Centrepoint Journal (Science Edition)
Volume 17, No. 2, pages 71 – 88 (2011)
http://www.unilorin.edu.ng/centrepoint

2141-3819/2011 $5.00 + 0.00
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CPJ 2011180/17201

Sedimentological and geochemical studies of Maastrichtian clays in Bida Basin, Nigeria: Implication for resource potential

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(Received August 29, 2011; Accepted November 21, 2011)

ABSTRACT

Bida Basin is located in the central part of Nigeria, trending northwest southeast. Present study is focused on the claystone units of the Maastrichtian Patti and Enagi Formations in southern and northern Bida Basins respectively, to determine the paleoenvironments, geochemical and geotechnical properties and, assess the economic potential of the clay deposits. At Share, towards the middle part of the Enagi Formation section, cream to white claystone beds are interbedded with cross to parallel stratified quartzarenitic sandstones. In the Patti Formation section at Agbaja, white, massive claystone beds are interbedded with herringbone and hummocky cross stratified sandstones. Gross sedimentological features suggest that the associated sandstone facies were deposited in tidal channel to shoreface environments whereas the claystone probably represent a low energy floodplain sub environment.

Geochemical data show that the claystone at Share is composed of SiO_2 content ranging from 45.2% to 64.8% (average of 58.1%) while at Agbaja, the values range from 48.5% to 74.7% (average of 63.3%). Al_2O_3 value for the clay at Share ranges from 20.3% to 37.9% (averaging 26.9%) while, the Agbaja samples is between 15.61% and 34.23% with an average of 24.6%. These indicate that the clays are essentially hydrated siliceous aluminosilicates. Relatively low abundance of MgO and K_2O (less than 0.30%) indicate lack of expandable clay mineral in the samples. Plastic limit less than 30% indicates that clays are kaolinitic. Average Plastic Index for the Share and Agbaja clays are 24.29 and 17.7% respectively and the shrinkage limit values (average) are 10.05% and 2.66%.

The clays compare favourably with the Plastic fire clay of St. Louis and Florida active kaolinite. Their characteristics are quite consistent with other sedimentary kaolin deposits in Nigeria. They also show low heavy metal concentrations and thus may be beneficiated and suitable as raw materials for ceramic, pharmaceuticals and paints.

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Introduction

The Bida Basin is a linear intracratonic sedimentary basin located in central Nigeria. It trends NW – SE and approximately perpendicular to the Benue Trough. It is separated from the basal continental bed of the Sokoto Basin by a narrow outcrop of the crystalline basement rocks in the west and it is adjacent to the Anambra Basin in the east (Fig.1). Often, experts working in the area have divided the basin geographically into northern and southern Bida basins probably due to rapid facies changes across the basins. Literature account suggests that the basin evolution is best explained by rift model [1, 2, 3 and 4]. The wrench fault tectonic model of [5] which postulated the Bida Basin as strike slip feature is based on facies distribution and evidence of syndepositional basin floor lowering. The northern and southern Bida basins comprises of about 3km thick Campanian to Maastrichtian continental to shallow marine sediments. The southern Bida Basin comprises of the basal Campanian Lokoja Formation (mainly conglomerate and sandstone), Maastrichtian Patti Formation (shale, claystone and sandstone) and the youngest Agbaja Formation (Ironstone). Their lateral stratigraphic equivalents in the northern Bida Basin consist of the basal Bida Formation (conglomerate, sandstone), Enagi Formation (siltstone, claystone and sandstone) and Batati Formation (Ironstone) (Fig. 2).

A wide range of investigations have been carried out in the Bida basins. Relevant ones include those that focused on the sedimentology and depositional environments of the sediments in the northern Bida Basin which suggested alluvial to braided stream depositional processes [6,7, 8, and 9]. Recent studies of [10, 11] provided substantial evidence of alluvial to coastal marine processes in the sedimentation of the Lokoja and Patti Formations in southern Bida Basin. [12 and 13] in their detail palynological study reported occurrence of biostratigraphic significant dinoflagellates of Mastrichtian age and thus re-affirm the Maastrichtian age [14] for the Patti shales. The ironstones of the Agbaja Formation have also received significant attention of researchers. [15] suggested that the oolitic ironstones contain high primary kaolinitic clays that were subsequently reworked into ooids by shallow marine waves and tides. [16] and [17] reported kaolinite replacement by haematite and goethite. From the above review, it is clear that, to date no scientific report has been published on the occurrence and characteristics of claystones in this basin. Previous studies of the Bida Basin by [12, 13] merely reported the occurrence of shales and clays, however, their physical, chemical characteristics, precise locations and industrial potential have not been assessed. This study therefore will focus on determination of the paleoenvironmental model, chemical and physical characteristics, and ascertain their industrial applicability. Clay is a major raw material in the ceramic, paint, paper, refractory, plaster of paris and pharmaceutical industries. Strategies for enhancing local sourcing of the mineral resource in Nigeria would involve effective exploration and developments.

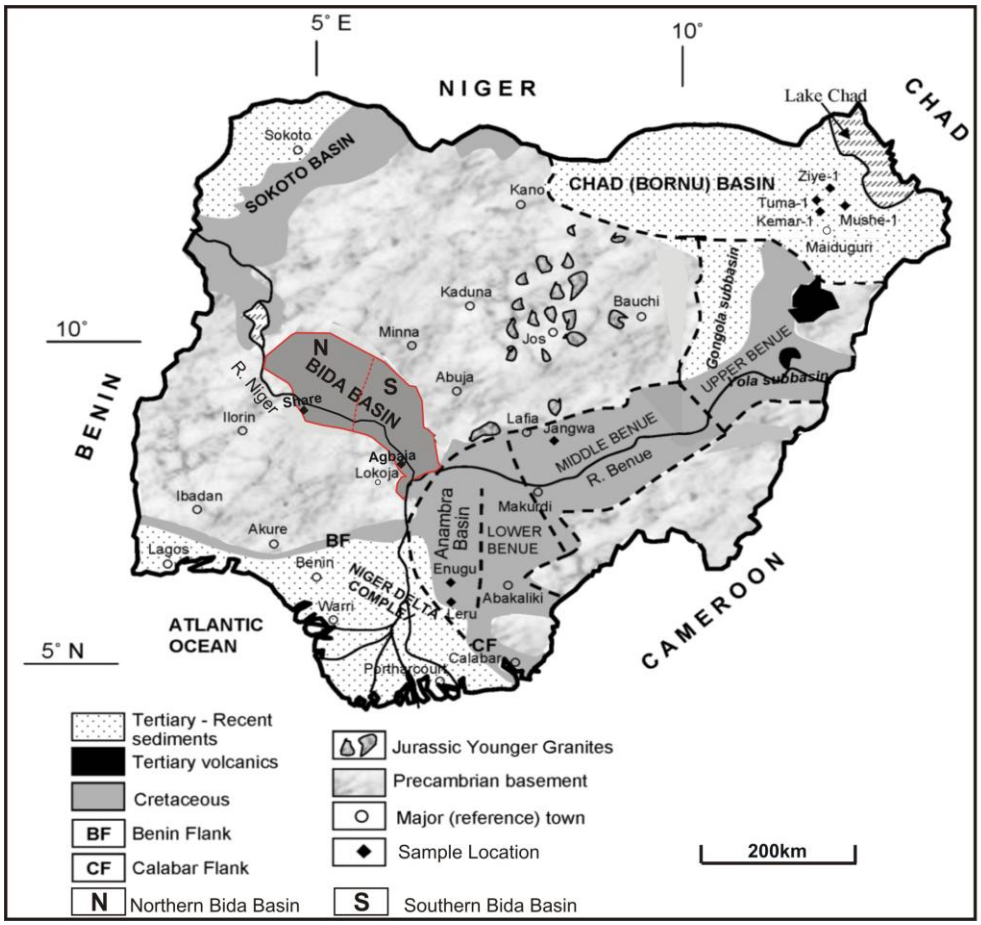


Fig. 1: Geological map of Nigeria and locations of the investigated samples (After Obaje *et al*., 2004).

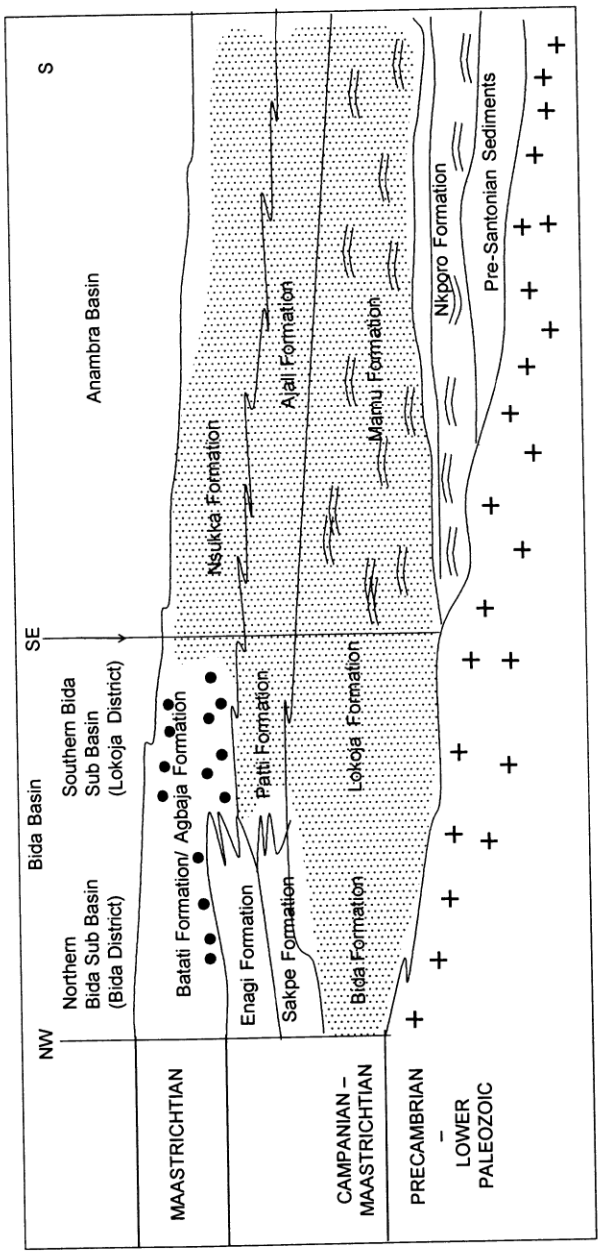


Fig. 2: Stratigraphic successions in the Bida Basins and correlations with adjacent Upper Cretaceous successions in Anambra Basin (Ojo and Adekunle, 2009)

Location of Investigated Samples and Methods

The investigated sediments of the Patti and Agbaja Formations are located at Share, northern Bida Basin and Agbaja near rivers Niger and Benue Confluence, southern Bida Basin (Fig. 1). At the locations, the clays occur around the middle part of the vertical sections of elongated ridges of about 400m above the sea level. At Agbaja, recently constructed road from Lokoja to Agbaja cutting through the ridge provided accessibility to fresh exposures of the studied Patti Formation sediments while at Share, accessibility to samples of the Enagi Formation was through the erosional channel cuts created by run offs from the top of the ridge. Here, activities of informal miners also provided very good exposures of the claystone. The sections were measured on a bed to bed scale, described and sampled. Vertical stratigraphic profiles were constructed to show the position of the claystone and their associated lithofacies (Figs. 3 and 4). Seven (3 and 4 from Agbaja and Share respectively) fresh samples of the clay beds were carefully selected for this study. The major and trace elements were determined by Inductively Coupled Plasma Atomic Mass Spectrometry ICP-MS and X-Ray Flouresence (XRF) at Acme Laboratory, Canada. Some geotechnical properties (Atterbeg limit, shrinkage limit and specific gravity) of the clays were also tested at the Civil Engineering workshop at the University of Ilorin, Nigeria.

Results and Discussion

Lithologic Section Description and Paleoenvironments

The exposed section at Agbaja is about 78m thick and in this location it consists from the base conglomerate and sandstone facies of the Lokoja Formation and passing through the sandstone and claystone facies of the Patti Formation into Agbaja Ironstone consisting mainly of ironstone at the top (Fig. 3). The Patti Formation (focus of the present study) occurs at interval between 24 to 70m and consists three claystone beds that are interbedded with sandstones. The medium to coarse grained sandstones of average thickness of 2m are commonly cross bedded (particularly of herringbone and hummocky types) and bioturbated. Clay drapes and reactivation surfaces are also significant features of the sandstones. The sandstones are friable in most cases, well sorted and quartzarenitc. The claystones are white to milky color, massive and having average thickness of 1m. In hand specimen, quartzs of sand size are visible in the clays and shrinkage crack is also common. The clay beds are laterally persistent along the depositional strike. The suite of environments envisaged for the lithofacies of the Patti Formation here based on the facies association and sedimentological features are shoreface, tidal channels and floodplains [11]. The hummocky cross bedded sands represent the shoreface while the sandstones with clay drapes, bi directional flow structures are interpreted as tidal channel deposits. The claystone were deposited in low energy, adjacent floodplains and overbanks.

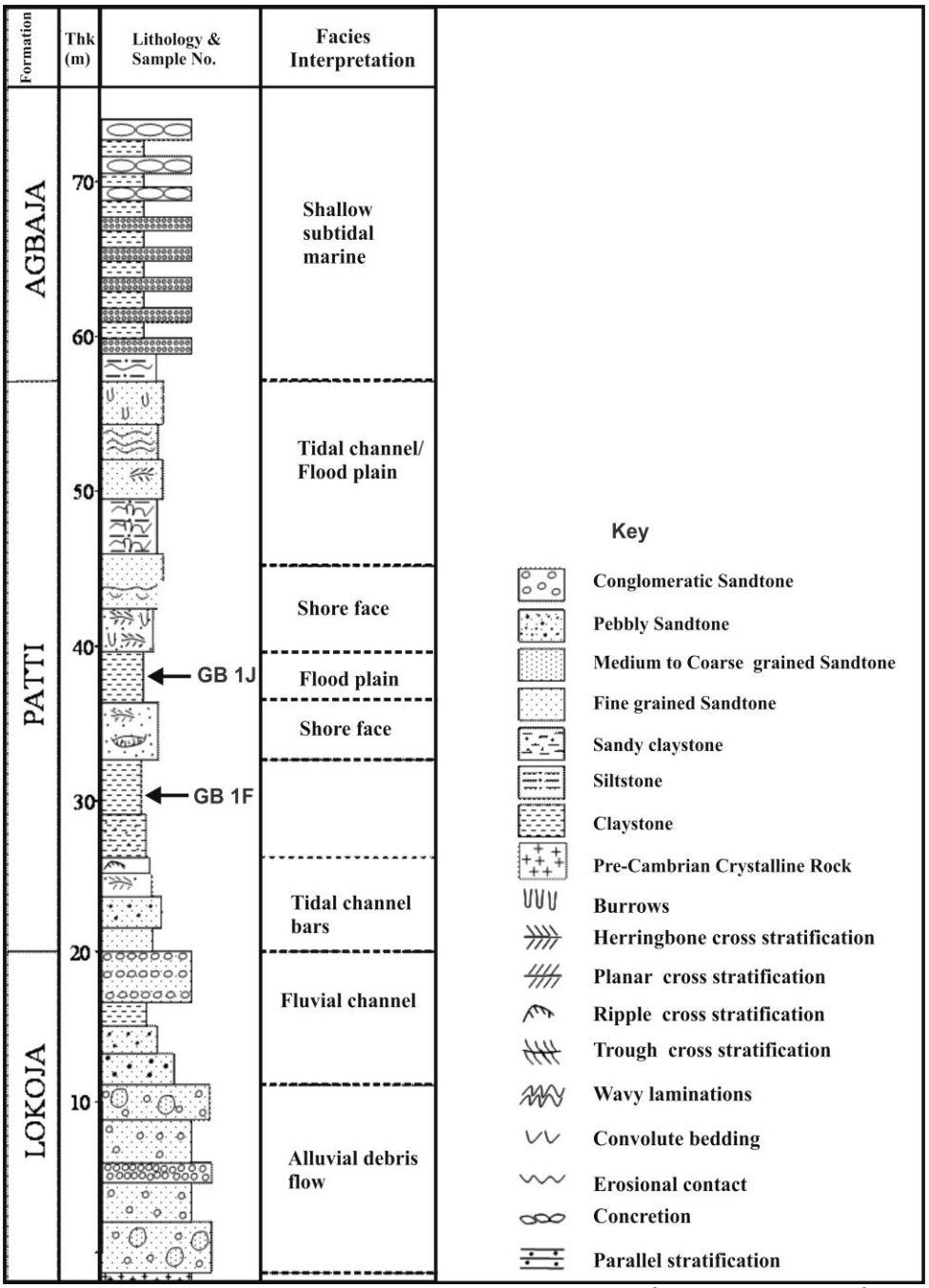


Fig. 3: Lithologic section of Patti Formation at Agbaja (Longitude E06^{o} 39' and Latitude N07^{o} 59').

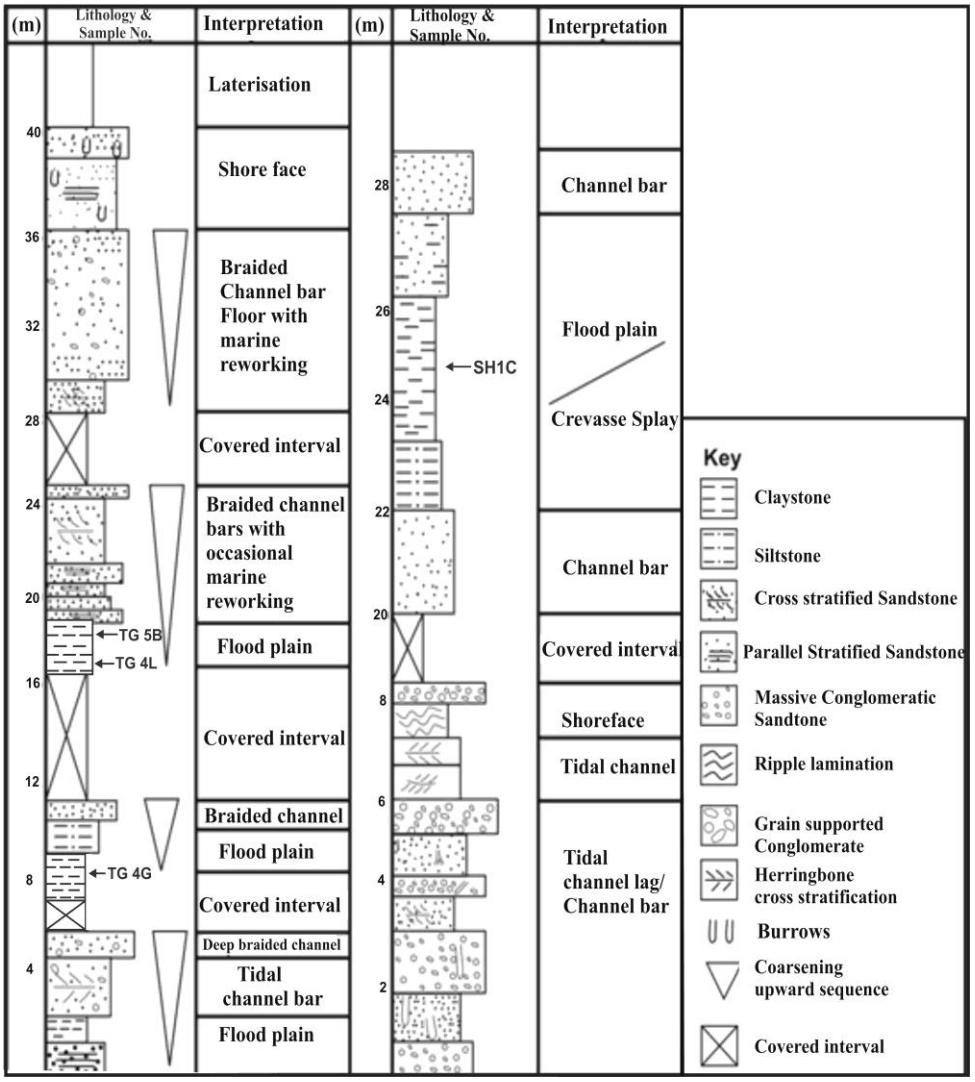


Fig. 4: Lithologic sections of Enagi Formation at Share: (a) East of Share ridge (Longitude E04^{o} 59' 469" and Latitude N08^{o} 49' 534"); (b) West of Share ridge (Longitude E04^{o} 59' 259" and Latitude N08^{o} 49' 469").

The Enagi Formation exposed at Share is about 47m thick (Fig. 4) at the eastern fringe of the eastwest trending ridge. It is this part of the ridge that offers the best access for complete logging from base to the top. The section consists of

three coarsening upward cycles and each cycle begins with clay / siltstone which grades into sandstones (Fig. 4). The claystones at the middle part of the section are the thickest with average thickness of about 2.5m (Fig. 5). They are massive, white to milky but with occasional brown stains probably due to percolation by water enriched in iron. The sandstones which range from medium grained to pebbly sandstone are moderately sorted, friable and quartsarenitic. Common bedding structures include wavy to parallel laminations, ripple marks, planar to trough cross beddings and burrows. Another important observation is that the sandstones typically contain clay clasts and clay partings. Generally there are striking lithological similarities between the Enagi Formation at Share and the Patti Formation at Agbaja. Sedimentary structures and textures preserved in the sandstones and facies association in these locations are indicative of braided channels and overbanks. However, the occurrence of shallow marine trace fossils, reworked clay clasts and high maturity of the sands suggest possible marine reworking during Maastrichtian time. The claystones are interpreted as floodplain deposits whereas the sandstones were deposited in braided to tidal channels [9].

Chemical Composition

The results of the geochemical analysis (Table 1) shows that the claystone exposed at Share is composed of SiO_2 content ranging from 45.2% to 64.8% with an average value of 58.1% while that of southern Bida Basin exposed at Agbaja has values ranging from 48.5% to 74.7% with an average of 63.3%. Also, Al_2O_3 value for Share clays ranges from 20.34% to 37.9% (averaging 26.99%) while the Agbaja clay ranges between 15.61% and 34.23% with an average of 24.6%. The above concentration values suggest that the clay samples from both locations are hydrated siliceous aluminosilicates [18 and 19].

The other Oxides are present in relatively very small amounts in both deposits. The Fe_2O_3 is relatively low (less than 2%) in the samples except sample TG4G (Fig. 4) from Share with values of 3.47% which was sampled from old local quarry face. The relatively high Fe_2O_3 is probably due to superficial oxidation and contamination by the Fe-rich percolating water from the highly ferruginous facies capping the ridge at Share. Low content of CaO (generally less than 0.1%) in both deposits may be attributed to the absence of marine carbonate facies in the associated sedimentary sequence [20]. The low amounts of K_2O and Na_2O probably suggest low feldspar content in the claystones while low abundance of MgO and K_2O (less than 0.08 and 0.53 respectively) indicate little or no expandable clay (montmorinolite/illite) in the investigated clays. It is remarkable to note however that K_2O and Na_2O is relatively higher for clays from Share than those from Agbaja suggesting more compositional maturity in the clays of Agbaja, southern Bida Basin.

Other significant observation is that the trace element, vanadium, has a stronger showing (average value of 59.66ppm) in the clays from Agbaja than that

of Share (average of 2.72ppm). Minor oxides TiO_2 and P_2O_5 concentration are however higher in Share samples than Agbaja. This may be due to paleoenvironmental condition. It is most probable that the claystone and the associated sedimentary facies of the Patti Formation at Agbaja have more influence of trangressive shallow marine than the Enagi Formation, northern Bida Basin [20].

The low total alkali contents coupled with low amounts of Fe_2O_3+TiO_2+MgO (average values of 3.32% and 2.55% respectively for the clays from northern and southern Bida Basins) implies that the clays are chemically inert and non-corrosive. Therefore, they may offer good quality kaolin.

An attempt is made here to compare the chemical compositions of the present investigated clay samples (Tables 2 & 3) with other known and characterized clays and the following observations are noted. A comparison with the China Clay [21] shows that SiO_2 values are higher whereas Al_2O_3 are lower for the samples analyzed but they favourably compare with Flourida Active Kaolinite, Plastic Fire Clay, St Louis [21] and Abraka Clay [22] as well for some clays deposits in other part of Nigeria [23 and 24]. Fe_2O_3 concentration in the present study area is lower relative to the reference samples except for the China clay. Generally, the chemical characteristics are quite consistent with the results obtained from other sedimentary kaolin deposits in Nigeria [19].

Physical Characteristics

Geotechnical evaluation results are presented in Table 4. Average Plastic and Liquid limits for the Share samples are 20.21% and 44.5% respectively while for the Agbaja samples, they are 15.6% and 33.6% respectively. These suggest that they are dominated by kaolinites. Bain [25] proposed that the plasticity limit of kaolinite is usually not greater than 40 and this tend to distinguish them from halloysites and other clay types. Plasticity index values of the clays from Share range from 21.86 to 27.1% which suggest high plasticity. Average Plasticity index for the Agbaja clay is 17.7 and is interpreted as medium plasticity [26]. The relatively higher plasticity recorded for Share clays may be attributed to their fineness. A direct relationship between percentage of fines in clays and plasticity was reported by [27, 24]. Generally, the clays are plastic enough and thus have potential for being molded to shapes.

Plot of the plastic index versus liguid limit values shows that the Agbaja and Share clays are of low compressibility to medium compressibility respectively and inorganic (Fig. 6). This is in line with interpretation according to [28] which indicates that the Agbaja clays with average liguid limit less than 35% are of low compressibility while the Share clays with average liguid limit of 44.5% are of intermediate compressibility. The average bulk density values obtained ranges for the Share and Agbaja clays are 1.47 and 1.51 g/cm3 and the specific gravity values are 2.60 and 2.65 respectively. According to Bowles [29]

classification, clay of specific gravity less than 4.0 is classified as inorganic. This deduction is supported by the low ignition loss shown by the clays which is indicative of little or no organic content. The linear shrinkage of the clays from Share is higher (average of 10.05%) compared to that of the Agbaja clay (average of 2.66%). The shrinkage limit is comparable to those of known sedimentary and residual clays in Nigeria [30, 24 and 19].

Table 1: Elemental Composition of Agbaja and Share Clay Deposits

Clay Deposits		(Wt %)										(ppm)		
		SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	TiO_2	P_2O_5	Pb	V	Cu
Agbaja (Southern Bida Basin)	GB1 I	66.7	23.98	2.39	0.09	0.16	0.04	0.43	<0.01	0.35	<0.01	4.1	23	4.4
	GB1 F	74.7	15.61	1.66	0.05	0.03	0.05	0.02	<0.01	0.63	<0.01	2.1	46	1.5
	GB1 J	48.5	34.23	0.75	<0.01	0.02	<0.01	0.02	<0.01	1.66	0.07	1.1	110	1.6
Share (Northern Bida Basin)	TG4L	57.9	26.98	1.01	0.05	0.07	0.02	0.2	<0.01	2.07	0.12	2.7	4.8	2.5
	TG4G	64.8	20.34	3.47	0.03	0.06	0.05	0.43	0.01	1.37	0.08	4.2	5.1	5.3
	TG5B	64.5	22.74	1.18	0.04	0.08	0.27	0.53	<0.01	1.57	0.06	2.5	5.8	2.1
	SH1C	45.2	37.9	0.41	0.04	0.03	0.01	0.1	<0.01	1.97	0.03	1.6	3.5	1.3

Table 2: Average chemical compositions of the Share/Tsaragi and Agbaja Clays

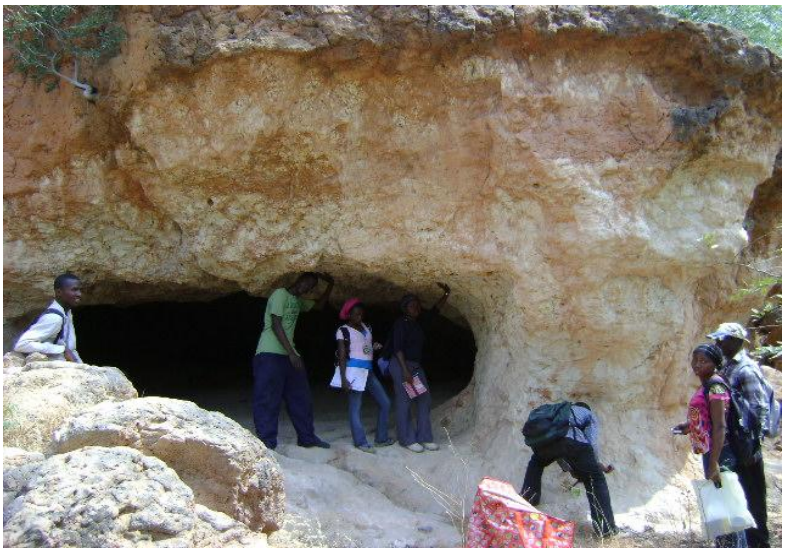
Oxides	Clay Deposits of Northern Bida & Southern Bida		References							
	Share	Agbaja	A	B	C	D	E	F	G	
SiO_2	58.10	63.3	52.92	57.67	46.88	54.22	61.92	60.47	60.7	
Al_2O_3	26.99	24.6	9.42	24.00	37.65	16.99	20.62	17.77	17.7	
Fe_2O_3	1.52	1.6	3.65	3.23	0.88	8.12	5.00	8.18	6.0	
MnO	0.01	0.01	-	-	-	0.38	0.11	0.03	0.0	
MgO	0.06	0.07	0.08	0.30	0.13	2.93	0.71	1.26	1.2	
CaO	0.04	0.04	1.91	0.70	0.03	5.90	0.02	0.47	0.8	
Na_2O	0.09	0.03	0.03	0.20	0.21	0.37	0.14	0.44	0.2	
P_2O_5	0.07	0.02	0.61	0.02	-	0.43	-	-	-	
K_2O	0.32	0.15	0.98	0.50	1.60	0.41	0.63	1.17	1.4	
TiO_2	1.75	0.88	-	-	-	0.25	3.20	-	-	
H_2O	-	-	-	-	-	9.96	10.69	9.72	10.	

(D) Abeokuta Clay (Elueze and Bolarinwa, 2001)

(A) Florida Active Kaolinite (Huber, 1985) (E) Abraka Clay (Emofurieta et al.1994)

(B) Plastic Fire Clay, St. Louis (Huber, 1985) (F) Isan Clay (Elueze and Bolarinwa, 1995)

(C) China Clay (Huber, 1985) (G) Ara-Ijero Clay (Elueze and Bolarinwa, 1995)

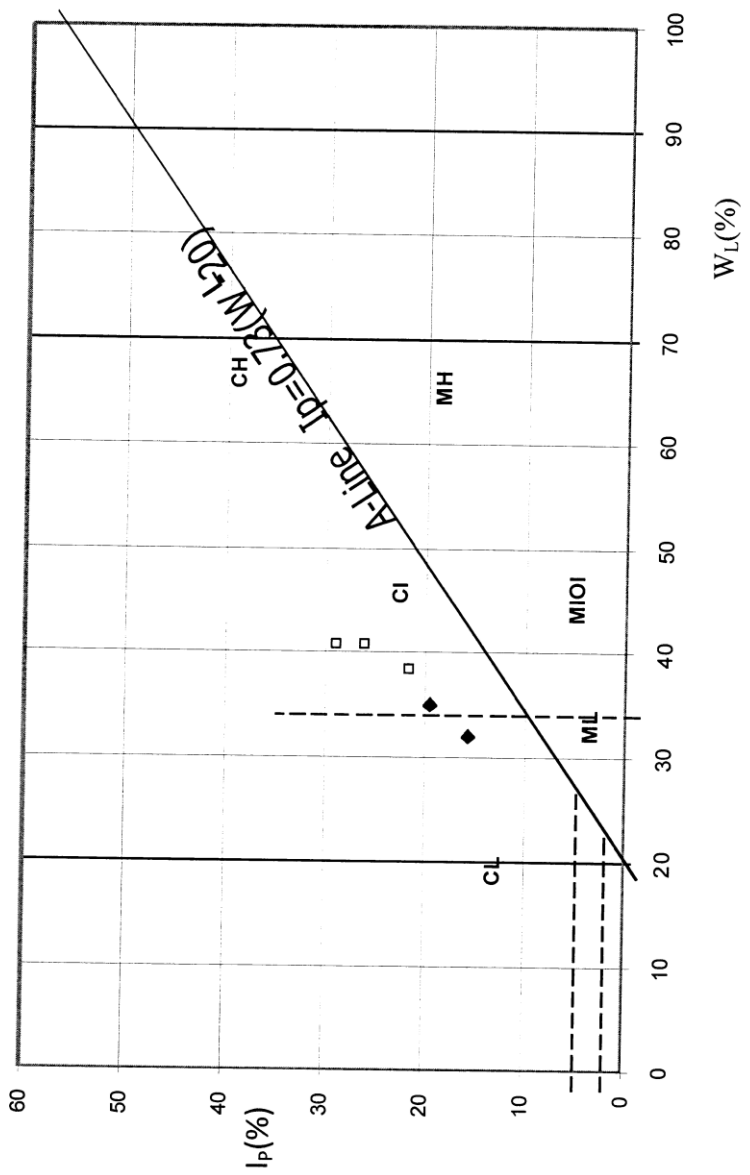


a



b

Fig. 5: Floodplain claystone interbedded with mature tidal channel sands west of Share ridge, showing (a) artificial cave created by local mning activities and (b) sampling pit (ca. 1.5m deep).



△ Agbaja Clay

▫ Share Clay

Fig. 6: Composite plasticity chart of the clay samples (after Casagrande, 1943)

Table 3: Comparison of the Share and Agbaja clays with some industrial chemical specifications

Element (Oxides)	Clay Deposits of Northern Bida & Southern Bida Basins		Some Industrial Specifications		
	*Share	**Agbaja	1 (%)	2 (%)	3 (%)
SiO_2	58.10	63.3	48.67	67.50	51.0-70.0
Al_2O_3	26.99	24.6	9.45	26.50	25.0-44.0
Fe_2O_3	1.52	1.6	2.70	0.50-1.20	0.2-0.7
MnO	0.01	0.01	-	-	-
MgO	0.06	0.07	8.50	0.10-0.19	0.2-0.7
CaO	0.04	0.04	15.84	0.18-0.30	0.1-0.2
Na_2O	0.09	0.03	2.76	0.20-1.50	0.8-3.5
P_2O_5	0.07	0.02	-	-	-
K_2O	0.32	0.15	2.76	1.10-3.10	-
TiO_2	1.75	0.88	-	-	-
H_2O	-	-	3.04	12.0-12.5	-

*Average values for four samples ** Average value for three samples

1) Paints (Payne, 1961)

2) Ceramics (Singer and Sonja, 1971)

3) Refractory Bricks (Parker, 1967)

Table 4: Summary of geotechnical analysis result for claystone from Northern and Southern Bida Basin

Agbaja (Southern Bida Basin)							
SAMPLE NO	**M C (%)**	**BD (g/cm^3)**	**S G**	**L L (%)**	**PL (%)**	**I P (%)**	**S L (%)**
GB1I	2.5	1.52	2.65	35.0	15.5	19.5	2.65
GB1J	2.1	1.50	2.67	32.0	16.3	15.7	2.67
GB1F	2.2	1.50	2.64	34.0	16.1	17.9	2.65
TOTAL	6.8	4.52	7.96	101.0	47.9	53.1	7.97
MEAN	2.66	1.51	2.65	33.60	15.96	17.7	2.66
Share (Northern Bida Basin)							
SAMPLE NO	**M C (%)**	**BD (g/cm^3)**	**S G**	**L L (%)**	**PL (%)**	**I P (%)**	**S L (%)**
TG 4G	3.8	1.52	2.60	45.0	23.14	21.86	11.4
SH 1C	2.1	1.48	2.60	44.0	18.10	25.9	11.0
TG 4L	2.7	1.41	2.56	40.0	17.7	22.3	7.2
TG 5B	3.0	1.48	2.67	49.0	21.9	27.1	10.6
Total	11.6	5.89	10.43	178	80.84	97.16	40.2
Mean	2.9	1.47	2.60	44.5	20.21	24.29	10.05

MC=Moisture content BD=Bulk Density LL=Liquid limit

S.G=Specific gravity PL=Plastic Limit

IP=Index of plasticity SL=Shrinkage Limit

Resource Potential

The physical and geochemical features of the analyzed samples from southern and northern Bida basins show they are kaolinitic clays and can be utilized for some industrial purposes. On the basis of observed features like; white coloration, fine particles and moderate alumina content and high plasticity, the kaolinitic clays can be used in paint manufacture since it meets the specifications [31]. The chemical composition of the investigated clays which compares with China clays [21] and other Kaolinitic Clays in Ibadan, Kaduna [32 and 18] suggest that the deposits can also serve as raw material for the Ceramic industries. The adequate mouldability, moderate shrinkage values, toughness suggest the clays are suitable for pottery and ceramics [33, 34, and 30]. It is important to note also that the typical high SiO_2 but low CaO, MgO and Na_2O shows that the clays in both location are amenable to beneficiation to achieve appropriate grade for manufacturing of sanitary hard wares. Another significant characteristic of the clays is their low concentrations of the heavy metals (Table 1) and thus meeting the specifications for raw material in the chemical industries for the manufacture of powder, metallurgical products, and as a catalyst.

With respect to economics, the thicknesses of the clays are quite substantial and they are also laterally extensive along the east-west trending ridges in both locations. It is important to highlight however, that despite the favourable physical and chemical characteristics for industrial applications, a major production risk is envisaged. In both locations, the claystones occur in the middle part of the sections with thick (about 30m) sediments of ironstone and sandstone capping them. Open cast mining may not be cost effective here as the cost of overburden removal would be enormous and the environmental impact of having to remove such amount of earth material may be counter productive. A detail assessment of this aspect of would be very significant in future work.

Conclusion

1. The sedimentary clays at Agbaja (southern Bida Basin) and Share (northern Bida Basin) are interbedded with tidal to shoreface quarzarenitic sandstones. The clays were deposited in floodplains adjacent to the channels.
2. The clays are dominated by SiO_2 and Al_2O_3 and the gross composition favourably compare with the Plastic fire clay of St Louis and Florida active Kaolinite and many known sedimentary clays in Nigeria.
3. Physical evaluation indicated that they are dominated by kaolonitic clay and of moderate to low compressibity, medium to high plasticity and inorganic.
4. Both the chemical and physical characteristics show that they may be beneficiated to high grade raw material for paint, ceramics, earth and sanitary wares and chemicals. However the thick overburden may not make the deposit competitive.

Acknowledgements: The authors are grateful to Exxon Mobil Producing, Nigeria and University of Ilorin for their financial support for the fieldwork training programme of the Department of Geology and Mineral Sciences, University of IIorin, during which the mapping aspect of the study was executed. The study also benefitted from stimulating discussions with senior colleagues in the department.

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