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Geology, Mineralogy and Geochemistry of Clay Occurrences within the Northern Anambra Basin, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors with out conflicting issues. Author TSA designed the study, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors SOI, EKA and YBG managed the analyses of the study, result interpretations, literature searches and sampling of deposit. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Clay occurrences at Aloji, Udane Biomi, Ofe-jiji and Agbenema, within Northern Anambra Basin were characterized mineralogically and geochemically in order to investigate its compositional characteristics and petrogenesis. Mineralogical analysis portrays kaolinite as the only observable clay mineral.
Abundances of major oxides show that SiO_2 (69.67 – 90.28%) and Al_2O_3 (5.10 – 15.24%) constitute over 76% of the bulk chemical compositions, the high content of $Si0_2$ shows that the source rocks are rich in quartz and silica-rich minerals confirming the grittiness of the clay. Other oxides are present in relatively very small amounts. The occurrences of Ca0, Na0 and K_20 which are the major components of feldspar in clay suggest the clay to be of granitic origin possibly from Oban Massif, east of the Anambra Basin.
Although notable disparities exist in the SiO_2 and Al_2O_3 contents of the clays, the Udane Biomi is more siliceous and less aluminous than the others whereas, the Aloji clay is more aluminous than others confirming a high degree of weathering activities.
Evaluation of the clays based on their mineralogical and geochemical characteristics

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revealed that they are suitable for the production of refractory bricks only.

Keywords: Mineralogy; geochemistry; clay; weathering; Northern Anambra Basin.

1. INTRODUCTION

Clay is a common name for a number of fine-grained, earthy materials that become plastic and tenacious when moist, and that becomes permanently hard when baked or fired. According to [1] clay is applied both to materials having a particle size of less than 2μ and to the family of minerals that has similar chemical compositions and common crystal structural characteristics.

Clay is a widely distributed, abundant mineral resource of major industrial importance for an enormous variety of uses [2]. In both value and amount of annual production, it is one of the leading minerals worldwide. In common with many geological terms, the term "clay" is ambiguous and has multiple meanings: a group of fine grained minerals — i.e., the clay minerals; a particle size (smaller than silt); and a type of rock — i.e., a sedimentary deposit of fine-grained material usually composed largely of clay minerals [3,4]. In the latter definition, clay also includes fine-grained deposits of non-aluminosilicates such as shale and some argillaceous soils.

Clay minerals are formed in soil environments, as well as under diagenetic and hydrothermal conditions. Chemically, clays are hydrous aluminium silicates, ordinarily containing impurities, for example potassium, sodium, calcium, magnesium, or iron, in small amounts, and are characterized by sheet silicate structures of composite layers stacked along the c-axis [5].

Clay minerals are commonly interested for industrial and medical purposes due to chemical and physical properties. Their application is numerous in literature which may be expressed as follows: diagenetic transformations and initiative of metamorphism; paleosalinity and clay geothemometer and organic maturity indicator; source rock and paleo-environment of sedimentary basin; provenance and stratigraphy studies; the nature and source of clay minerals; petroleum source rock evaluation; effects on net porosity, fluid and hydrocarbon saturation.

Globally, clay has a wide spread occurrence. In Nigeria, clay is widely distributed though not always found in sufficient quantity or suitable quality for modern industrial purposes. More than 80 clay deposits have been reported from all parts of the country. For instance, clay deposits occur in Abak, Akwa Ibom State, Uruove near Ughelli in Delta State, Ifon in Ondo State, Mokola in Oyo State, Sokoto in Sokoto State, Gombe in Gombe State, Umuahia in Abia State, Dangara in Niger State, Onitsha in Anambra State and Aloji, Udane Biomi, Agbenema and Ofe jiji all in Kogi State e.t.c.

The focus of this paper is to investigate the occurrences of claystone within the Northern Anambra Basin as well as to determine its mineralogical and geochemical properties.

2. LOCATIONS AND FIELD OCCURRENCE

2.1 Aloji Clay

Aloji is a town about 35 kilometres from Anyigba, where Kogi State university is located (Fig. 1). Here, at the first location (N 07º24'45˝ and E006º56'17) with sample locations: Aloji, Aloji 1.1, Aloji 1.2 and Aloji 1.3, the entire deposit has a weathered surface as exposed at a road side section but the pit mined reveals a massive dirty white clay of about 9.90 metres thickness, brown and grey clays of 0.75 metre, brown clay of 1.55 metres and conglomeritic sandstone of 0.50 metre (Fig. 2). The clay which is a unit of the Mamu Formation is, therefore, of variable thickness which increases southwards. It is smooth but gradually changes to slightly gritty sandy clay and at the second location within Aloji, (N 07º24'44˝ and E006º56'14) with sample locations: Aloji 2.1, Aloji 2.2, Aloji 2.3, Aloji 2.4 and Aloji 2.5, the entire deposit is highly weathered with dirty white alternating with dark grey and light bands, suggested to be iron oxide, each band is approximately 1cm thick.

2.2 Agbenema Clay

The Agbenema clay, at the first location (N 07º48'00˝ and E007º27'14) and at the second location (N 07º47'47˝ and E007º27'07) with sample location Agbenema 2.1 are exposed at about 30 kilometres NNE of Iyale General Hospital in Kogi State (Fig. 1). The exposed clays are road cuts, very massive and low lying about 200m^2, 15m thick and 20m in length with intercalation of sandstone and clay, the clay is mostly dirty white with little stain of brown which is attributable to oxidation.

2.3 Ofe-jiji Clay

The Ofe-jiji clay (N 07º45'57˝ and E007º26'32˝) with sample location: Ofe -Jiji 2.1 and Ofe-Jiji 2.2 is exposed at about 25 kilometres NNE of Iyale General Hospital in Kogi State (Fig. 1). The exposed clay is a road cut, very massive and extensive about 450m^2, 50m thick and 40m in length with intercalation of sandstone of 1-2.3m thick with clay lenses and it overlies a shale layer. The topography is distinctly rugged with height reaching 277m above sea level. The clay deposit is mostly dirty white with reddish and brownish stains which is attributable to oxidation of the overburden lateritic capping.

2.4 Udane Biomi Clay

The Udane Biomi Clay (N 07º34'55˝ and E006º56'29) with sample location: Udane B. 1.1, Udane B. 1.2 and Udane B. 1.3 is exposed at a top of a hill with an elevation of 323 metres and about 45 kiolometres from Abocho town in Kogi State (Fig. 1). The exposed clay is not massive but miners are mining the deposit, its a road cut with over all thickness of about 5 metres with alternating dirty white at the bottom of 1.1 metres thick, mixed brown and dirty white layer of 1.5 metres thick, brownish layer of 2.4 metres thick and a lateritic capping of 0.3 metres.

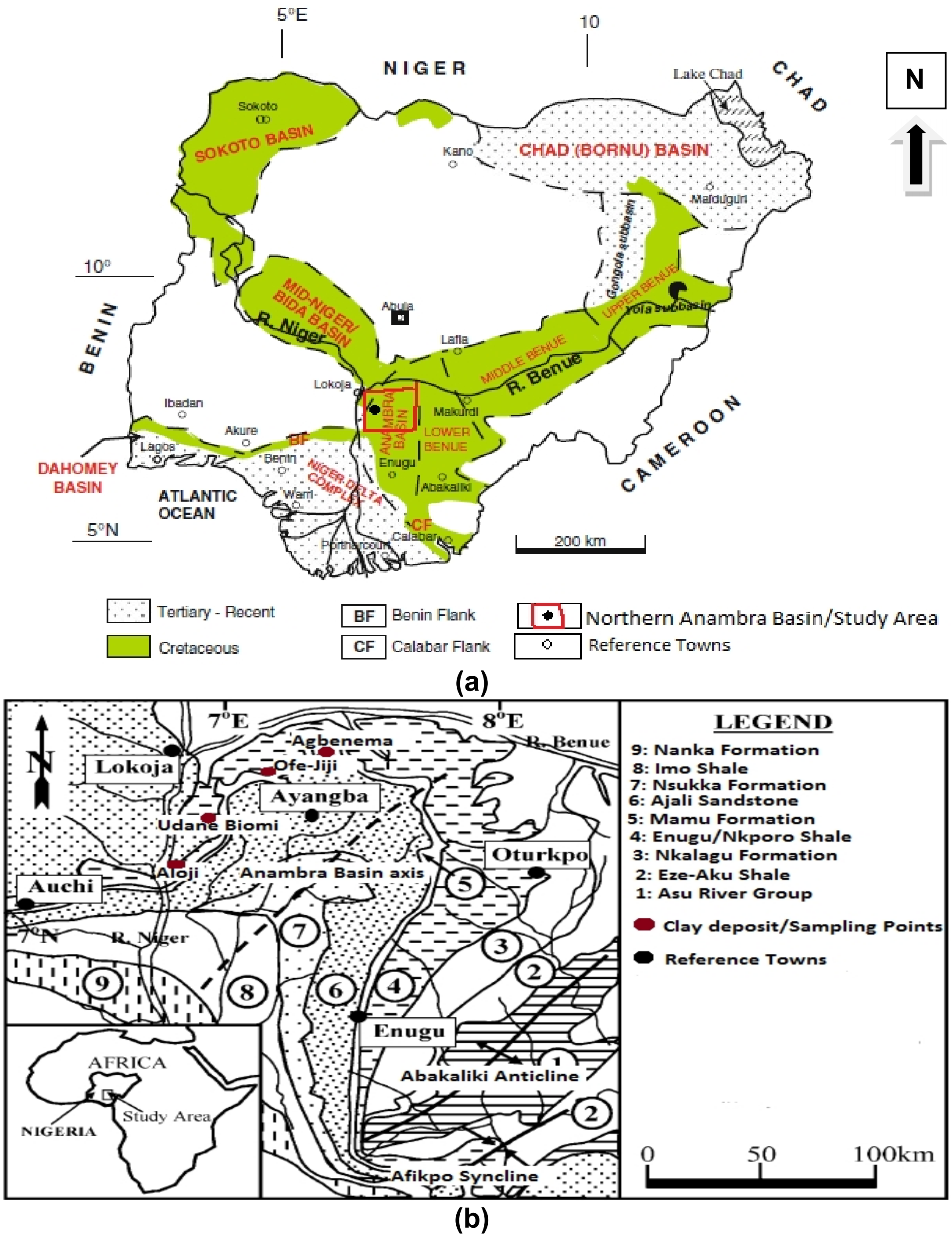

Fig. 1. a) Map of Nigeria showing the Anambra Basin and other Sedimentary Basins of Nigeria; b) Geological Map of Anambra Basin showing the different locations of Clay Deposit/Sampling Points at the Northern Part of the Basin and different Sedimentary Units (Inset: Showing Location of Nigeria and the Anambra Basin)

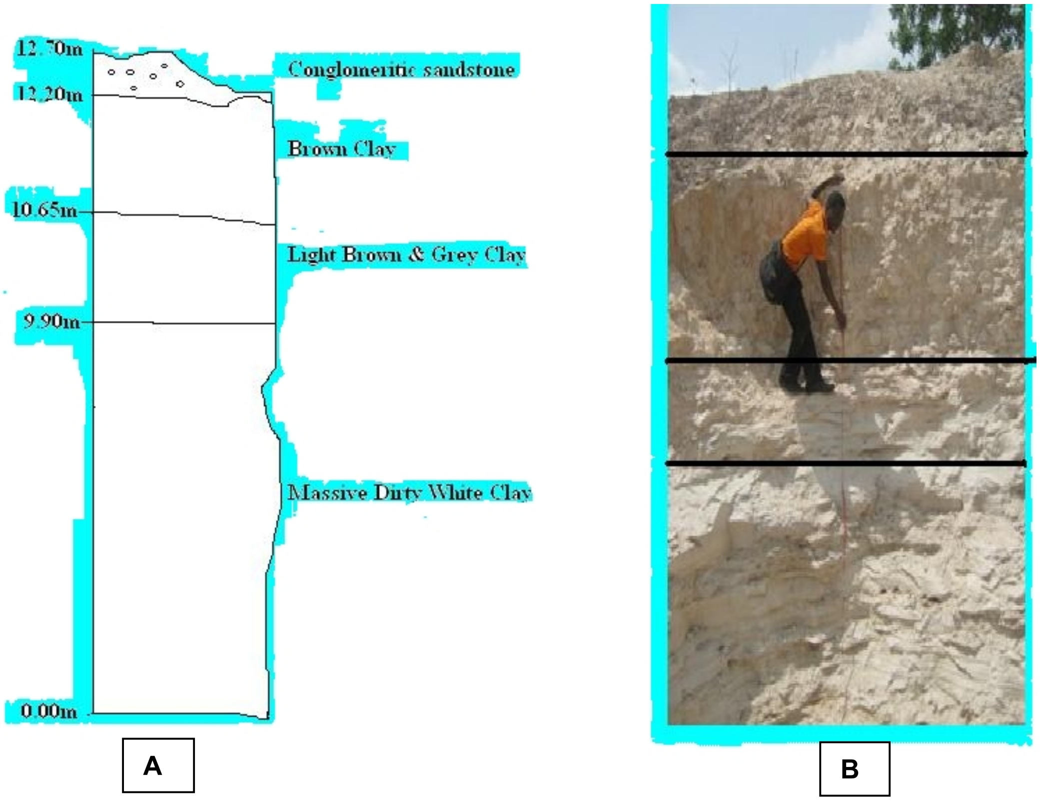

Fig. 2. A: Lithostratigraphy of Aloji Clay deposit and B: The Photograph of the Deposit along Ayingba-Itobe road, Kogi State (N 07º24'45˝ and E006º56'17˝)

3. SAMPLING AND METHODS

Fifteen (15) representative samples were collected from different parts of the clay deposits as exposed along the road in Aloji, Udane Biomi, Ofe-Jiji and Agbenema in Kogi State (Fig. 2). The number of samples was determined by the outcropping pattern of the clay deposit.

A quantitative determination of the mineralogical property of the clay samples using X-ray diffraction were carried out at ACME Analytical Laboratories Ltd, Vancouver, Canada.

To study clay mineral assemblage, the selected samples were subjected to different processes: grinding and homogenization. Grind the dried sample thoroughly with the mortar and pestle. The particles should be much finer than 0.062mm to avoid fractionation of the minerals. The finer the powder the greater the opportunity for obtaining an adequate number of particles with random orientation and less likely the surface roughness will reduce low-angle intensities. The powdered sample was weighed and tested using a PW 1840 automated powder diffraction equipped with a Cu – Kα radiation source, inbuilt standards, Peak/width and a detector.

The angles and intensities of diffractions for each minerals are recorded electronically using a detector, electronics and specialized MDI Jade 5.0 software resulting in a plot of 2θ (horizontal axis) vs. intensity (vertical axis) for the specimen was used, from the angles recorded electronically and which also gives us the area of the peak under d-spacing for each mineral, the mineralogical composition in percentages were done.

Major and trace element composition of the clay samples were determined using Inductively Coupled Plasma-Emission Spectrometry (ICP-ES and Inductively Coupled Plasma-Mass Spectrometry (ICPMS) at ACME Analytical Laboratories Ltd, Vancouver, Canada.

4. RESULTS AND DISCUSSION

4.1 Mineralogy

A sample of the results obtained from the X-ray diffraction analysis is presented in Fig. 3. A summary of the XRD results of the mineralogical in Table 1.

The XRD results of the mineralogical assemblages of the sample, the major minerals present have been indicated against the diagnostic peaks as shown in Fig. 3.

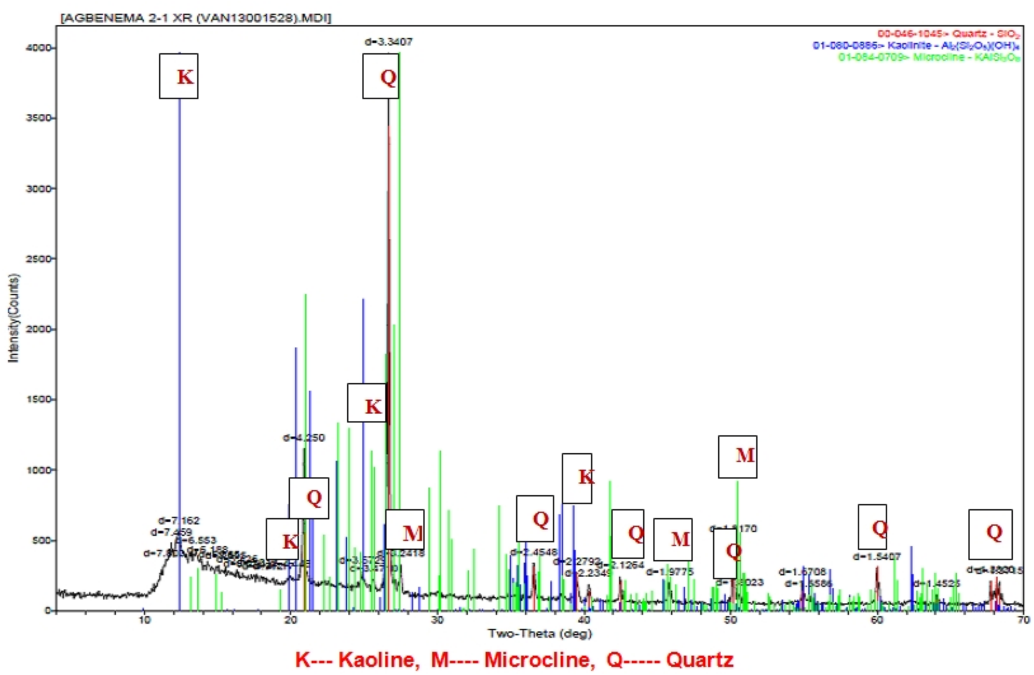

Fig. 3. X –ray diffraction result of Agbenema clay deposit in Kogi State, Northern Anambra Basin

Table 1. Mineralogical composition (in percentages) of clay deposits from different locations in Kogi State, Northern Anambra Basin

Minerals %	Agbenema 2.1 XR	Aloji 1.1 XR	Ofe-jiji 1.1 XR	Udane B. 1.1
Kaolinite	22	26	25	25
Quartz	70	74	70	75
Microline	08	-	5	-

The results of the mineralogical composition of the clay show that the dominant minerals present are kaolinite and quartz, while microclines occur as traces. Of all the mineral presents, kaolinite covered a range of 22 – 25%, Quartz about 70 – 74% and microcline about 5-8%. However, result of the investigated clay deposits differ significantly from those of some well-known kaolin deposits in term of mineralogical compositions. The kaolinite content of Northern Anambra Basin (22-25%) is by far lower than that of Ibadan (91%), China clay (85%), Kaduna (96%), Oza-Nagogo (86%) and NAFCON recommended value (85%). Whereas the quartz content of Northern Anambra Basin clay (60-75%) is far higher than those of Ibadan (6%), Oza-Nagogo (14%), Kaduna (2%), China-clay (traces) and NAFCON recommended value (4%). The Microcline content of the Northern Anambra Basin constitutes about 5-08% which is not present in Ibadan, Kaduna, Oza-Ngogo, china-clay and NAFCON [6,7,8].

The high dominance of quartz in the clay deposits explains its grittiness and also suggests the clay to be of residual origin.

4.2 Whole Rock Geochemistry

Table 2 and Fig. 4 presents the results of chemical analysis showing the different oxide forms of the major elements contained in the clay samples, with a little over 85% of the materials being characterized by ten elements. The remaining 15% of the composition is ascribed to water, trace elements and, perhaps, organic matter. For comparison, typical composition of Okija clay (Onitsha), Ubiaja clay (Edo State), Iyuku (NNW of Auchi), Afam clay and an average clay-shale (AVCS) are shown in Table 3. It was apparent that most clay samples in Table 2 varied slightly regarding SiO_2 as dominant (71.39 – 90.28%), had moderately high Al_2O_3 (6.32 – 19.22%) and a small variation in Fe_2O_3 values (0.28 – 2.06%); they were, however, low in TiO_2, CaO, Na_2O and K_2O. Such low K_2O content indicated the low amount of illite or K-feldspar present [9]. The claystone at Aloji is relatively richer in Al_2O_3 compared to the claystone at Ofe-jiji, Agbenema and Udane Biomi. Most samples had low P_2O_5 content; P_2O_5 depletion could have been due to the lower amount of accessory phases, such as apatite and monazite.

The alkalis (K_2O, Na_2O) as well as MgO and MnO which occur in relatively insignificant proportions are in the range 0.01 to 0.09% that is indicative of the high degree of weathering, under tropical conditions, from which the clay bodies resulted. The claystone MgO and CaO content was low; the samples thus did not indicate associated carbonates or dolomitisation. Claystone silica- alumina ratio was high (8.58) indicating that the claystone were highly siliceous and gritty. The 4.99% average loss on ignition (LOI) for the claystone was high, showing potential for carbonaceous compounds. The average SiO_2 (82.88%) and Al_2O_3 (9.66%) chemical composition in clay constituted about 76% of the samples' total chemical composition. The other chemical impurities in claystone samples from the Mamu formation of the Northern Anambra Basin were Fe_2O_3 (0.73%) and TiO_2 (1.06%).

Table 2. Chemical analysis of the clay samples in percentage

Oxides	Al	Al.1.1	Al. 1.2	Al.1.3	Al.2.1	Al.2.2	Al.2.3	Al.2.4	Al.2.5	Of. 2.1	Of.2.2	Ud.1.1	Ud.1.2	Ud.1.3	Ag.2.1	Av.
SiO_2	83.62	69.67	82.62	75.84	82.81	87.32	85.49	88.77	87.75	84.65	71.39	86.53	90.28	86.43	79.99	82.88
TiO_2	0.98	1.63	1.00	1.41	0.90	0.79	1.08	0.85	0.85	0.97	1.22	1.29	0.66	1.00	1.31	1.06
Al_2O_3	10.05	19.22	10.53	15.24	10.32	7.34	8.73	6.65	7.24	6.32	12.91	7.95	5.10	7.28	9.57	9.66
Fe_2O_3	0.37	0.70	0.32	0.55	0.28	0.33	0.33	0.31	0.39	0.76	1.46	0.41	1.02	1.63	2.06	0.73
MnO	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MgO	0.03	0.07	0.03	0.05	0.02	0.02	0.02	0.02	0.02	0.04	0.12	0.03	0.02	0.03	0.09	0.04
CaO	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Na_2O	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.06	0.05	0.01	0.01	0.01	0.07	0.02
K_2O	0.10	0.33	0.14	0.22	0.07	0.04	0.07	0.04	0.04	1.63	1.19	0.09	0.07	0.07	1.87	0.40
P_2O_5	0.02	0.04	0.02	0.03	0.01	0.01	0.02	0.01	0.01	0.06	0.16	0.04	0.02	0.01	0.03	0.03
LOI	4.7	8.1	5.2	6.5	5.5	4.0	4.1	3.3	3.6	5.2	11.1	2.7	2.7	3.4	4.7	4.99
Sum	99.9	99.8	99.89	99.87	99.94	99.88	99.87	99.98	99.93	99.71	99.62	99.07	99.9	99.88	99.71	
SiO_2/Al_2O_3	8.32	3.62	7.85	4.98	8.02	11.90	9.80	13.35	12.12	13.39	5.53	10.88	17.70	11.87	8.36	8.58

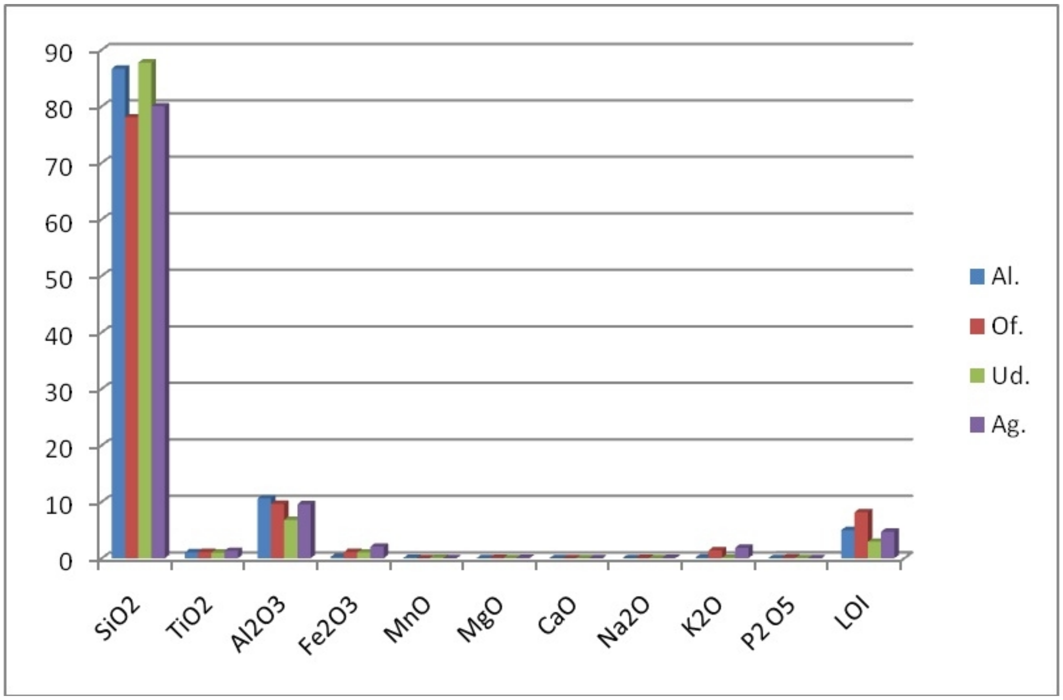

Fig. 4. A plot of major oxides composition of the clay sample
Al.----Aloji, Of.---Ofe-jiji, Ud.---Udane Biomi, Ag.---Agbenema

Table 3. Comparison of the average chemical composition of the studied clays with average chemical composition of other types of clay

Oxide	Al.	Of.	Ud.	Ag.	Okj.	Iyu	Ubj	Af	AVCS	Fl .K	Kutigi
SiO_2	86.65	78.02	87.75	79.99	60.42	64.45	50.41	42.20	58.10	45.57	66
TiO_2	1.05	1.10	0.98	1.31	1.16	0.84	2.73	-	-	0.01	1.45
Al_2O_3	10.59	9.62	6.78	9.57	18.62	20.28	31.62	26.20	15.40	38.45	26.87
Fe_2O_3	0.24	1.11	1.02	2.06	3.42	0.63	2.43	5.10	4.24	0.75	0.99
MnO	0.10	0.01	0.10	0.01	0.02	0.01	0.02	0.03	-	-	-
MgO	0.02	0.08	0.03	0.09	1.28	0.12	0.17	0.70	2.44	0.05	-
CaO	0.01	0.01	0.01	0.01	0.38	0.28	0.11	1.60	3.11	-	-
Na_2O	0.01	0.06	0.01	0.07	0.35	0.18	0.02	2.90	1.30	-	-
K_2O	0.12	1.41	0.08	1.87	1.33	0.42	0.29	8.30	3.24	0.06	-
P_2O_5	0.02	0.11	0.02	0.03	0.03	-	0.14	-	-	-	-
LOI	5.00	8.15	2.93	4.7	11.66	12.02	9.82	10.23	-	-	-
SiO_2/Al_2O_3	8.18	8.11	12.94	8.36	3.24	3.18	1.59	1.61	3.77	1.18	2.46

Al----- Aloji Clay (This present study)
Of.---- Ofe-jiji clay (This present study)
Ud.----Udane Biomi Clay (This present study)
Ag.----Agbenema Clay (This present study)
Okj.---Okija Clay [10]
Iyu.---Iyuku Clay [10]
Ubj.---Ubiaja Clay [10]
Af.----Afam Clay [11]
AVCS.---Average Clay-Shale [12]
Fl.K.----- Florida non-active Kaolinite [13]
Kutigi-----[8]

[14,15,16,17,18] used the ternary diagrams Al_2O_3 -(CaO + Na_2O)-K_2O (the A-CN-K), diagram and Fe_2O_3 + MgO-(CaO + Na_2O + K_2O)-Al_2O_3 (the A-CNK-FM), diagram to deduce weathering trends. On both the A-CN-K diagram (Fig. 5a), and the A-CNK-FM diagram (Fig. 5b), all the sediments display an intense weathering history. The sediments plot in a region clearly suggesting different relative contents in Al_2O_3, CaO, Na_2O, and K_2O and plot closer to high Al_2O_3 contents (Figs. 5a and 5b), which is suggestive of a relatively high intensity of weathering.

Weathering has proceeded to a stage at which significant amounts of the alkali and alkali earth elements were removed from the sediments. Albite was not identified in the samples, indicating that the sediments have reached maturity.

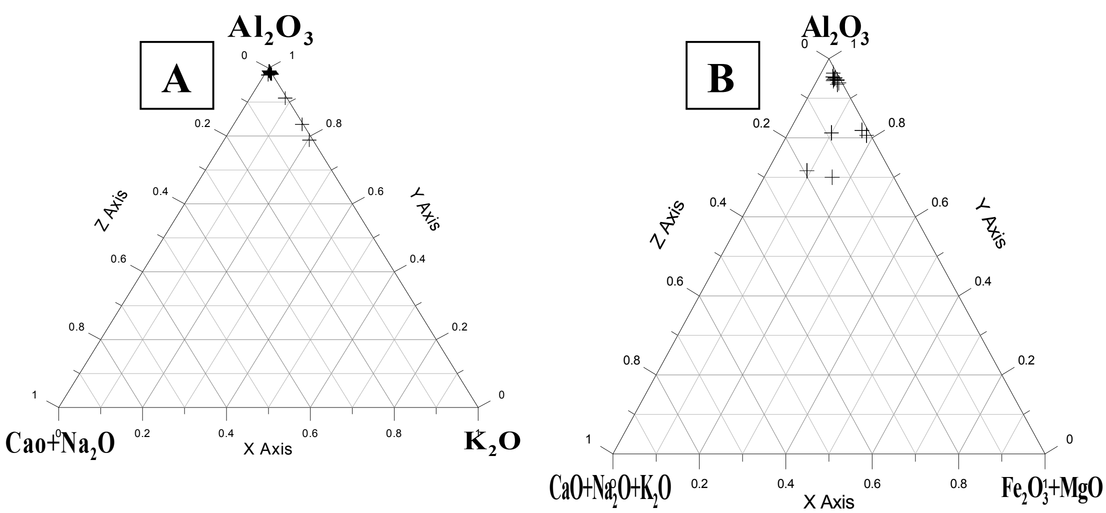

Fig. 5. Ternary Plot of A: Al_2O_3-(CaO + Na_2O)-K_2O and B: Al_2O_3-(CaO + Na_2O + K_2O)-Fe_2O_3 + MgO of clay samples from the Northern Anambra Basin, Nigeria

5. CONCLUSION

Samples of clay from northern Anambra Basin, Nigeria which belong to the Mamu Formation were analyzed in order to determine their mineralogical and chemical compositions and petrogenesis. XRD analyses showed that the sediments are dominated by kaolinite with other none clay minerals such as quartz and microcline.

The Mamu Formation’s Claystone samples showed considerable variation regarding their major elemental composition and properties. The major element varied slightly regarding SiO_2 as dominant (71.39 – 90.28%), had moderately high Al_2O_3 (6.32 – 19.22%) and a small variation in Fe_2O_3 values (0.28 – 2.06%); they were, however, low in TiO_2, CaO, Na_2O and K_2O. Such low K_2O content indicated the low amount of K-feldspar present, this is because rocks rich in feldspar commonly weather to kaolinite, in order to form, ions like Na, K, Ca, Mg, and Fe must first be leached away by the weathering or alteration process. This leaching is favoured by acidic conditions (low pH). Granitic rocks, because they are rich in feldspar, are a common source of kaolinite and this is confirmed by the presence of microline (K-feldspar) in the claystone of the Mamu Formation suggesting its source from Oban Massif, east of the Anambra Basin.

All the sediments display an intense weathering history. From the weathering diagrams (Figs. 5a and 5b), it is possible to infer that the samples underwent a relatively high degree of weathering. Weathering has proceeded to a stage where a major part of the alkali and alkali earth elements were removed. The low CaO contents in sediments indicate their maturity. The sediments plot in a region clearly suggesting different relative contents in Al_2O_3, CaO, Na_2O, and K_2O and plot closer to high Al_2O_3 contents (Figs. 5a and 5b), which is suggestive of a relatively high intensity of weathering.

COMPETING INTERESTS

Authors declare that there are no competing interests.

REFERENCES

1. Velde B. Diagnostic reaction in Clays in sediment diagenesis (Ed. A., Parker and Sellword, B.W. D. Raidal Publ. Comp. 1981;427.
2. Ampian SG. Clays. In: Mineral facts and problems. Washington, DC, US Bureau of Mines Bulletin. 1985;675:1–13.
3. Patterson SH, Murray HH. Clays. In: Lefond SI ed. Industrial minerals and rocks, 5th ed. New York, American Institute of Mining, Metallurgical, and Petroleum Engineers. 1983;585–6
4. Bates RE, Jackson JA, ed. Glossary of geology, 3rd ed. Alexandria, Virginia, American Geological Institute. 1987;65, 123, 262, 432.
5. Grim RE. Clay mineralogy. Mc Graw-Hill Book Co., New York. 1968;596.
6. NAFCON. Tender Document for the supply of Kaolin from Nigeria sources; 1985.
7. Coker SA, Emofurieta WO, Kayode AA. Mineralogy, Geochemistry and Economic Evaluation of the Kaolin Deposits near Ubulu-Uku, Awo- Omama and Buan in Southern Nigeria. Journal of Mining and Geology. 1992;28(2).
8. Akhirevbulu OE, Amadasu CVO, Ogunbajo MI, Ujuanbi O. The Geology and Mineralogy of Clay Occurrences around Kutigi Central Bida Basin, Nigeria. Ethipian Journal of Environmental Studies and Management. 2010;3:49-56.
9. Akpokodje EG, Etu-Efeotor JO, Olorunfemi BN. The composition and physical properties of some ceramic and pottery clays of South Eastern Nigeria. Journal. Mining and Geology. 1991;27:9-15.
10. Onyeobi TUS, Imeokparia EG, Ilegieuno OA, Egbuniwe IG. Compositional, Geotechnical and Industrial Characteristics of Some Clay Bodies in Southern Nigeria. Journal Of Geography and Geology. 2013;5(2):73-84.
11. Jubril MD, Amajor LC. Mineralogical and Geochemical aspects of the AFAM Clay (Miocene) Eastern Niger Delta, Nigeria. Journal Of mining and Geology, 1991;27(1):95-105.
12. Pettijohn FJ. Sedimentary Rocks, 2nd edn. Harper & Row, New York; 1957.
13. Huber JM. Kaolin Clays, Huber Coperation (Clay Division), Georgia, U.S.A.; 1985.
14. Nesbitt HW, Young GM. Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. Nature. 1982;299:715–717.
15. Nesbitt HW, Young GM. Prediction of some weathering trends of plutonic and volcanic rocks based on thermodynamic and kinetic considerations. Geochimica et Cosmochimica Acta. Acta. 1984;48:1523–1534.

16. Nesbitt HW, Young GM. Formation and diagenesis of weathering profiles. Journal of Geology. 1989;97:129–147.
17. Nesbitt HW, Young GM. Petrogenesis of sediments in the absence of chemical weathering: effects of abrasion and sorting on bulk composition and mineralogy. Sedimentology. 1996;43:341–358.
18. Nesbitt HW, Young GM, McLennan SM, Keays RR. Effects of chemical weathering and sorting on the petrogenesis of siliciclastic sediments, with implications for provenance studies. Journal of Geology. 1996;104:525–542.

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