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Compositional characteristics and industrial assessment of sedimentary clay bodies in part of eastern Dahomey Basin, southwestern Nigeria

M.E. NTON and A.A. ELUEZE
Department of Geology, University of Ibadan, Ibadan

Abstract

Clay bodies occur as lenses and interbeds within the predominantly shaley Akinbo Formation in the eastern Dahomey Basin. They are greenish to grayish, plastic, and in some places contain concretions. In order to assess their sedimentological significance as well as evaluate their potential as industrial raw materials, representative outcrop and borehole samples were subjected to mineralogical, chemical and physical characterisation.

Mineralogical determination by X-ray diffraction (XRD) method, indicates kaolinite as the major clay mineral, with a range of 32.86-58.33%. Other constituents are illite (4.95%), smectite (2.87-14.29%) and palygorskite (2.87%). The non-clay minerals are quartz, K-feldspar, micas and graphite. In terms of chemical composition, the clay bodies are characterized by the following; SiO_2 (52.96-55.84%), Al_2O_3 (16.22-17.74%), Fe_2O_3 (7.13-10.35%); CaO (4.65-7.95%); MgO (2.26-3.98%); while Na_2O, K_2O, MnO, TiO_2 and P_2O_5 have individual values < 1%. The relatively high CaO reflect some contribution from the limestone bed underlying this formation. The clay specimens generally display colour ranging from grayish in fresh, to brownish-red on firing. Corresponding values of physical parameters include linear shrinkage (3.75-7.50%), plastic limit (23-31%), liquid limit (48-56%), plasticity index (21-30%) and water absorption capacity (5.80-11.90%).

The average silica sesquioxide and alumina-iron oxide ratios are respectively 2.17 and 2.08. These values are within the range suitable for clays or shales to be used in the manufacture of good quality cement. The clays have high silica content and are relatively rich in fluxing elements such as Ca and Mg, and could be utilized in the manufacture of domestic and sanitary earth wares. The high plasticity as reflected by the values of the relevant physical indices, and the general fineness qualify the clays to be useful as fillers or coating materials in paper and paint industries. They could also be useful in the production of construction bricks, ceramics, and with beneficiation, the quality might improve for other applications.

Introduction

The Dahomey Basin extends considerably along the continental margin of the Gulf of Guinea, westward from the Volta Delta in Ghana to the Okitipupa Ridge in Nigeria (Fig. 1). It is a marginal sag basin (Kingston et al., 1983) or a marginal pull apart basin (Klemme, 1975), whose development in the Mesozoic (Jurassic – Cretaceous) is associated with the separation of the African and South American lithospheric plates (Burke et al., 1971). The basin contains over 3,000m of Cretaceous to Recent sediments, which thicken from the onshore margin to the offshore (Whiteman, 1982).

Detailed accounts on the geology, stratigraphy and economic potential of the eastern Dahomey Basin have been reported, notably by Jones and Hockey (1964), Omatsola and Adegoke (1981) and Nton (2001). Sediments within the basin, largely comprise conglomerates, sandstone, grit, shale and limestone. Besides these lithologies, other occurrences of economic importance are hydrocarbons, phosphorites, ironstones and clay bodies (Nton 2001).

Several other clay occurrences have been reported in Nigeria. These include lateritic and residual profiles derived from the weathering of basement rocks, especially in the southwestern part of the country (Ajayi and Agagu, 1981; Elueze and Bolarinwa, 1995). In addition, are the sedimentary units and alluvial bodies within the other depositional basins and along the major fluvial channels (Adeleye, 1978; Emofurieta et al., 1992, 1994; Elueze et al., 1999; Elueze and Bolarinwa, 2001).

As observed by Wright et al. (1985), many of the indigenous clay – based projects in West Africa, utilize materials mostly from the younger basins. On the other hand, clay products including ceramic wares, burnt bricks, roofings and floor tiles have been found to be cheaper and more durable building materials than cement, particularly under tropical conditions (Emofurieta et al., 1994). However, it has been observed that in Nigeria, most mineral-based industrial undertakings do not have significant linkage to internal supply of raw materials, due largely to lack of adequate evaluation and development (Adegoke, 1988). There is no doubt that in most developing nations like Nigeria, effective exploitation of local raw materials, notably non-metallic minerals such as clays, constitute a major pre-requisite for sustainable economic growth, creation of employment opportunities and improvement in living standards (Elueze, 1998).

In the eastern Dahomey Basin, the clay bodies occur most prominently within the essentially shaley Akinbo Formation, though not much had been done in appraising their sedimentological significance and economic prospects. Consequently, efforts have been in this study, to examine the mineralogical, chemical and industrial characteristics of these occurrences.

Location and geology of area of study

The study area is within the eastern Dahomey Basin, and lies between latitudes 6°45' to 7°15'N and longitudes 3°00' to 4°00'E. Clay samples were obtained from the Ewekoro quarry, located south of Abeokuta on the Abeokuta-Lagos road, and Somo Well, drilled about 15km west of Sagamu (Fig. 2).

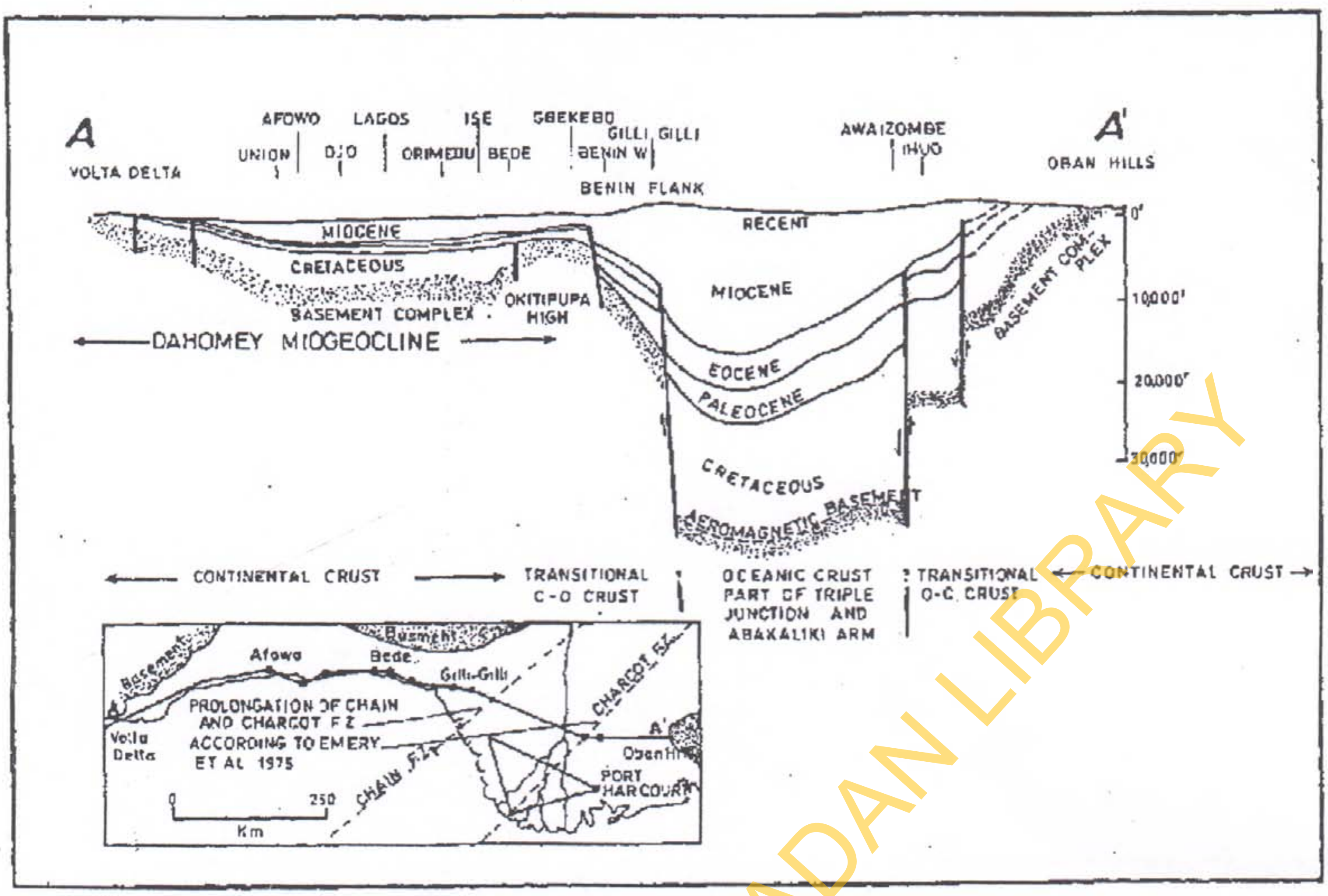

Fig. 1. East-west geological section showing position, extent and sediment thickness variations in the onshore Dahomey Basin and the upper part of the Niger Delta (after Whiteman, 1982)

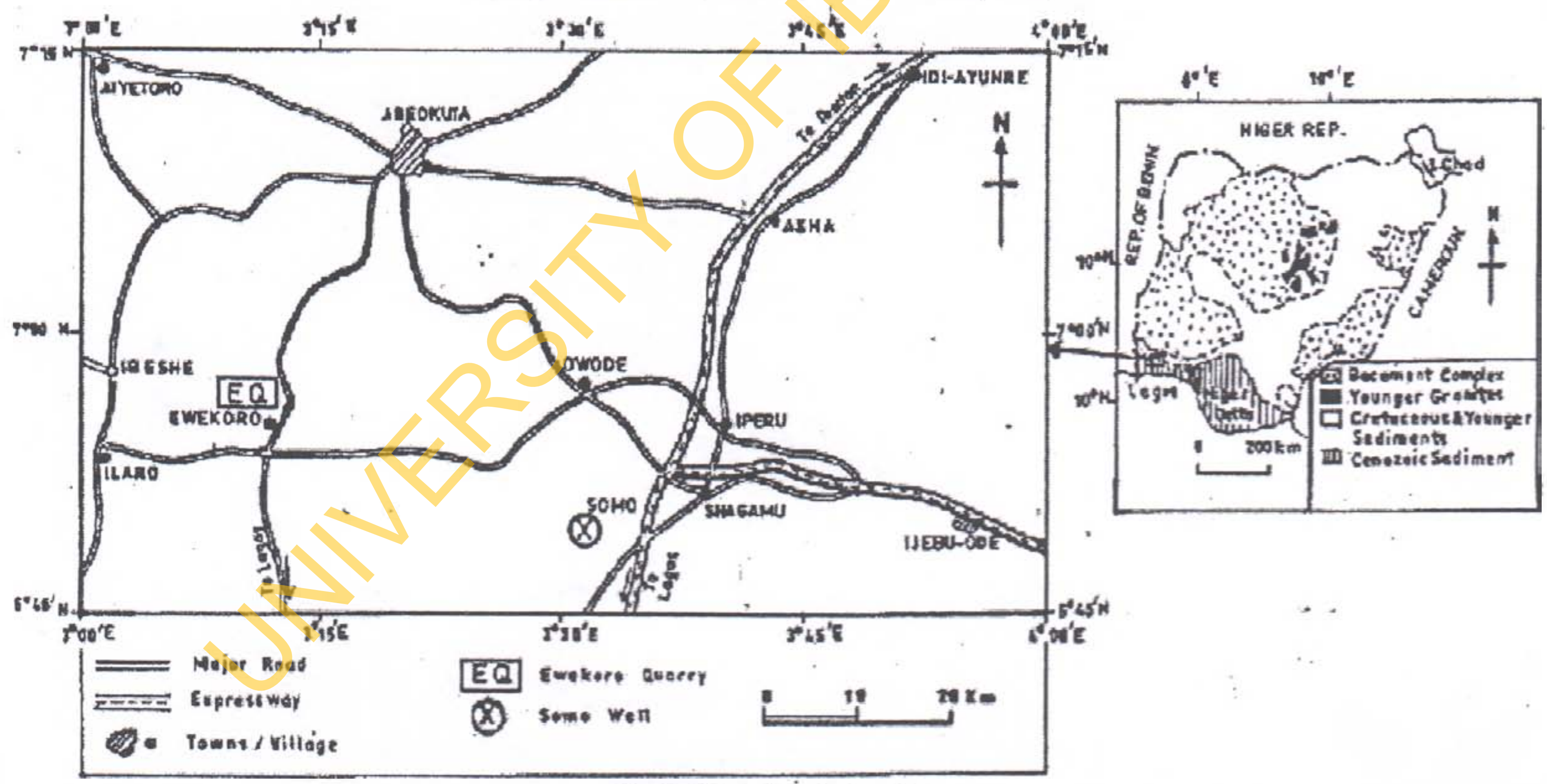

Fig. 2. Map of study location

The stratigraphic description of sediments in the eastern Dahomey Basin has been provided by various authors (Jones and Hockey, 1964; Fayose, 1970; Omatsola and Adegoke, 1981; Nton, 2001; Elueze and Nton, 2004) among others. Omatsola and Adegoke (1981) proposed the Cretaceous stratigraphy of eastern Dahomey basin as beginning with the Ise Formation at the base. This is accordingly succeeded by Afowo, Araromi, Ewekoro and

Akinbo Formations. In addition, above the Akinbo Formation successively are the Oshosun, Ilaro and Benin Formations. These sediments range in age from Neocomian to Recent.

The Ise Formation is made of conglomerates, grits, coarse-grained sandstones and , ironstones with interbedded kaolinitic clays. The overlying Afowo Formation comprised medium grained sandstones with interbedded shale, siltstone and claystone. Medium to fine-grained sandstones at base, overlain by shale and siltstone with interbedded limestone constitute the lithologies of the Araromi Formation. In addition, the shale of Araromi Formation is dark and organic- rich (Nton, 2001; Elueze and Nton; 2004). The Ewekoro Formation, which overlies the Araromi Formation, is essentially a fossiliferous limestone body.

Overlying the Ewekoro Formation is the Akinbo Formation. The name Akinbo Formation was proposed by Ogbe (1972), and comprises shale and clayey sequence with a type locality at the Ewekoro quarry. It is demarcated at the base by a glauconitic band that separates it from the underlying limestone body. At the quarry, the clay occurs as lenses and as interbeds within the predominantly shale lithology (Figs. 3). The shales are greenish grey, fissile, clayey, plastic and gently dipping (<5°) to the southwest (Nton, 2001). In Somo borehole, the clay bodies occur at three intervals within shale lithology (Fig.4).

The Oshosun Formation overlies the Akinbo Formation and consists of greenish – grey or beige clay and shale with interbeds of sandstones. The shale is thickly laminated and glauconitic. According to Okosun (1998), the basal beds consist of any of the following facies; sandstones, mudstones, claystones, clay-shale or shale. This formation is phosphate- bearing (Nton, 2001).

Overlying the Oshosun Formation is the Ilaro Formation, which consists of massive, yellowish poorly, consolidated, cross-bedded sandstones. The youngest stratigraphic sequence in the eastern Dahomey basin is the Benin Formation. It consists of poorly sorted sands with lenses of clays. The sands are in parts cross-bedded and show transitional to continental characteristics. The age is from Oligocene to Recent.

Sampling and analytical methods

Over twenty clay samples were obtained, and subsequently grouped into five composite samples, each representative of the intervals, with 2 from Ewekoro quarry and 3 from Somo Well (Figs. 3 and 4). Mineralogical and chemical analyses were carried out on whole sample and (<2μm)

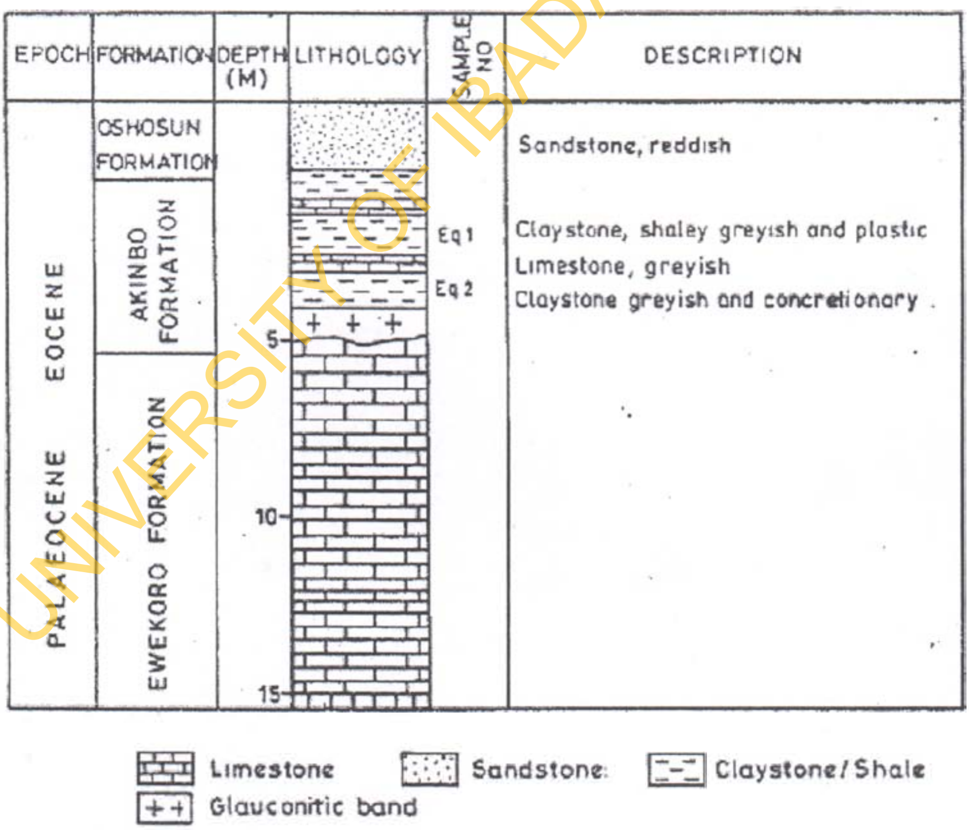

Fig. 3. Schematic illustration of Akinbo Formation showing associated clay bodies as exposed at Ewekoro quarry

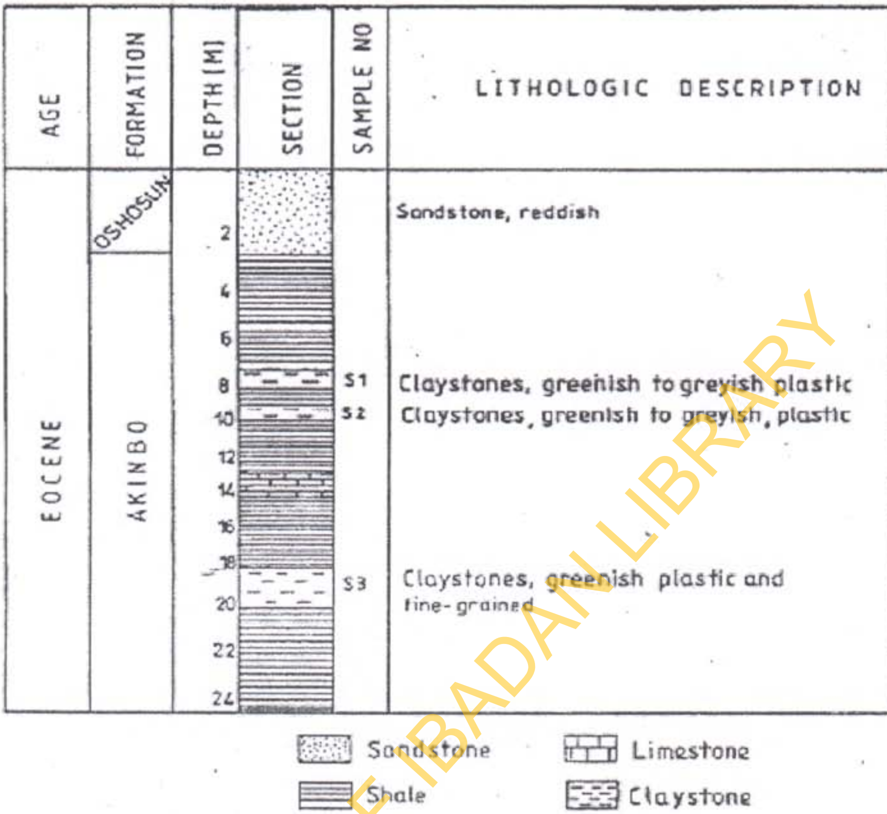

Fig. 4. Schematic illustration of Somo well showing associated clay bodies

clay fraction. In determining the physical characteristics, the samples were subjected to wet sieving analysis and Atterberg limit tests. Casagrande's (1948) method was employed for the determination of plasticity while thermal characteristics were also determined through series of firing tests on sample pellets.

Mineralogical studies were carried out on pressed pellets of the clay samples using a Phillip – PW 1011 model X-ray diffractometer. The diffractograms were compared with established standards and interpreted with reference to Brown (1972), JCPDS (1974) and Pei-Yaun Chen (1977) tables of X-ray diffraction patterns. Quantitative estimation of the different minerals was carried out by computing their peak areas based on Gibbs, (1967). Chemical composition such as SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, MnO and TiO_2 were determined by atomic absorption spectrophotometer (AAS) technique while P_2O_5 was analysed by X-ray fluorescence (XRF) technique.

Detailed analytical procedures for the different aspects are reported in Nton (2001).

Results

Typical diffractograms for the mineralogical studies are shown in Figs. 5 and 6 while Table 1 presents the percentage composition of the respective minerals for the different locations. Results show that kaolinite is the major clay mineral in the studied samples with a range of 32.80 – 58.33%. Other constituents are smectite (2.87-14.29%), illite (4.95%) and palygorskite (2.87%). The non-clay minerals are quartz, k-feldspar, mica and graphite.

Conspicuous intensities are reflected by kaolinite at 2θ values of 12.4°, 24.9° and 39.6°. Illite peak is identified at 2θ value of 43.4°. Quartz is identified at values of 20.85°, 26.7 and 60.6°, while palygorskite is recorded at 13.93°. Graphite has distinctive peaks at 2θ value of 44.8°. K-feldspar is identified at 2θ values of 21.0° and 27.6° while smectite is noted at 9.9°. In this study, the higher proportion of kaolinite is attributable to weathering of feldspar - rich rocks in humid climatic setting (Nton 1999). On the other hand, the presence of smectite may be attributed to poorly drained terrain that could result in swelling of the clays.

Table 1. Mineralogical composition of claystones compared to reference samples

Mineral %	S1	S2	S3	Eq 1	Eq2	Reference samples (A)	Reference samples (B)
Kaolinite	47.52	58.33	53.33	51.92	32.86	85	85
Illite	4.95	-	-	-	-	-	-
Smectite	-	-	6.27	2.87	14.29	--	-
Palygorskite	-	-	-	2.87	-		
Graphite	29.70	19.64	-	-	28.59		
Mica	-	-	3.92	-	-		
Quartz	17.82	19.64	20.0	25.84	24.27	Trace	4
K-feldspar	-	2.68	7.06	16.50	-	15	
Others							8

(A) China Clay (Huber, 1985)
(B) NAFCON (1985) recommended values

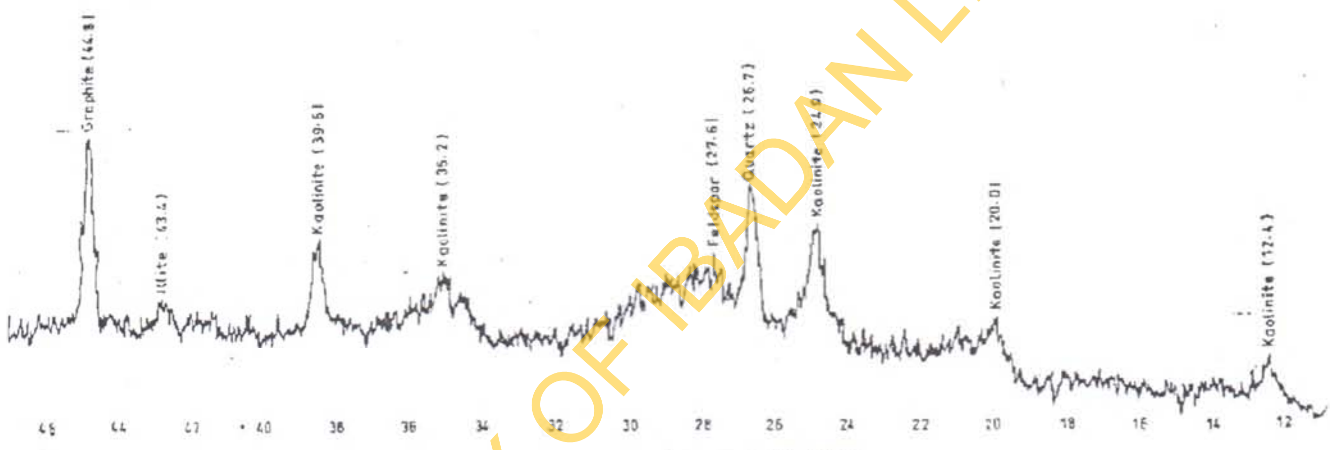

Fig. 5. Diffractogram for sample S1

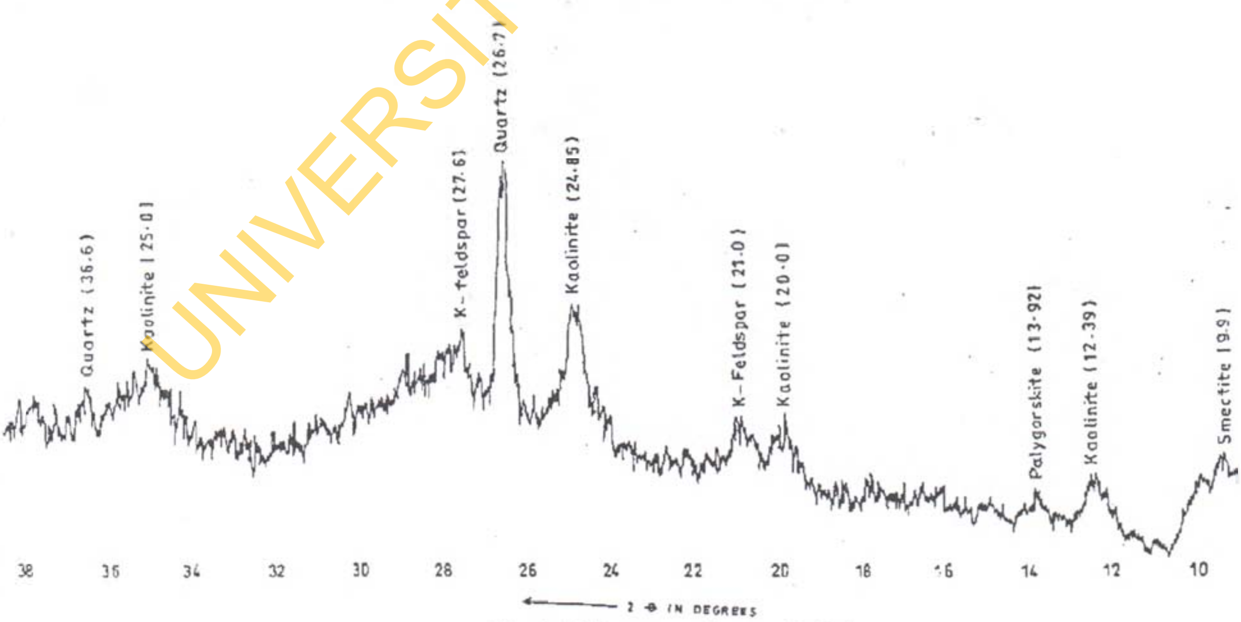

Fig. 6. Diffractogram for sample Eq1

The presence of illite in the predominantly shaley lithology of the Akinbo Formation is primary in origin and supports the findings of Read (1970). Graphite content in some of the samples shows some input of carbonaceous material of sedimentary origin, which in this case may be associated with the shales. Earlier, Elueze and Nton (2004) reported TOC values of 0.10 to 1.00 wt. % and 0.20 to 1.60wt. % respectively for associated limestones and shales within this basin. This high organic content, no doubt, may contribute to the presence of graphite.

Major elements concentration of the claystones is presented in Table 2. Their ranges are; SiO_2 (52.96 – 55.84%), Al_2O_3 (16.22 – 17.74%), Fe_2O_3 (7.13 – 10.35%), CaO (4.15 – 7.95%) and MgO (2.26 – 3.98%); while Na_2O, K_2O, MnO, TiO_2 and P_2O_5 have values individually less than 1%. It can be observed that the predominance of SiO_2, Al_2O_3 and H_2O^+ in the studied samples is in line with its classification as hydrated aluminum silicates, contaminated by free silty quartz. This is in agreement with the proposition of Emofurieta et al. (1992). The average percentages of CaO and MgO are 5.90% and 2.93% respectively (Table 2). The high CaO, may be due to some contribution from the underlying limestone body of the Ewekoro Formation. The equally comparatively higher average value of MgO may be the reflection of dolomitization that has been reported as affecting the Ewekoro limestone and associated rocks in the area (Petters, 1978). Fe_2O_3 has a range of 7.13 – 10.35%, which is relatively high. Nton (2001) reported the occurrences of ironstones within the Dahomey basin, which may probably be manifested in the iron oxide content of the claystone.

Plots of plasticity index against liquid limits, based on Casagrande's (1948) chart, indicate that the claystones are from the range of medium to highly compressible and tough (Fig 7). Colour ranges from dark grayish and dark green in fresh samples of Somo and Shagamu clays respectively to mainly brownish on firing of both. Other physical parameters include linear shrinkage (3.75 – 7.50%), plastic limit (23 – 31%), liquid limit (48 – 56%), plastic index (21 – 30%), water absorption capacity (5.80 – 11.90%) and loss on ignition (3.30 – 12.30%) (Table 3). Based on size analysis (Table 3), the clay fraction is greater than 80% (Nton, 2001).

Table 2. Chemical analysis of claystones in the study area (concentrations in %)

Oxides	S1	S2	S3	EQ_1	EQ_2	Average
SiO_2	55.84	53.98	54.78	52.96	53.56	54.22
Al_2O_3	17.73	16.91	16.29	16.22	17.44	16.92
Fe_2O_3	10.35	7.30	8.69	7.15	7.13	8.12
CaO	5.98	6.24	4.67	7.95	4.65	5.90
MgO	3.98	3.34	2.26	2.29	2.80	2.93
Na_2O	0.36	0.21	0.11	0.26	0.91	0.37
K_2O	0.39	0.38	0.43	0.40	0.43	0.41
MnO	0.48	0.36	0.26	0.36	0.42	0.38
TiO_2	0.39	0.26	0.13	0.24	0.21	0.25
P_2O_5	0.87	0.46	0.39	0.26	0.16	0.43
H_2O^+	3.30	10.30	12.00	11.91	12.30	9.96
Total	99.67	99.74	100.01	100.00	100.01	99.89
*S.R.	1.99	2.23	2.19	2.27	2.18	2.17
**A.R.	1.71	2.32	1.87	2.27	2.45	2.08
MgO+CaO	9.96	9.58	6.93	10.24	7.45	8.83
$Na_2O + K_2O$	0.75	0.59	0.54	0.66	1.34	0.78

Note: * Silica-sesquioxide ratio
** Alumina-iron ratio

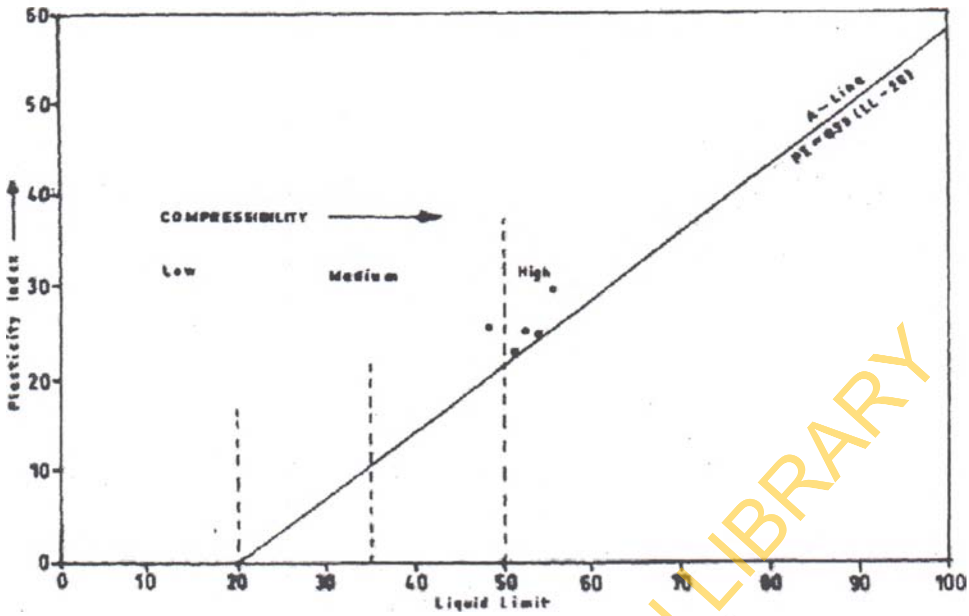

Fig. 7. Plasticity chart for the classification of the clay bodies (after Casagrande, 1948)

Table 3. Data of plasticity test for studied samples

Sample No	PL%	LL%	PI%	LS %	LOI%	WAC%	Particle size (<2μm) %	Colour of fresh pellets	Colour of fired pellets
S1	23	48	25	3.75	3.30	9.20	84.45	Brownish Grey	Brownish
S2	26	56	30	5.00	10.30	5.80	87.19	Dark Grey	Brownish
S3	31	52	21	7.50	12.00	11.90	89.56	Dark Grey	Brownish
EQ_1	30	54	24	6.00	11.90	9.40	81.01	Dark Green	Light Brown
EQ_2	28	53	25	6.20	12.30	8.60	86.12	Dark green	Light Brown

LS = Linear Shrinkage
WAC = Water absorption capacity
PI = Plasticity index
L L = Liquid limit
LOI = Loss on ignition
PL = Plastic Limit

Industrial assessment

The main clay mineral in the samples is kaolinite, which in abundance ranges from 32.86 – 58.33%. Quartz content varies from 17.82 to 25.84 %. The presence of illite, smectite and palygorskite plus graphite, are the major disparities between these clays and China clays (Huber, 1985) and the National Fertilizer Company of Nigeria (NAFCON, 1985) specification (Table 1). However, with appropriate processing, a comparable mineralogical composition could be achieved. Similar views have been expressed by Emofurieta et. al. (1992). The clays are relatively rich in silica and other fluxing elements as Ca and Mg and could be utilized in domestic sanitary wares.

A comparison of average chemical composition of the clays under investigation with China clays (Huber, 1985) shows that the former contain higher SiO_2, Fe_2O_3, CaO, MgO, but less in Al_2O_3, K_2O and H_2O than the reference sample (Table 4). In comparison to the Florida active kaolinite, the SiO_2 content is a little higher in the investigated clays. The LOI value of 9.96% in the investigated samples is similar to those of the three reference sample, except that of China clay, which is relatively higher (Table 4). Other metal oxides notably, TiO_2, K_2O and Na_2O are similar to the three reference samples (Table 4).

Table 4. Comparison of average claystones values in the study area with industrial specifications (concentrations in %)

	Reference samples				SOME INDUSTRIAL SPECIFICATIONS		
Oxides	*Average for study area	A	B	C	(1) %	(2) %	(3) %
SiO_2	54.22	46.88	52.92	57.67	48.67	67.50	51.0-70.0
Al_2O_3	16.92	37.65	9.45	24.00	9.45	26.50	25.0-44.0
Fe_2O_3	8.12	0.88	3.65	3.23	2.70	0.5-1.20	0.5-2.4
CaO	5.90	0.03	1.91	0.70	15.84	0.18-0.3	0.1-0.2
MgO	2.93	0.13	0.08	0.30	8.50	0.1-0.19	02-0.7
Na_2O	0.37	0.21	0.03	0.20	2.76	0.2-1.5	0.8-3.5
K_2O	0.41	1.60	0.98	0.50	2.76	-	-
MnO	0.38	-	-	-	-	-	-
TiO_2	0.25	0.09	1.18	-	-	0.1-1.2	1.0-2.8
P_2O_5	0.43	-	0.02	-	-	-	-
H_2O^+	9.96	12.45	10.19	10.50	3.04	12.04-12.5	-
Total	98.87	99.92	80.38	97.1	-	-	-

* Average of 5 samples
(A) China clay (Huber, 1985)
(B) Florida active kaolinite (Huber, 1985)
(C) Plastic fire clay, St. Louis (Huber, 1985)
(1) Brick clay (Murray, 1960)
(2) Ceramic (Singer and Sonja, 1971)
(3) Refractory Bricks (Parker, 1967)

In comparison with some industrial specifications (Table 4), it can be deduced that these clay bodies could be utilized as raw materials in the production of bricks (Murray, 1960), ceramics (Singler and Sonja, 1971), and refractories (Parker, 1967). The silica-sesquioxide ratio (S.R.) varies from 1.99 to 2.27 with an average value of 2.17, while the alumina – iron ratio (A.R.) ranges from 1.71 to 2.45 with corresponding average value of 2.08 (Table 2). It can be deduced that both ratios are within the ranges of 1.5 to 4.0 and 1.4 to 3.5 respectively considered for clay or shale suitable for utilization in the manufacture of good quality cement (Abatan et. al., 1993). This corroborates the findings of Olade et al., (1981), on the suitability of the clay-shale sequence of Akinbo Formation, in Ibeshe, which is within the eastern Dahomey Basin, for cement manufacture.

The low to medium loss on ignition (LO1) of 3.30 – 12.30% and water absorption capacity (WAC) of 5.80 – 11.90 respectively (Table 3) may portray that the finished products could withstand cracks or damages on firing, hence could be utilized in ceramics and sanitary wares. Elueze et al. (1999) attributed high plasticity with general fineness of clays. In the investigated samples, the clay fraction (<2μm) is above 80% and highly compressible (Table 3 and Fig. 7). These qualities portray the clays as useful in fillers and coating materials in the paint, rubber, cosmetics and paper industries.

Nurse (1960) stated that colour changes in fired clays are important properties, which have implications on their industrial suitability. It has been observed here that the clays fire brown in colour in addition to being plastic. They could therefore be utilized in the manufacture of bricks.

Elueze and Bolarinwa (2001) examined the sedimentary clays within the eastern Dahomey Basin and reported optimum glassy bond strength of 2.2 –2.50 N/mm². These values indicate that the clays could withstand stress thereby making them suitable for the manufacture of structural materials such as tiles (Aribisala, 1989). Such physical parameter was not carried out in this work, however, comparable values of loss on ignition, water absorption capacity and toughness could support such deduction and therefore such uses.

Conclusions

Clay bodies, which occur as lenses and interbeds within the predominantly shaley Akinbo Formation in the eastern Dahomey Basin, were examined for their mineralogical, chemical and physical properties in order to determine their industrial suitability. Results of the mineralogical study show that kaolinite is the predominant clay mineral with other constituents such as smectite, illite and palygorskite. Non- clay minerals are quartz, k- feldspar, mica and graphite.

Major elements concentration shows that the following oxides;SiO_2, Al_2O_3, Fe_2O_3, CaO and MgO constitute more than 90 % while Na_2O, K_2O, MnO, TiO_2 and P_2O_5 relatively have lower values. The high CaO values reflect some contributions from the underlying limestone body of the Ewekoro Formation, while the equally high average value of MgO indicates some dolomitization process that has been reported as affecting the limestones and other rock types in the area.

Results of physical determinations show that the samples range from medium to highly plastic, compressive, tough and with the clay fraction (<2μm) above 80%. In comparison with reported industrial specifications, it can be deduced that the studied samples could be employed as raw materials in the production of bricks, ceramics, refractories, fillers in paper industries and in paints manufacturing. The silica sesquioxide and alumina-iron ratios are within the range considered for clays or shales suitable for utilization in the manufacture of good quality cement. The low to medium loss on ignition and water absorption capacity may portray that the clays could be found useful in the manufacture of sanitary wares.

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References

ABATAN, S.O., ODUKOYA, A.A., EHIMIYEN, U.A. and BANKOLE, B.O., 1993. Limestone and Shale investigation for cement manufacture at Somo, near Sagamu, Ogun State, Geological Survey of Nigeria, Abeokuta, Report, 110p.

ADEGOKE, O.S., 1988. Resources development in relation to industrial and technological growth. Ibadan Geologist Newsletter, Vol. 1: pp.15 – 25.

ADELEYE, D. R., 1978. Tertiary provenance changes and clay mineralogy of western Niger Delta, Nigeria. Journal of Mining and Geology Vol. 15 No. 2: pp. 90-96.

AJAYI, J.O. and AGAGU, O.K., 1981. Mineralogy of primary clay deposits in the basement complex areas of Nigeria. Journal of Mining and Geology, Vol. 18, No.1, pp. 27 – 31.

ARIBISALA, O.A., 1989. Sourcing of local raw materials and investment opportunity in the building/construction industrial sector, Proceeding National Workshop, Association of Housing Corporation of Nigeria, Kano. pp. 23 – 37.

BROWN, G. 1972. The X-ray identification and crystal structures. Mineralogical Society, 544p.

BURKE, K.C.B., DESSAUVAGIE, T.F.J. and WHITEMAN, A.J., 1971. The Opening of the Gulf of Guinea and the geological history of the Benue Depression and Niger Delta. Nature Phys. Sci. 233 (38) pp. 51-55.

CASAGRANDE, A., 1948. Researches on the Atterberge Limits of soils. Public Road, New York, Vol. 13B pp. 121 – 136.

ELUEZE, A. A.1998. Promoting the development and exploitation of mineral resources in Nigeria. In: Proceedings of the first mining in Nigeria conference and workshop NIMAMOP. Fed. Min. of Solid Minerals, Abuja, pp. 9-22.

ELUEZE, A.A. and BOLARINWA, A.T., 1995. Assessment of functional application of lateritic clay bodies in Ekiti environ, Southwestern Nigeria, Journal of Mining and Geology, Vol. 31, No.1, pp. 79 – 87.

ELUEZE, A.A. and BOLARINWA, A.T. 2001. Appraisal of the residual and sedimentary clays in part of Abeokuta area, Southwestern Nigeria. Journal Mining and Geology, Vol. 37, No.1, pp. 7 –14.

ELUEZE, A.A., NTEKIM, E.E. and EKWERE, S.J., 1999. Compositional and industrial assessment of clay bodies in Itu area, southeastern Nigeria. Journal of Mining and Geology, Vol. 35, No.2, pp. 117 - 124.

ELUEZE, A. A. and NTON, M. E., 2004. Organic geochemical appraisal of limestones and shales in part of eastern Dahomey Basin, Southwestern Nigeria. Journal of Mining and Geology, Vol. 40, No. 1, pp. 29-40.

EMOFURIETA, W. O., KAYODE, A.A. and COKER, S.A., 1992. Mineralogical, geochemical and economic evaluation of the kaolin deposit near Ubulu – Uku, Awo – Omama and Buan in Southern Nigeria. Journal of Mining and Geology, Vol. 28, pp. 211-220.

EMOFURIETA, W.O., OGUNDIMU, T.O., and IMEOKPARIA, E.G., 1994. Mineralogical, geochemical and economic appraisal of some clay and shale deposits in Southwestern and Northwestern Nigeria. Journal of Mining and Geology, Vol. 30, No.2, pp. 151 – 159.

FAYOSE, E.A., 1970. Stratigraphical Paleontology of Afowo – 1 Well; Southwestern Nigeria. Journal of Mining and Geology, Vol. 5, Nos.1&2, pp. 1 – 99.

GIBBS, R.J., 1967. Quantitative X-ray diffraction analysis using clay mineral standards extracted from the samples to be analyzed. Clay Minerals, Vol. 7, pp. 79 – 90.

HUBER, J.M., 1985. Kaolin Clays. Huber Corporation (Clay Division), Georgia U.S.A.).

JCPDS, 1974. Selected powder diffraction data for mineral. 1st Edition. In: L.G. Berry (ed.), Joint Committee on Powder Diffraction Standards, Philadelphia, 833p.

JONES H.A. and HOCKEY, R.D., 1964. The Geology of part of Southwestern Nigeria, Explanation of 1; 250,000 sheets Nos. 59 and 68. Geological Survey of Nigeria Bulletin 31, 101p.

KINGSTON, D.R., DISHROON, C.P., and WILLIAMS, P.A., 1983. Global basin classification system. American Association of Petroleum Geologist Bulletin, Vol. 67, pp. 2175 – 2193.

KLEMME, H.D., 1975. Geothermal gradient, heat flow and hydrocarbon recovery. In: A.G. Fischer and S. Judson (eds.) Petroleum and Global Tectonics. Princeton University Press. pp. 251 - 304.

MURRAY, H.H. 1960. Clay industrial minerals and rocks 3rd Ed. Publ. Am Inst. of Mining Metall. and Petroleum Engineers.

New York, Seeley W. Mudd. Series. pp. 259 – 284.
NAFCON 1985. Tender document for the supply of kaolin from Nigeria.
NTON, M.E., 1999. Sedimentology and depositional environment of Awi Formation, Calabar Flank, southeastern Nigeria. Journal of Mining and Geology, Vol. 35 No.1 pp. 23-36.
NTON, M.E., 2001. Sedimentological and geochemical studies of rock units in the eastern Dahomey Basin, Southwestern Nigeria. Unpub. Ph.D. Thesis, University of Ibadan. 315p.
NURSE, R.M., 1960. The relationship between the constitution of brick-making clays and firing properties. Clay Min. Bull. 4(23) pp 127-133.
OGBE, F.G.A., 1972. Stratigraphy of strata exposed in the Ewekoro Quarry, Western Nigeria. In: T.F.J. Dessauvagie and A.J. Whiteman (eds.) African Geology, Ibadan University Press, pp. 305 – 322.
OKOSUN, E. A.,1998. Review of the early Tertiary stratigraphy of southwestern Nigeria. Journal of Mining and Geology, Vol. 34, No.1, pp.27-35.
OLADE, M. A., AGAGU, O. K., OFFREY, O., ODEYEMI, I. B., ELUEZE, A. A. and AJAYI, J. O., 1981. Raw materials investigations for cement manufacture in Ibese, Ogun state, University Consultancy Services (Geology Division) University of Ibadan, Ibadan, 75p.
OMATSOLA, M.E. and ADEGOKE, O.S., 1981. Tectonic evolution and Cretaceous stratigraphy of the Dahomey Basin, Journal of Mining and Geology, Vol. 18, No.1 p. 130 - 137.
PARKER, E.K., 1967. Minerals data book for engineers and scientists. Publ. Mc Graw Hill Book Co. New York, 283p.
PEI - YUAN CHEN, 1977. Table of key lines in X-ray powder diffraction pattern of minerals, clays and associated rocks. Dept. of Nat. Res. Geol. Surv. Occasional paper 21, 66p.
PETTERS, S. W., 1978. Dolomitization of the Ewekoro Limestone. Journal of Mining and Geology, Vol.15 No.2, pp. 78-83.
READ, H.H., 1970. Rutley's Element of Mineralogy. George Allen and Unwin Ltd. London, 560p.
SINGER, F. and SONJA, S.S., 1971. Industrial ceramics. Publ. Chapman and Hull London, pp. 18 – 56.
WHITEMAN, A. J., 1982. Nigeria: Its petroleum geology, resources and potential.Graham andTrottan, London. 394p.
WRIGHT, J.B.; HASTING, D.A.; JONES, W.B.; WILLIAMS, H.R., 1985. Geology and mineral resources of West African. George Allen and Unwin, London, 187p.

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