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MINERALOGY AND CERAMIC PROPERTIES OF LATERITIC CLAYS DERIVED FROM BASEMENT COMPLEX ROCKS IN IBADAN AREA, SOUTHWESTERN NIGERIA

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ABSTRACT

Lateritic clays derived from weathered basement complex rocks around Ibadan, were subjected to mineralogical and ceramic property tests to characterize them for production of ceramics The results of the study show that the clay bodies consist essentially of kaolinite with admixtures of minor or trace amounts of halloysite, illite and vermiculite. Although the clays and their ceramic products exhibit highly variable properties, they can be divided into four types (A, B, C and D) on the basis of plasticity, workability and quality of fired products

The type A is characterized by high plasticity, workability, and casting slip water limit as well as by low greenware and firing linear shrinkage and low water absorption capacity. This type of clay, which occurs at Apomu, 9 km east of Ibadan, is suitable for bricks, tile, sewer pipes, pottery and stoneware The type B clay, found at Aba Ajao and Alapako, also has high plasticity, but it differs from type A by having medium greenware and firing linear shrinkages and low to high water absorption capacity These clay bodies are thus suitable for pottery and for bonding in foundries The type C comprises clays of medium plasticity and of nil to medium drying and firing shrinkages and could be used for refractories, stoneware and pottery This clay type exists at Abanla, Seko and Orisumbare The clays of the type D have low plasticity and low to medium drying and firing shrinkages and are only useful for refractories if blended with more plastic clays These are located at Podo (Ibadan Toll gate), Alapako North and an area some 6 km east of Ibadan on the Ibadan-Ife Expressway

KEYWORDS: Lateritic clays, ceramics, mineralogy, ceramic properties

INTRODUCTION

Within the last three decades, Nigerian entrepreneurs have shown greater interest than ever before in setting up ceramic industry. This is apparently in response to Government's incentives to industrialists who are interested in establishing domestic industries that are based on locally sourced raw materials It is therefore not surprising that within the period there is an upsurge in the quest for information on clays suitable for establishing ceramic industry in Ibadan area. It is also noteworthy that a few ceramic works have actually sprung up in the area. Consequently, this study was undertaken to assess the ceramic qualities of selected lateritic clays deposits within a radius of 30 km of the Ibadan metropolis (Fig. 1) The choice of sites for investigation was greatly influenced by accessibility to major roads through which the clays can be transported to Ibadan

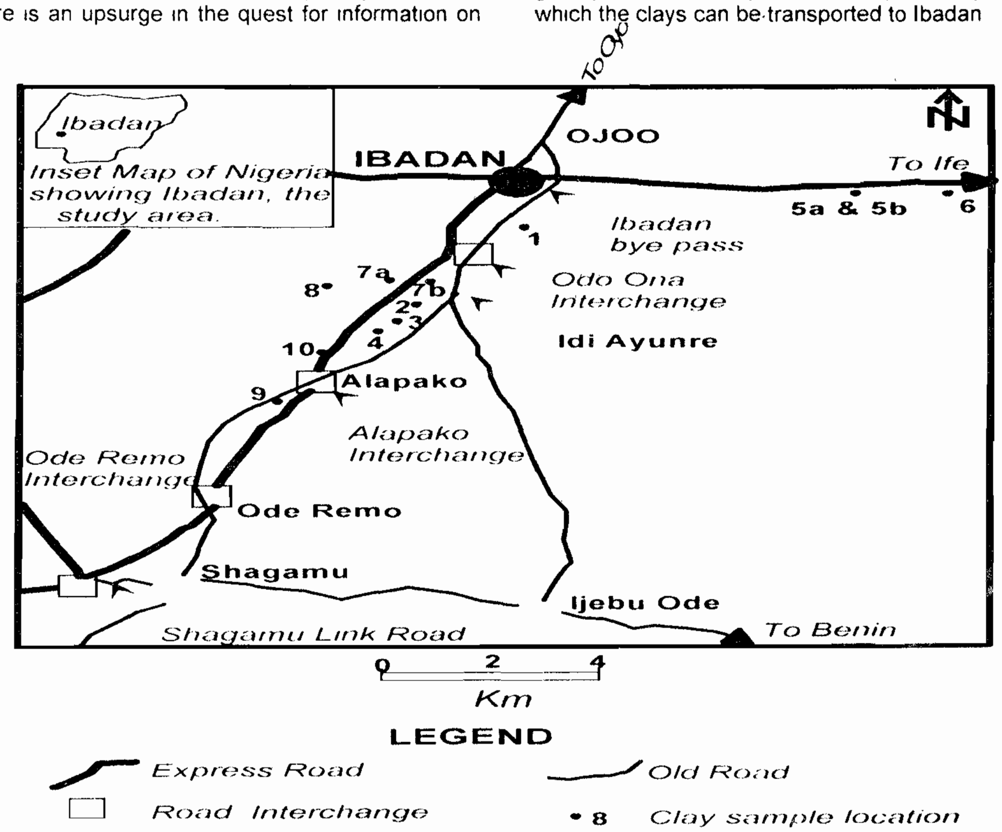

Figure 1 Location map of the investigated clay bodies

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GEOLOGICAL SETTING

The Ibadan area is located within the southwestern Nigeria basement complex, which has been mapped and described by Jones and Hockey (1964). In the area, a gneiss-migmatite complex is the dominant rock type, which is interbanded by quartzite and augen granite gneiss in places particularly within Ibadan Township. Intrusions of the Older granites, pegmatites and dolerite dykes commonly cut through the gneiss-migmatite-quartzite complex (Fig. 2).

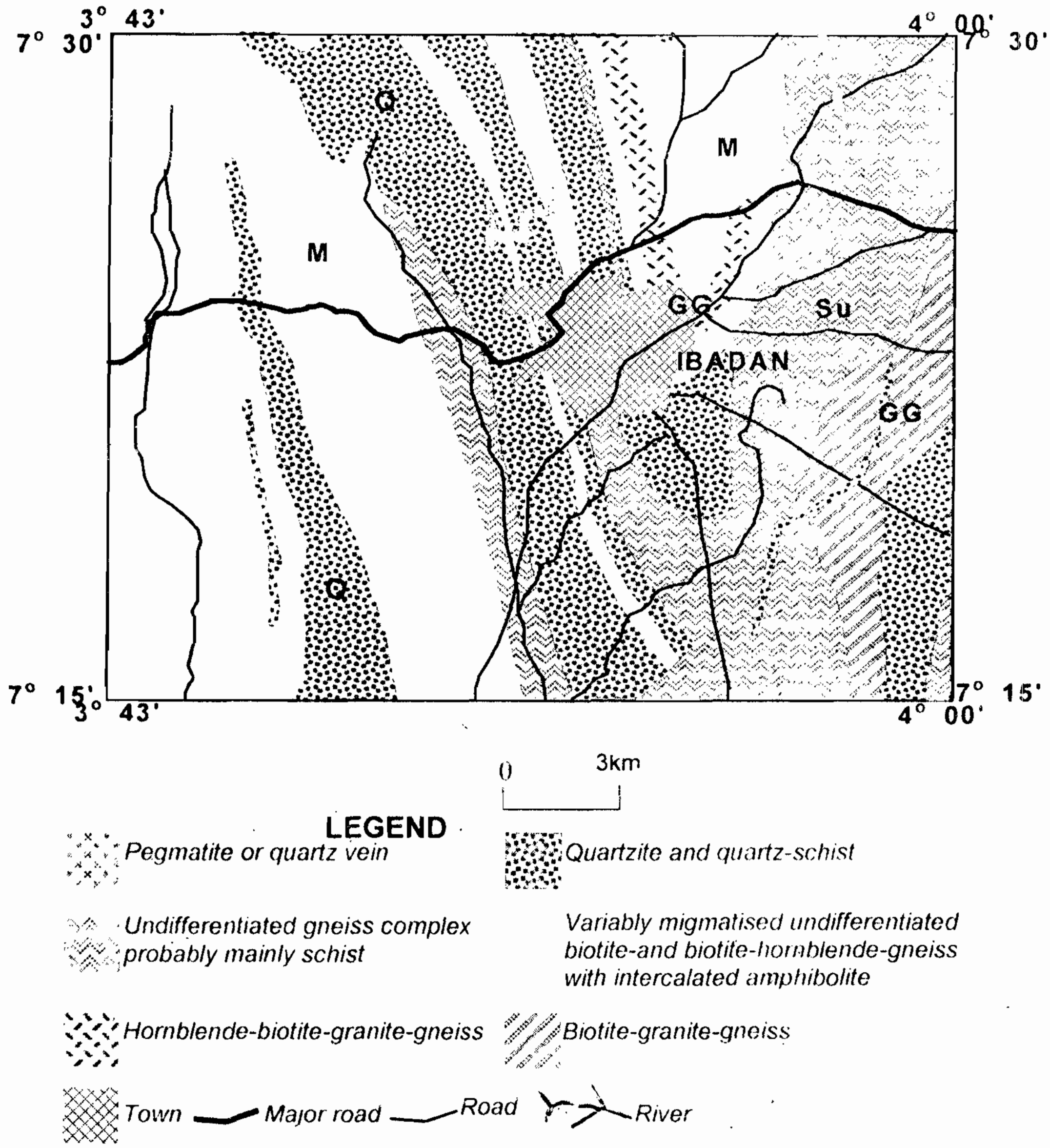

Figure 2: Geological map of Ibadan area (after Jones and Hockey, 1964)

All the basement complex rocks have undergone intense tropical weathering producing deep soil profiles especially in the area underlain by gneisses and migmatites. Three types of soil profile have been recognized in the study area. They include lateritized or duricrust, unlateritized or kaolinized (krasnozem) and transported or detrital soil profiles (Burke and Durotoye, 1972; Adekoya, 1987). The first two profiles are residual, being formed by *in situ* chemical breakdown of the basement complex rocks. They both contain a mottled zone, which is usually clay-rich and is therefore a primary target of this study. Road cuts, laterite quarries and borrow pits in the area have revealed that the clay-rich zone particularly in the unlateritized profile of the hilly areas is up to 70 m thick. All the samples for this study are collected from the clay-rich zone

FIELDWORK

Ten clay occurrences located around Ibadan-Lagos and Ibadan-Ife express roads were visited and sampled for laboratory study (Fig. 1). The samples (about 20 kg each) were taken by the channel sampling technique from either road cuts or shallow (maximum 2 m deep) pits dug for that purpose. The fieldwork also involved a reconnaissance survey of the clay occurrences aimed at estimating roughly the probable reserves of the clay available in each site (Table 1). The rationale behind this is to ensure that only deposits that contained a minimum quantity of raw materials to support at least a small-scale ceramic industry are characterised

Table 1: Localities and Reserve Estimates of Clay bodies.

Samp. No.	Claybody locality	Reserve Estimate (in million ton)
S01	Ibadan Tollgate Hill	0.5
S02	Abanla South	1.5
S03	Abanla North	1.2
S04	Seko area	0.7
S05A	Ife-Ibadan Road 1	1.3
S05B	Ife-Ibadan Road 2	1.3
S06	Apomu area	2.8
S07A	Aba Ajao North	1.1
S07B	Aba Ajao South	1.1
S08	Orisumbare	0.8
S09	Alapako	1.6
S10	Alapako North	1.2

LABORATORY TESTS

Mineralogical Determination

The laboratory tests performed included the determination of mineralogical composition and ceramic properties of the collected samples.

For the determination of the mineralogy, samples of the clay bodies were studied by X-ray diffractometry (XRD) in the X-ray Diffractometer Laboratory of The Polytechnic, Ibadan, Nigeria. These samples were taken from air-dried 63-micron sieved portions of the clay materials and dispersed in distilled water. Some drops of the clay suspensions were put on glass slides and left to dry up without heating. Thereafter, the slides were introduced one after the other into a Phillips PW 1011 diffractometer with Iron (FeKα) radiation generated at 28 kv and 12 mA, while the instrument was set at a scanning rate, time constant and range of 2°θ/min/cm, 4 s and 4 × 10° cps, respectively.

Ceramic Tests

For the determination of the ceramic properties, the clay samples were sieved with a locally made 60-mesh sieve in the ceramic laboratory. The sieved samples were thoroughly kneaded with water until they formed smooth pastes, which were then subjected to ceramic tests using the procedure of Jolyon (1974). The ceramic tests included firing, shrinkage, plasticity, workability, casting slip water limit, tile and water absorption tests. For the purpose of classifying the clays, the Atterberg limits of the clays were also determined. The procedure employed for these various tests are explained below.

Firing test

Portions (about 1 kg each) of the kneaded clay samples were moulded into small open bowls (Fig 3) and air-dried under room temperature for two weeks after which they were subjected to firing in a kiln in two stages. First, the samples were fired to a temperature of 110° C for a period of 24 hours and were subsequently withdrawn to cool down completely. Two days later, they were again subjected to controlled firing to 800° C initially and later up to 1000° C for a total period of 48 hours.

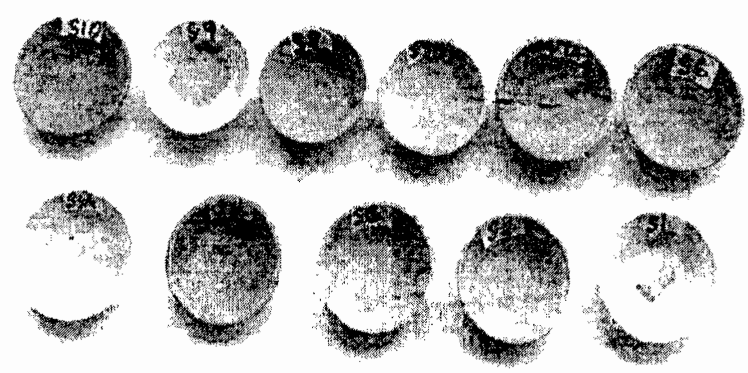

Figure 3 Small open bowl moulds of the kneaded clay samples

The colour of each clay sample before and after firing was noted. The fireability of the clays was reckoned as good or bad depending on the absence or presence of cracks after firing to 1000° C.

Shrinkage test

Two shrinkage tests were conducted on the clay samples, the greenware (drying) and terracotta (firing) linear shrinkage tests. For the greenware shrinkage test, small rectangular slabs measuring exactly 7 × 4 cm were made from the clay samples at the leather-hard stage (Fig 4). The slabs were left to dry under room temperature for two weeks after which their lengths were measured again. The difference between the original and new lengths of the slabs represents the greenware shrinkage expressed in percent.

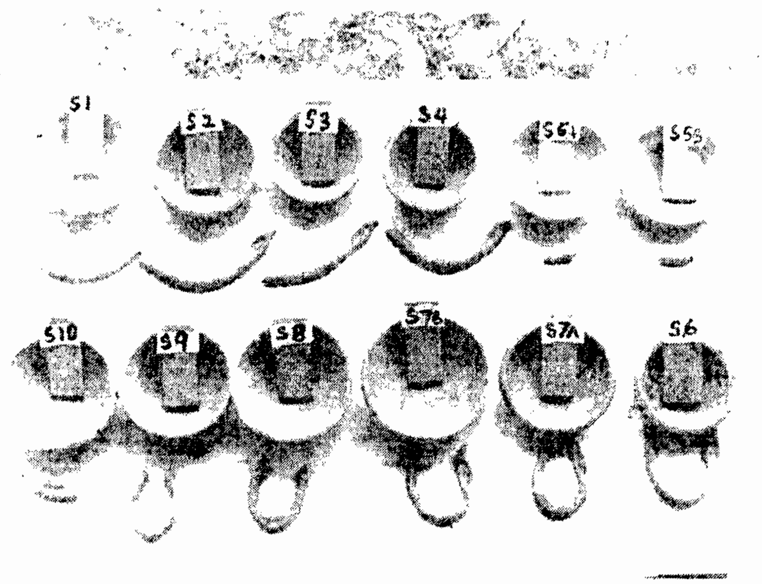

Figure 4. Small rectangular slabs (inside the respective sample bowls) used for greenware shrinkage test and threads (coils on the floor beside the respective sample bowls) used for plasticity test

The terracotta shrinkage test was done on the greenware slabs by subjecting them to firing in the kiln at a temperature of 110° C for 12 hours Subsequently, the firing was gradually increased to 800° C and later to 1000° C for 9 hours The difference in length of the slabs at the greenware and terracotta stages was recorded as the linear shrinkage expressed in percent

Plasticity test

For this test a small quantity of each of the clay samples was rolled into a thread of 15 cm long and 1 cm thick and then bent into a coil (Fig 4) The amount of coil curvature obtained without breaking was used as a yardstick of the clay plasticity When the thread was bent end to end without breaking, the plasticity was reckoned as 100 % Where the two ends of the clay threads could not meet without breaking, their plasticity was determined by measuring the distance between the two ends of each coil (Fig 4) and computing this as a percentage of the total length of the coil. When a clay sample could not be rolled into a bendable thread, its plasticity was recorded as nil

Workability test

To a ceramist the workability of clay is a function of its plasticity. By a rule of thumb, very plastic clay is reckoned as 100 % workable and non-plastic clay is non-workable and has zero workability The workability of the clay samples was determined on the wheel during throwing It was based on a skillful estimation in percent of a combination of the following clay characteristics during the wheel operations

(a) the speed with which the clay could be pulled at throwing,
(b) the height obtainable at throwing and extent of its pulling strength and
(c) reaction or sensitivity of the clay to water during lubrication

Casting Slip Water Limit test

Five kilograms of each air-dried clay sample was weighed into a container Regulated amounts of water were added to the clay gradually while the mixture was stirred to allow blending and formation of a good suspension The amount of water required for each clay suspension was recorded The suspensions were used for casting and the results of the casting were recorded as good, fair or poor

Tile test

Three different methods can be used for tile production Some ceramists cast in slip, others cast by pressing the clay into moulds, and still others use powdered clay in press moulds In this investigation the tile was made by pressing the clay into a mould of internal dimensions of 15 cm × 10 cm To achieve this, 1 kg each of the air-dried sieved clay samples was kneaded with water until it reached a leather-hard stage The samples were then pressed into the moulds and left to dry for two weeks to obtain the greenware tiles (Fig 5), which were later subjected to controlled firing up to 1000°C The greenware and terracotta tiles were assessed as good, fair or poor depending on the absence or density of cracks in them

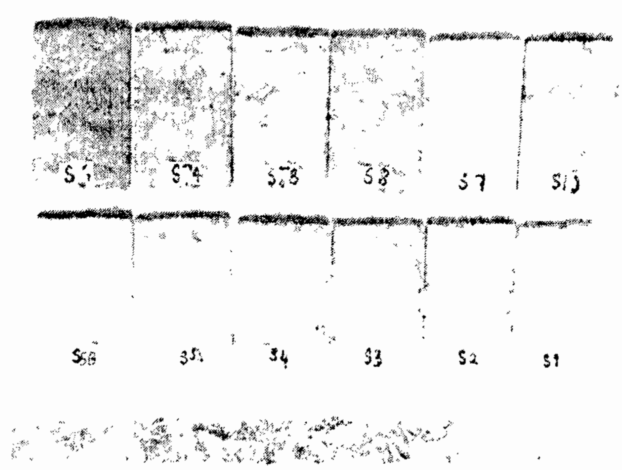

Figure 5 Greenware tile moulds used for the tile test

Water Absorption test

The terracotta pieces, which were fired at 1000°C, were subjected to the water absorption test after cooling for five days. The test involved determining the water absorption time of and the amount of water absorbed by the terracotta bowl pieces. For the former test, each terracotta bowl was immersed in water until the hissing sound of water absorption ceased and no air bubbles came out of the pottery. The time it took each terracotta piece to attain this water saturation point was recorded. In the case of the second test, the amount of water absorbed by each terracotta piece was determined by weighing it before and after immersion in water for 6 hours.

Atterberg limits test

The tests involved the determination of the liquid and plastic limits according to the standard laboratory procedures specified by the ASTMD 423 – 66 and D 424 – 59 standards.

RESULTS

Table 2: Clay Mineralogy of the Claybodies

Samp. No.	Claybody locality	Clay Mineralogy
S01	Ibadan Tollgate Hill	Kaolinite, minor halloysite
S02	Abanla South	Kaolinite, minor halloysite and vermiculite
S03	Abanla North	Kaolinite, minor vermiculite and illite
S04	Seko area	Kaolinite, minor halloysite
S05A	Ife-Ibadan Road 1	Kaolinite, minor halloysite and traces of vermiculite
S05B	Ife-Ibadan Road 2	Kaolinite, minor vermiculite
S06	Apomu area	Kaolinite, minor illite
S07A	Aba Ajao North	Kaolinite, minor vermiculite and illite
S07B	Aba Ajao South	Kaolinite, minor vermiculite and traces of illite
S08	Orisumbare	Kaolinite, minor halloysite
S09	Alapako	Kaolinite, minor illite
S10	Alapako North	Kaolinite, minor halloysite and illite

Table3: Results of the Ceramic Tests

Samp No	Claybody Localities	Fired colour	Firea-bility	Linear Shrinkage		Plasti-city (%)	Worka-bility (%)	Casting Slip Water Limit (%)	Tile Quality		Water Absorption	
				Green Ware (Drying) (%)	Terra-Cotta (Firing) (%)				Green Ware	Terrra Cotta	Water Absorbed (%)	Water Absorption Time (Minutes)
S01	Ibadan Tollgate Hill	Brownish white	Poor	2.9	5.7	12	78	690	Fair	Good	8.5	14
S02	Abanla South	Reddish brown	Good	8.6	Nil	45	96	700	Fair	Good	7	12
S03	Abanla North	Reddish brown	Good	8.6	10.0	45	95	705	Good	Good	13.5	20
S04	Seko area	Reddish brown	Good	7.1	8.6	45	100	690	Poor	Good	10	16
S05A	Ife-Ibadan Road 1	Light brown	Good	5.7	7.1	15	48	650	Poor	Poor	11	15
S05B	Ife-Ibadan Road 2	Light brown	Good	5.0	5.7	Nil	5	600	Good	Fair	11.5	18
S06	Apomu area	Brown	Good	2.9	4.3	100	100	750	Good	Good	11	16
S07A	Aba Ajao North	Brown	Good	8.6	9.3	95	100	750	Fair	Good	9	16
S07B	Aba Ajao South	Reddish brown	Good	7.1	8.6	100	80	750	Fair	Good	14	20
S08	Orisumbare	Reddish brown	Good	8.6	Nil	75	98	750	Good	Good	6	10
S09	Alapako	Brown	Good	7.1	8.6	100	75	650	Good	Good	10	16
S10	Alapako North	Light brown	Good	2.9	5.7	Nil	40	550	Good	Good	12	18

Table 4: Atterberg limits

Sample No.	Claybody Localities	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)
S01	Ibadan Tollgate Hill	45	33	12
S02	Abanla South	51	43	8
S03	Abanla North	40	34	6
S04	Seko area	99	35	24
S05A	Ife-Ibadan Road 1	33.5	27	6
S05B	Ife-Ibadan Road 2	37	26.5	11
S06	Apomu area	42	24	18
S07A	Aba Ajao North	47	25	22
S07B	Aba Ajao South	43	25	17
S08	Orisumbare	45	31	14
S09	Alapako	44	16	28
S10	Alapako North	43	36	7

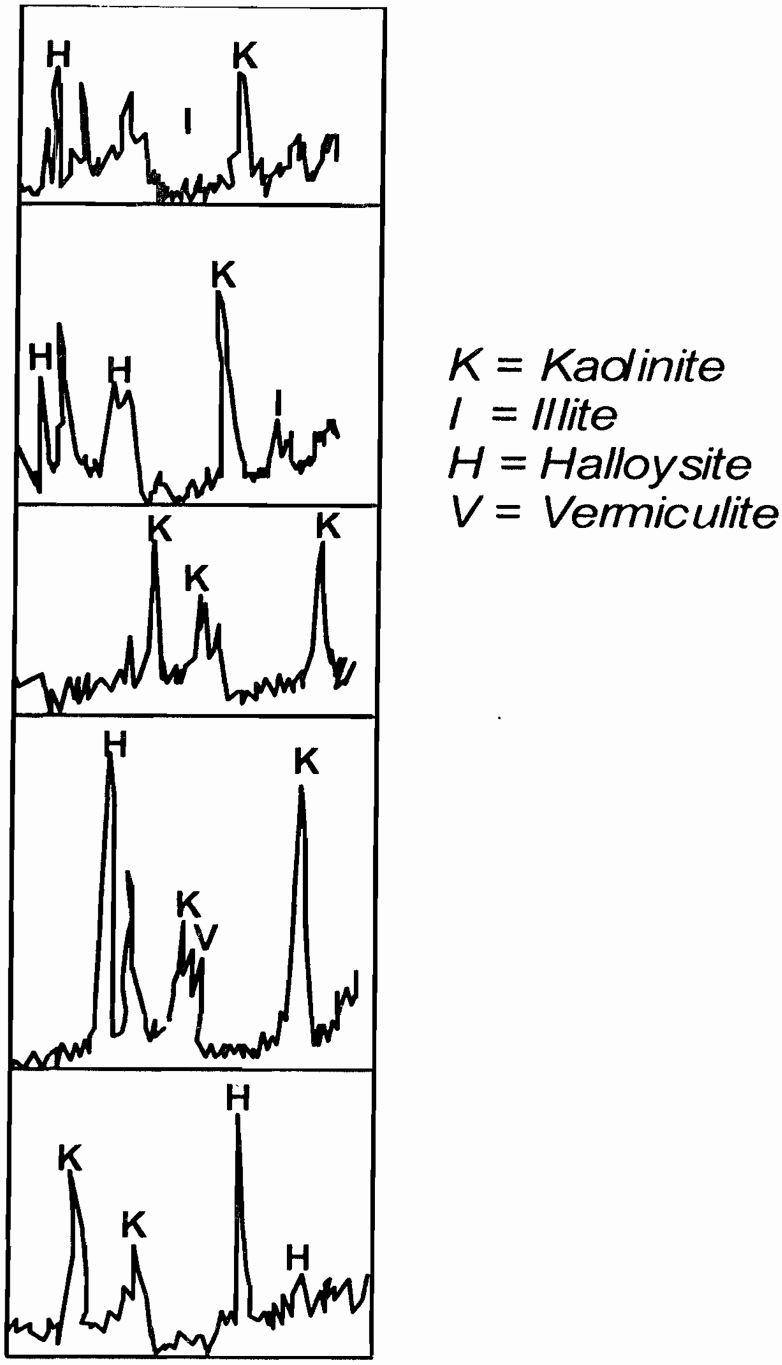

Figure 6 Deffractograms showing the clay mineralogy of selected samples of the clay bodies.

The mineralogy of the clay is presented in Table 2 and Fig 6 These results show that the clay bodies consist essentially of kaolinite with admixtures of minor or trace amounts of halloysite. illite and vermiculite. Other minerals present in the clay are quartz, goethite and muscovite in varying quantities

The results of the various ceramic tests are presented in Table 3 while those of the consistency limits are presented in Table 4. All the clay samples, except sample S01, show good fireability, being devoid of cracks Only minor colour changes occurred after firing the ceramic products, which are in the shades of light brown and red

In general, the linear shrinkage in the greenware pottery ranges from 2.9 % to 8.6 % while that of the fired terracotta pieces varies more widely from 0 to 10 % just like the workability values which range from 5 % to 100 % It is noted that the clays with low plasticity (e.g sample numbers S01, S05A, S05B and S10 from Ibadan Tollgate Hill, Ife-Ibadan Road 1, Ife-Ibadan Road 2 and Alapako North, respectively) generally have lower workability while those with relatively higher plasticity (e.g sample numbers S06, S07A, S07B and S09 from Apomu area, Aba Ajao North, Aba Ajao South and Alapako, respectively) also possess high workability (Tables 3 and 4)

In general, the clay that has high plasticity and, therefore high workability exhibit generally higher casting slip water limits than those of lower plasticity (Table 3) The water absorption capacities of the ceramic products were measured in terms of both water absorption time and amount of water absorbed as a percentage of the weight of the ceramic product While the former varies from 12 to 20 minutes, the later ranges from 6 to 14 % (Table 3) The clays (e.g sample numbers S03, S07A, S07B and S09 from Abanla North, Aba Ajao North, Aba Ajao South and Alapako, respectively) with high terracotta linear shrinkage values tend to have higher water absorption time and capacity

The results of the consistency limits (Table 4) show that the liquid limits of the clay samples vary from 34 to 59 while their plastic limits fall in the range of 16 to 43, resulting in highly variable plasticity index of 6 to 32. These values when plotted on the plasticity chart show that the clays are of no plasticity to medium plasticity (Fig 7)

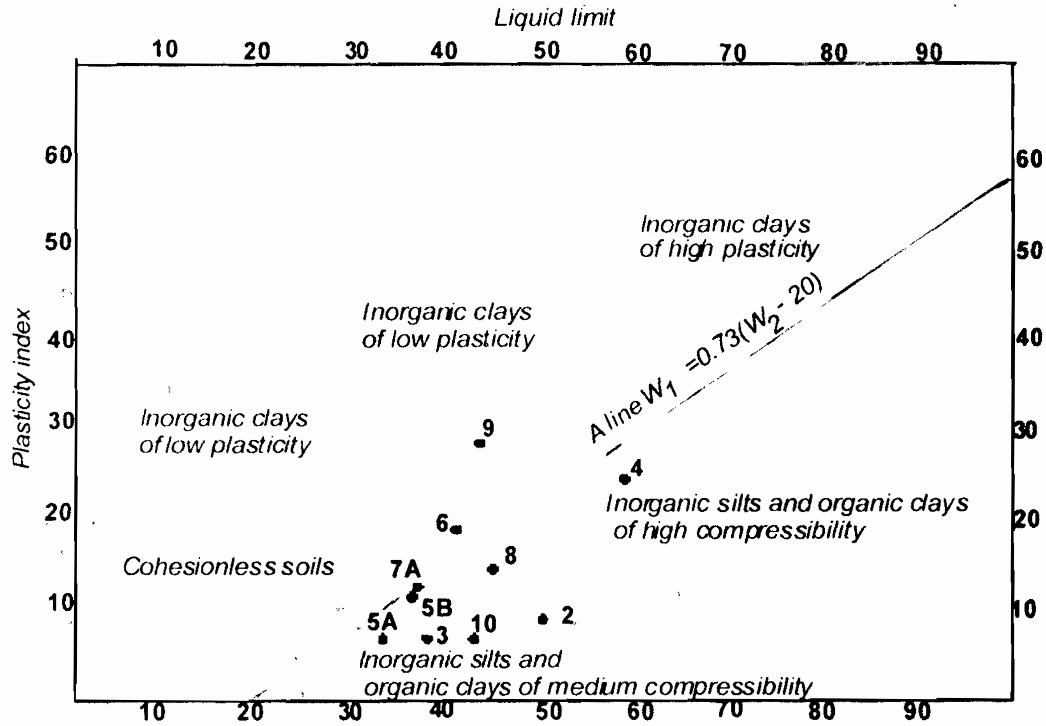

Figure 7 Plotting of the clay samples on the plasticity chart

DISCUSSION AND CONCLUSION

The following criteria were used to determine the suitability of the clays for ceramics

(1) plasticity of the clays,

(2) workability of the clays on the wheel, and

(3) quality of the fired terracotta products, which includes

(a) firing characteristics such as absence or presence of cracks, shrinkage and after-firing colour of products, and

(b) water absorption capacity

On the basis of these criteria the investigated clay bodies can be divided into four broad types (Table 5)

Table 5 Group Characterisation of the Clay bodies

Type	Sample No	Claybody Localities	Characteristics	Assessment Of Ceramic Products
A	S06	Apomu area	High plasticity (> 74 %) High workability (> 74 %) Good firing quality Low firing shrinkage (< 5 %) Low water absorption capacity (< 10 %)	Very good
B	S07A S07B S09	Aba Ajao North Aba Ajao South Alapako	High plasticity (> 74 %) High workability (> 74 %) Good firing quality High drying shrinkage High firing shrinkage (> 5 %) Low to high water absorption capacity	Fair to Good
C	S02 S03 S04 S08	Abanla South Abanla North Seko area Orisumbare	Medium plasticity High workability Nil to high firing shrinkage Low to high water absorption capacity	Poor to Fair
D	S01 S05A S05B S10	Ibadan Tollgate Hill Ife-Ibadan Road 1 Ife-Ibadan Road 2 Alapako North	Little or no plasticity Generally low workability Medium to low drying shrinkage Medium to low firing shrinkage High water absorption capacity	Poor to Fair

The first type (A) consists of clays characterized by high plasticity, workability and firing quality, by low (< 5 %) greenware (drying) and terracotta (firing) linear shrinkages and by low water absorption capacity of the fired products. This category is exemplified by the clay deposits near Apomu (S06). Mineralogical study has revealed that this clay consists mainly of kaolinite and minor illite. It is noteworthy that the best ceramic products (pottery and tiles) were made from the Apomu deposit, the high plasticity of the clay is likely to be related to kaolin crystallinity and the presence of minor illite (Bell, 1983). Bell (1983) observed that poorly crystalline kaolinite of small particles has a substantially higher plasticity than relatively coarse well-cryslallised particles. The high plasticity, low firing shrinkage and the preponderance of kaolinite content of the clay suggest that it has a great potential for wide application in the ceramic industry. It is not only suitable for production of structural ceramics such as bricks, drain tile, sewer pipe, conduit tile terracotta and glazed tile but also for pottery and stoneware. By blending with a small amount of quartz it can also be used for the manufacture of refractories.

The second type (B) shares similarity of high plasticity and workability with the first type but differs from it in having medium (5 – 10 %) drying and firing linear shrinkages, as well as low to high water absorption capacity. The clays of this category, which include Aba Ajao (S07A and S07B) and Alapako (S09) clay bodies, produce ceramic products adjudged to be of fair to good quality. On account of their high plasticity, these clays can be used as bonding clays in foundries (Murray, 1960) and for pottery (Alabo and Odigi, 1989). However, to produce higher quality ceramics from them, there is need to reduce their high plasticity and firing shrinkage through blending with cohesionless granular sand or silt (Akpokodje et al., 1991). Thus the utilization potential of the clay in this group can be enhanced to include production of structural ceramics such as tiles, bricks and sewer pipes, as well as of pottery and stoneware of high quality.

The third type (C) includes clays of medium plasticity and of nil to medium drying and firing shrinkages. When soaked for over a fortnight, the clays showed a high workability on the throwing wheel. The clay bodies from Abanla area on the Ibadan-Salami road and Orisumbare road, off Ibadan Express road (S02, S03, S04 and S08) fall into this category. They produce poor to fair tiles and good bowls. Various uses suggested for clays of similar characteristics include pottery making (Emofurieta et al., 1994), stoneware (Murray, 1960) and refractories.

The clay deposits of the fourth type (D) have either very low or no plasticity and consequently low workability, medium to low drying and firing shrinkages as well as medium to high water absorption capacity. The clay bodies at Toll Gate Hill (S01), Ife-Ibadan Road (S05A and S05B), and Alapako North (S10) exemplify this category. Poor to fair quality tiles and pottery were made from these clay bodies (Figs 3 and 5; Table 1). X-ray studies have revealed that the clays are predominantly kaolinite with minor admixture of halloysite. The physical and mineralogical features of the clay deposits of this group suggest that they can also be used for refractories (Murray, 1960). If these clays are blended with highly plastic ones such as those of types A and B, their potential for ceramic utilization will be greatly improved and will likely be similar to type C clays in behaviour.

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