. Without the clay to act as a carrier, it would be difficult to evenly mix the paint base and colour pigment. Ilukuno clay stands out to meet this particular and peculiar application. The unique purity of Ilukuno clay will most likely make it attractive to the pharmaceutical industry as raw material for the preparation of certain drugs, notably those that are used in the treatment of stomach disorders and those for which it could serve as carrier because it is non-corrosive, chemically inert and fit for human consumption. Clays are important vehicle for transporting and widely dispersing contaminants from one area to another. For this purpose, clays with montmorrillonites such as Ara type are suitable because of a net charge deficiency that exists in its structure. Thus it can be used as a carrier for pesticides. The geochemistry of the clays reveals high composition of alumina; this can be extracted for the production of fertilizer and animal feeds and other products in which high alumina content is desired.

Buckley (2003) observed that kaolinitic clays of any particular specification, for a wide variety of end use can be made by beneficiation and /or blending of different types of kaolin. Experts in the clay industry established that common refractory materials lack plasticity, so plastic clay must be used to help in forming, shaping and retention and to impact necessary strength. Kaolinitic clays are the most important from the commercial point of view because they meet the requirements of high-grade ceramic products. In the refractory industry, kaolinite is very important because of its high proportion of alumina. Kaolinitic clays are traditionally used worldwide for refractory, ceramic and pottery works.

Notable industrial properties evaluated include thermal characteristics, specific gravity, consistency limits, firing colour, pH and water absorption capacity. The above results and discussion generally, imply that the clay deposits are mainly composed of kaolinite; the design of an appropriate beneficiation processes such as removal of Fe_2O_3 and other constituent impurities (especially from Ijero and Ara depo-sits) would enhance Al_2O_3 and depreciate the abundance of SiO_2. The obtained clays would meet industrial requirements, and thus indicate good promise for industrial utilization.

World consumption rate of kaolinite increases yearly. It is therefore recommended that further investigations be carried out to ascertain the extent and reserves of these clay deposits particularly the Ilukuno white clay of which no record of previous study and reserve estimates are available.

Conclusion

The results of mineralogical analyses indicate that the Ijero clay deposits are all residual kaolinitic clay deposits. Chemical analyses reveal a preponderance of silica, alumina and iron in the deposits. This reflects their derivation from the underlying basement rocks through *in situ* weathering. The Ilukuno clay deposit, being described for the first time, is non plastic, friable, contains low quartz compared with the others and fires white. On the bases of the chemical, mineralogical and physical characteristics of the clays, described in the text here, they seem suitable raw materials for the manufacture of paints, ceramic refractories, pharmaceutical and agro-chemical products, and for use as fillers in paper and structural bricks. In the manufacture of the above products, the clays can be mixed in appropriate proportions with specific amount of additives so as to produce the desired finished products.

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