International Journal of Geophysics and Geochemistry
2018; 5(2): 45-52
http://www.aascit.org/journal/ijgg
ISSN: 2381-1099 (Print); ISSN: 2381-1102 (Online)

American Association for Science and Technology

Geochemical and Geophysical Investigations of Kaolin Deposits of the Maastrichtian Mamu Formation, Northern Anambra Basin, Nigeria

Baba Yahaya, Omali Aurelius Ojoina, Usman Ayatu Ojonugwa

Department of Earth Sciences, Kogi State University, Anyigba, Nigeria

Email address

babayahaya62@gmail.com (B. Yahaya), omaliaurelius@yahoo.com (O. A. Ojoina), ayatuusman@gmail.com (U. A. Ojonugwa)

Citation

Baba Yahaya, Omali Aurelius Ojoina, Usman Ayatu Ojonugwa. Geochemical and Geophysical Investigations of Kaolin Deposits of the Maastrichtian Mamu Formation, Northern Anambra Basin, Nigeria. *International Journal of Geophysics and Geochemistry*. Vol. 5, No. 2, 2018, pp. 45-52.

Received: March 11, 2018; **Accepted**: April 2, 2018; **Published**: May 30, 2018

Abstract: Geochemical and Geophysical investigation of clay deposits at Ofe-Jiji, Aloji and Udane-Biomi, Northern Anambra Basin, has been carried out in a view of delineating the chemical contents and the thickness of the clay deposit within the study area. Geochemical analysis of the clay deposits were carried out using Minipal 4 XRF Analyser to analyse the chemical contents of the clay deposits while the vertical electrical sounding of the Schlumbergier arrays was used to delineate the lithologic unit across the mapped area. Results of the geochemical analysis reveals that SiO_2 and Al_2O_3 are the major oxides found in the clay deposits. SiO_2 is 65.91% at Ofe-Jiji, 61.53% at Aloji and 70.59% at Udane-Biomi. Al_2O_3 has a reverse trend to SiO_2 ranging from 19.42% at Ofe-Jiji to 21.72% at Aloji, and 16.67% at Udane-Biomi. Minor oxides are Fe_2O_3, MgO, CaO, Na_2O, K_2O, TiO_2, MnO, V_2O_5 and Cr_2O_3. Geochemical parameters, such as Al_2O_3/TiO_2 and SiO_2/Al_2O_3 ratios suggest that the 3 kaolin deposits studied have been derived from intermediate source rocks. Results from the geophysical interpretation show that the average thicknesses of the clay unit at Ofe-Jiji, Aloji and Undane Boimi are 62.7 meters, 14.1 meters and 9.7 meters respectively and the average resistivity values of the clay unit in each of the location are 554.33 Ωm, 583.15 Ωm and 421.77 Ωm. The geochemical results also show that the kaolins meet the criteria for use as, ceramic and brick clay raw materials.

Keywords: Geochemical Analysis, Resistivity Survey, Clay Minerals, Kaolinite, Provenance, Conductivity

1. Introduction

Clay minerals are essential hydrous aluminum phyllosilicates, sometime with variable amount of magnesium or iron replacing wholly or in part the aluminum in some of the clay minerals [20]. Comparing soils along a gradient towards progressively cooler or drier climates, the proportion of kaolinite decreases, while the proportion of other clay minerals such as illite (in cooler climates) or smectite (in drier climate) increases, Such climatically-related differences in clay mineral content are often used to infer changes in climate in the geological past where ancient soil have been buried and preserved. The Ofe-Jiji, Aloji and Udane-Biomi clay deposits lie between Longitudes 7°26′17.7″E, 7°26′31.9″E, 6°56′16.6″E and 6°56′29.3″E and Latitudes 7°45′50.7″N, 7°45′57.8″N, 7°24′44.9″N and 7°34′55.2″N, respectively, within the Anambra basin.

In this work clay is used as a rock and clay mineral for the relatively small number of minerals that occurs as particles that are less than 2μm in size. Geochemical analysis done on the clay deposits helps in identification of possible industrial potentials of the deposits. Again, the conductivity and thickness of the subsurface clay units were delineated using the vertical electrically sounding. This research attempt to re-evaluate and analyses the clay deposits within the study area.

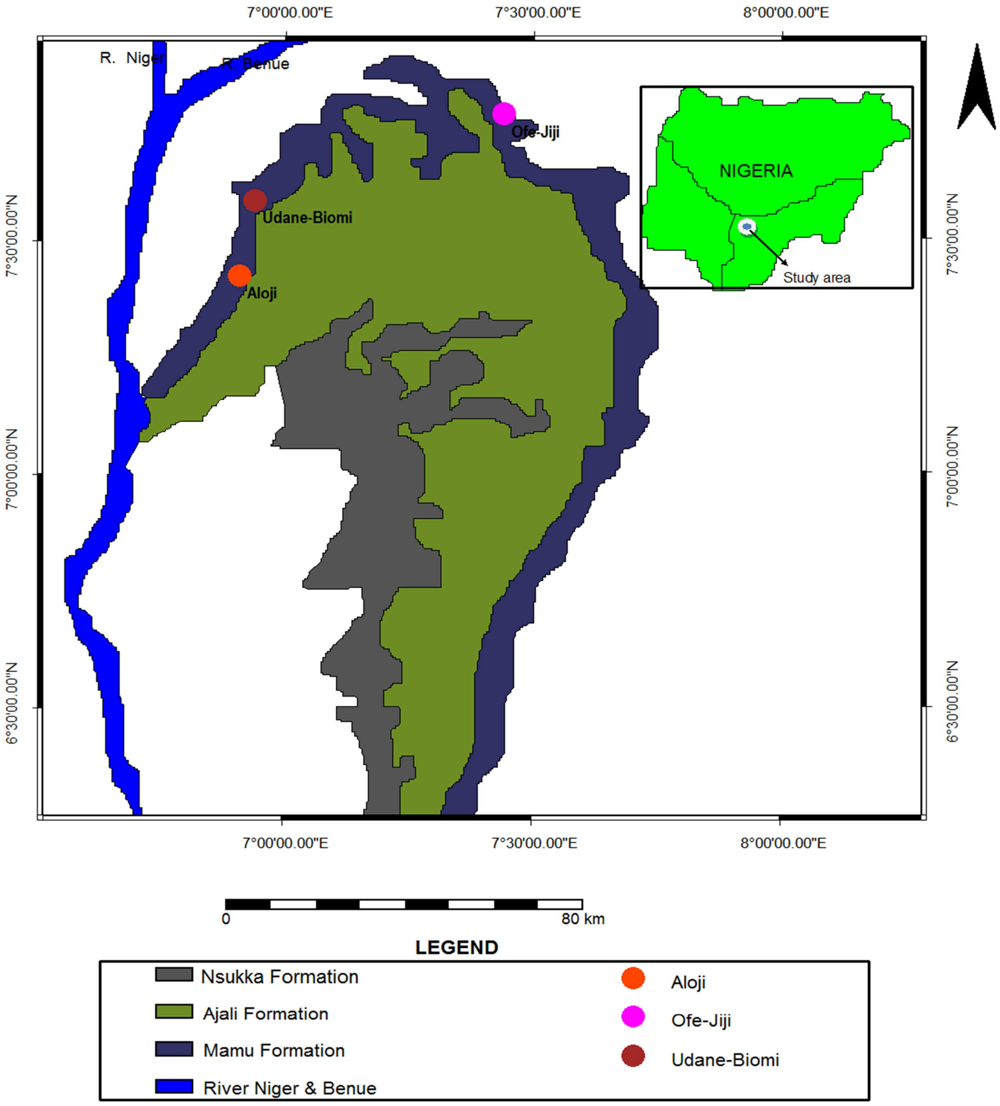

Figure 1. *Geological Map of Anambra Basin Showing the Study Area (modified from Umeji, 2005).*

2. Geology of the Study Area

The Anambra basin is located in the southeastern part of Nigeria. It is bounded to the north by Bida basin and Northern Nigerian massif, to the east by Benue Trough, to the west by West African massif, and to the south by Niger Delta [14]. The Anambra basin is a Cretaceous basin having almost a roughly triangular shape (Figure 1) with a total sediment thickness of about 9km, covers an area of about 40,000 sq.km. It is characterized by enormous lithologic heterogeneity in both lateral and vertical extensions derived from a range of paleoenvironmental settings [1].

According to [1] sedimentation in the Anambra Basin commenced with the Campanian-Maastrichtian marine and paralic shales of the Enugu and Nkporo Formations, overlain by the coal measures of the Mamu Formation. The fluvio-deltaic sandstones of the Ajali and Owelli Formations constitute lateral equivalents that lie on the Mamu Formation. The marine shales of the Imo and Nsukka Formations overlie the Ajali. The tidal Nanka Sandstone of Eocene age overlie the Nsukka Formation. Towards the Niger Delta, the Akata Shale and Agbada Formation constitute the Paleogene equivalents of the Anambra Basin [14].

Enugu and the Nkporo shales represent the brackish marsh and fossiliferous pro-delta facies of the Late Campanian-Early Maastrichtian depositional cycle [16 and 14]. Deposition of the sediments of the Nkporo/Enugu formations reflect a funnel-shaped shallow marine setting that graded into channeled low-energy marshes. The overlying Mamu Formation occurs as a narrow strip trending north-south of the Calabar flank, swinging west around the Ankpa Plateau and terminating at Idah near the River Niger [14]. The Ajali Sandstone which overlies the Mamu marks the height of the regression at a time when the coastline was still concave. The converging littoral drift cells governed the sedimentation and are reflected in the tidal sand waves which are characteristic for the Ajali Sandstone. The Nsukka Formation and the Imo Shale mark the onset of marine transgression in the Anambra Basin during the Paleocene.

This study examines the claystone members of the Mamu Formation at Aloji on the Anyigba -Itobe road, Ofe-Jiji on the Anyigba-Abejukolo road and Udane-Biomi on the Abocho-Ogbabede road.

3. Methodology

Field geological mapping was carried out at Ofe-Jiji; Aloji and Undane-Boimi areas. Detailed examination of the Lithostratigraphy profiles of the exposure at different sampling locations led to the collection of samples from 18 locations for further laboratory study.

The determination of the oxides composition of the clay samples was carried out using Minipal 4 XRF Analyser at National Geosciences Research Laboratory (NGRL), Kaduna. The clay samples were grinded into a fine powdered form and 5g was poured into a sample holder of transparent base and loaded into the automated XRF machine (minipal 4 model). The samples were subjected to an X-ray source which bombard the samples and translate the X-ray photon count-rates into elemental concentrations, followed by the oxides composition of the samples.

Geophysical investigation using the vertical electrical sounding (VES) and Schlumbergier electrode configuration were used to delineate the sub-surface lithology and map the thickness of the clay unit of the study area. This method was applied in the research area at this stage to help in determining the surface resistivity by sending an electrical current into the subsurface and measuring the potential field generated by the current on the resistivity meter (OMEGA). Vertical Electrical Sounding (VES) was conducted at three stations in the study area using Schlumberger configuration. The maximum half-current electrode spacing (AB/2) ranges from 250 to 500m. The survey was conducted along the exposure where samples were collected.

4. Field Descriptions

Ofe-Jiji clay deposit is an extensive outcrop with maximum exposed thickness of 46m and a length of 215m. The hill is steepy around Ajiyolo and fairly gentle around Ofe-Jiji and has poor vegetative covers. It consists of a coarse-grained, thin layer of lateritic overburden of 0.9 – 1.2m thick. The clay outcrop consist of 3 layers, a dirty-white layer of 23m thick at the base, overlaid by thin bands of grayish-white layer and directly below the overburden is a bed of brownish-white clay of 18m thick (Figure 2a,). The clay which is about 36m-46m in thickness, thins out towards Ofe-Jiji village. Exposures of clay at this location occur at six (6) different points on the road cut along the road from Ajiyolo village to Agbenema village.

The Aloji clay is exposed along the Anyigba-Itobe road. It is an extensive outcrop that runs N-S with an average thickness of 12m and a length of 315m.

The bottom layer is 4.5m thick and is dirty-white in colour. The bottom layer is overlaid by another layer of a greyish-white clay of about 6m thick at the middle and directly below the overburden is a bed of brownish-white clay of 3m thick (Figure 2b). Aloji clay which is 10m-12m in thickness, thins out at the either sides of the ridge as exposed by the road cut.

The Udane-Biomi outcrop is exposed along the road leading to Ogbabede town. It is an extensive outcrop that runs NE-SW direction with an exposed thickness of 5.4m and a length of 90m (Figure 2c). The hill consists of an overburden of a mixture of laterite and sandstone. The clay varies from reddish-brown to dirty-white in colour from hand specimen. The decolouration of the clay was probably as result of stains from the laterite overburden.

The Lithostratigraphy of Clay Deposits of the Study Area.

Stratigraphically, the clay deposits in the study area consist of 3 main horizons, based on colour distinction, with lateritic capping being the fourth layer.

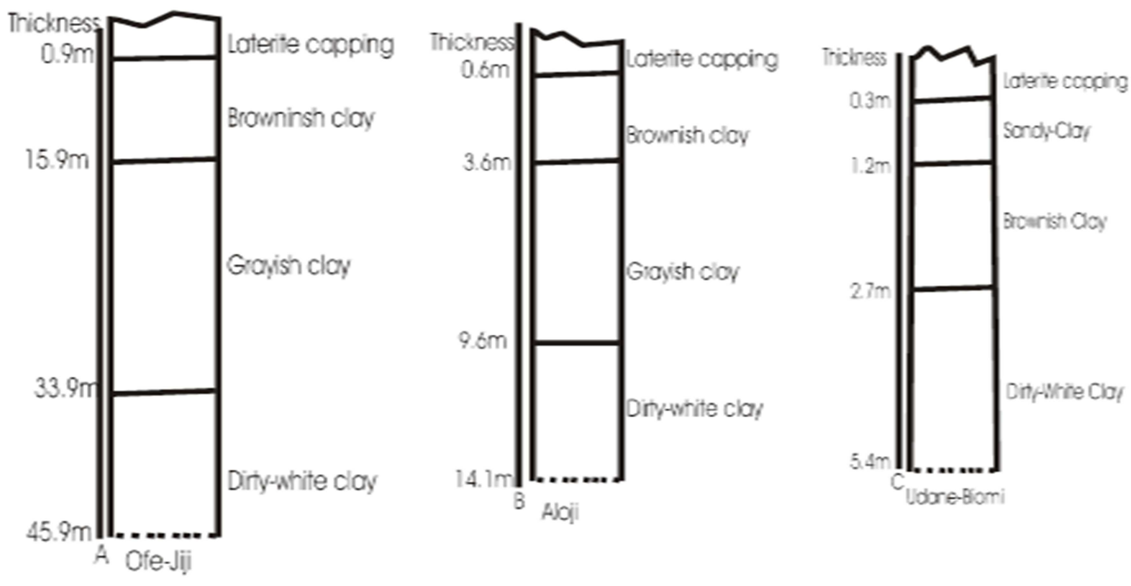

***Figure 2.** A-C Sections across the clay outcrops at Ofe-Jiji, Aloji and Udane-Biomi.*

5. Geophysical Results and Discussion

Result of Geo-electric Section at VES 1 around Ofe-Jiji

Five geo-electric sections are delineated (Figure 3. and Table 1). The topmost layer has a resistivity value of 1005.3 Ω-m, it is 0.9 meters thick and interpreted as top lateritic sand. The second layer is 15.0 meters thick with a low resistivity value of 615.9 Ω-m and interpreted as clayey sand. The next layer has a thickness value of 18.0 meters with relatively high conductivity and interpreted as sandy clay. The fourth layer has a thickness of 12 meters and has a resistivity value of 346.2 Ω-m which is interpreted as dirty white clay. The last layer whose base was not reached has very low resistivity value of 945.3 Ω. Layer two, three and four are delineated as clay unit and they have an accumulated thickness of 62.7 meter.

Result of Geo-electric Section at VES 2 around Aloji

In Figure 4 and Table 2 below, five geo-electri horizons are delineated in this location. The topmost layer has a resistivity of 1130.2 Ω-m and a thickness of 0.6 metres. It is interpreted as top lateritic soil. The next layer has a lower resistivity value of 763.2 Ω-m and a thickness of 3.0 metres. It is interpreted as clayey sand. The third layer has a very high conductivity value and a thickness of about 6.0 metres. It is interpreted as dry sandy clay. The fourth layer has a very high thickness of about 24.5 metres and at a depth of 14.1 meter with a resistivity value of 340.45 Ω-m. It is interpreted as dirty white clay. The last layer whose base is not reached has a very low resistivity value of 890.9Ω-m and it is interpreted as sandy clay. The sum of the clay unit in the VES is 14.1 meters.

Result of Geo-electric Section at VES 3 around Undane-Boimi

The Sounding curve at VES station 3 (Figure 5 and Table 3) is a five layer HK type curve. The first layer is made up of topsoil/clayey sand with a thickness of 3.97 meters and resistivity of 56.93 Ωm. Second layer is composed of Clay, with a thickness of 1.3 meters to a depth of 15.72 meters and resistivity of 511.1 Ωm. The third layer is interpreted as sandy clay with thickness of 2.7 meters to a depth of 10.4 meters and resistivity of 452.9 Ωm. Underlying is the fourth layer which is made up of clay with a resistivity of 301.3 Ωm. The base, which is the last layer, was not reach. The clay unit within this VES has a total thickness of 9.7 meters.

COMPARISON OF VES 1, VES 2 and VES 3

The correlation of the interpreted geo-electric units at VES 1, VES 2 and VES 3 (Figure 6), showed a strong correlation between the three sounding. The resistivity values of the clay with an average of 554.33 Ωm, 583.15 Ωm and 421.77 Ωm respectively for the three sounding point, show a linear relationship between the sounding point. The average thickness of the clay units also shows that the clay unit at Ofe Jiji has the greatest thickness of 62.7 meters with the Aloji Clay having a thickness of 14.1 meters. The Undane Boimi has the last clay unit of thickness 9.7 meters.

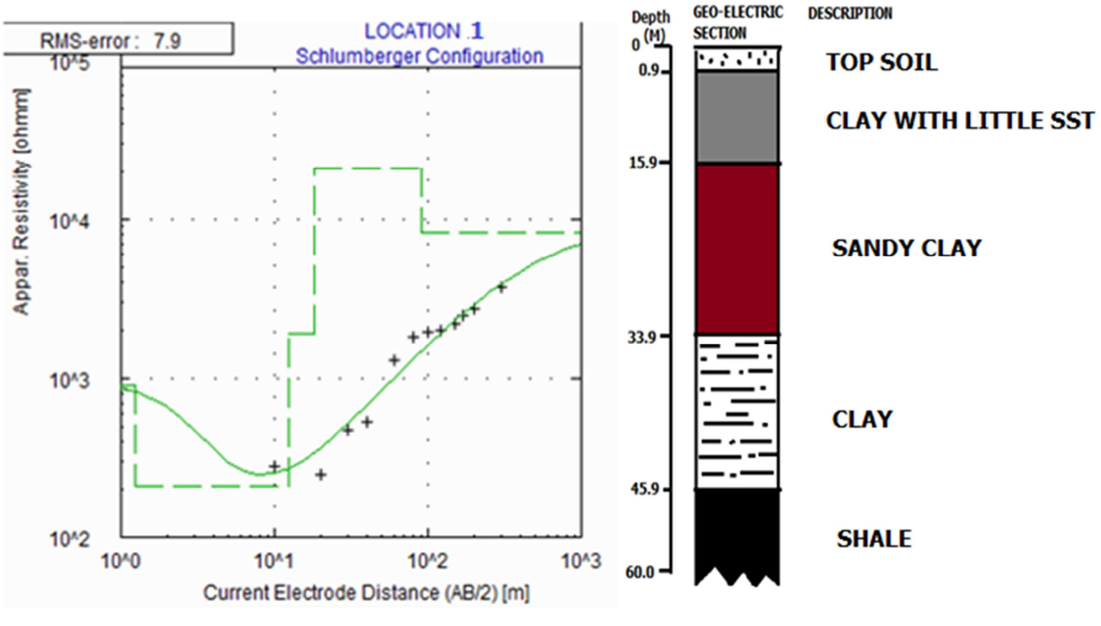

Figure 3. *Sounding curve and descriptive section for VES 1 (KHA-Type).*

Table 1. *Geo-electric section of VES 1.*

OFE-JIJI VES 1				
Layer	$\rho_a(\Omega m)$	**Thickness (m)**	**Depth (m)**	**Remarks**
1	1005.3	0.9	0.9	Top lateritic soil
2	615.9	15.0	15.9	Clayey sand
3	700.9	18.0	33.9	Sandy clay
4	346.2	12.0	45.9	Dirty white clay.
5	945.3	Base Not	Reached	Shale

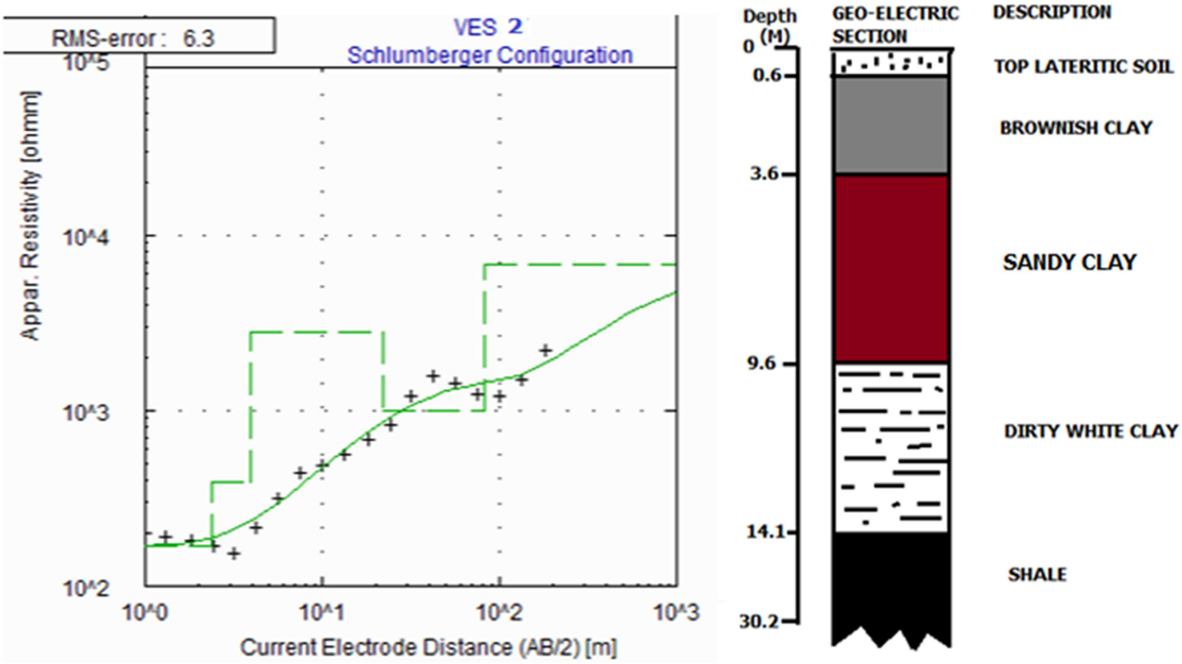

Figure 4. *Sounding curve and descriptive section for VES 2 (KHA-Type).*

Table 2. *Geo-electric section of VES 2.*

ALOJI VES 2				
Layer	$\rho_a(\Omega m)$	**Thickness (m)**	**Depth (m)**	**Remarks**
1	1130.2	0.6	0.6	Top soil
2	763.2	3.0	3.6	Brownish clay
3	645.8	6.0	9.6	Sandy clay
4	340.45	4.5	14.1	Dirty white clay
5	890.9	Base Not	Reached	Shale

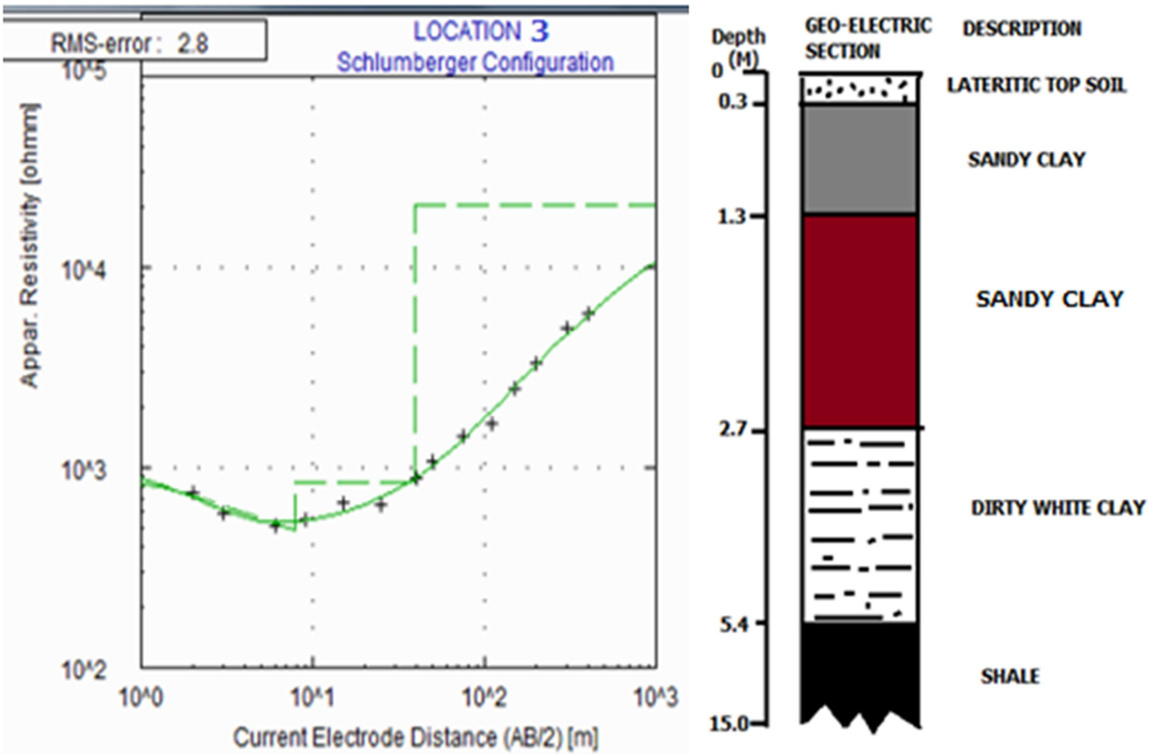

Figure 5. *Sounding curve and descriptive section for VES 3 (HK-Type).*

Table 3. *Geo-electric section for VES. 3*

OFE-JIJI VES 1				
Layer	$\rho_a(\Omega m)$	**Thickness (m)**	**Depth (m)**	**Remarks**
1	5693	3.97	0.3	Top lateritic sand
2	511.1	15.72	1.3	Brownish clay
3	452.9	10.40	2.7	Sandy clay
4	301.3	33.30	5.4	Dirty white clay.
5	940.4	Base Not	Reached	Shale

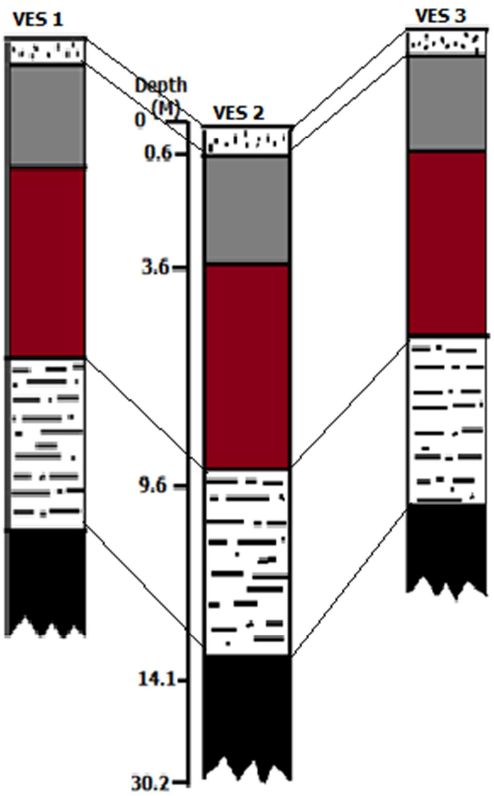

Figure 6. *COMPARISON VES 1 (Ofe-Jiji clay), VES 2 (Aloji clay) AND VES 3 (Udane-Biomi clay).*

6. Geochemical Results and Discussion

The XRF data (Tables 4) for major oxides for the clay samples from the study area indicates predominance of SiO_2 and Al_2O_3 followed by Fe_2O_3, MgO, Na_2O and TiO_2 which are heterogeneously distributed relative to depth. The average SiO_2 values are 65.91wt%, 61.53wt% and 70.59wt% in Ofe-Jiji, Aloji and Udane clay, respectively. The Al_2O_3 mean values of 19.42wt%, 21.72wt% and 16.67wt% in Ofe-Jiji, Aloji and Udane clay, respectively. The Fe_2O_3 contents generally increases upward due to the laterite overburden. The contents of MgO, Na_2O, K_2O, TiO_2, CaO and MnO are low. The clays have moderate loss on ignition which indicates that clays would show no cracks or damage when moulded. It is also observed that the Udane-Biomi clay has the highest SiO_2 concentration of 70.59wt% and lowest Al_2O_3 content compared to Ofe-Jiji and Aloji clays. The observed large amount of silica, alumina and iron contents in the clay samples clearly defined them as Alumino-silicate type. Al_2O_3, SiO_2 and Fe_2O_3 contents of the investigated deposits are similar to the Ibadan, Bida and Ashenge basin clays (Emufurieta, 1988; Okunlola *et al.,* 2012 and Kurkura *et al.,* 2012). Ofe-Jiji samples have an average CIA value of 87.50%, Aloji sample have an average CIA values of 88.50% and Udane-Biomi samples have an average CIA values of 87.02%. The unexpectedly high values of CIA for the fresh samples of clay clearly indicate the fact that primary source material(s) must have been subjected to substantially high degree of weathering and reworking that may have resulted in the destroying of smectite, illite/smeltite and organic matter and leached alkalies, alkaline earths, Fe and other metals. The geochemical signatures of clastic sediments have been used to ascertain provenance characteristics [2 and 4].

Most clastic rocks' Al_2O_3/TiO_2 ratios are essentially used to infer source rock composition because Al_2O_3/TiO_2 ratios increase from 3 to 8 for mafic igneous rocks, 8 to 21 for intermediate rocks and 21 to 70 for felsic igneous rocks [7]. The Al_2O_3/TiO_2 ratios ranged from 7.64 to 12.01 in the clay samples from Ofe-Jiji, 8.44 to 13.72 in the clay samples from Aloji and 7.11 to 17.77 in the clay samples from Udane-Biomi (Table 1). Hence the Al_2O_3/TiO_2 ratios suggested intermediate source for the 3 clay deposits studied.

Ofe-Jiji clay has Silica-Alumina ratio of 3.64, Aloji clay has 2.87 and Udane-Biomi clay has Silica-Alumina ratio of 4.42 (Table 1). The 4.42 Silica/Alumina ratio of Udane-Biomi clay deposit showed that the Udane-Biomi clay is highly siliceous followed by Ofe-Jiji and Aloji clay clay deposits.

Table 4. *Major oxides composition of clay samples from the study area wt%.*

Oxide %	ALOJI CLAY DEPOSIT*							UDANE-BIOMI CLAY DEPOSIT*						
	BB1	**BB2**	**BB3**	**BB4**	**BB5**	**BB6**	**Mean Value**	**BB7**	**BB8**	**BB9**	**BB10**	**BB11**	**BB12**	**Mean Value**
SiO_2	58.63	60.73	71.5	59.25	60.32	58.72	61.53	72.73	62.25	68.57	76.93	77.6	65.43	70.59
Al_2O_3	23.8	22.5	18.4	21.7	22.1	21.8	21.72	14.2	21.5	18.5	13.1	13.6	19.1	16.67
Fe_2O_3	3.33	1.05	0.707	1.37	1.33	1.44	1.54	4.14	4.18	0.922	1.89	0.972	0.812	2.15
MgO	2.28	2.01	3.11	3.12	2.15	2.68	2.56	2.36	3.12	3.01	2.03	2.13	2.17	2.47
CaO	0.290	0.269	0.272	0.241	0.208	0.20	0.247	0.287	0.198	0.206	0.382	0.225	0.313	0.269

Oxide %	ALOJI CLAY DEPOSIT*							UDANE-BIOMI CLAY DEPOSIT*						
	BB1	BB2	BB3	BB4	BB5	BB6	Mean Value	BB7	BB8	BB9	BB10	BB11	BB12	Mean Value
Na_2O	1.84	2.43	1.46	2.37	2.34	2.19	2.12	2.07	2.53	1.96	0.96	1.43	2.68	1.94
K_2O	0.552	0.435	0.242	0.530	0.489	0.473	0.454	0.253	0.314	0.266	0.15	0.085	0.237	0.218
TiO_2	1.93	1.64	2.05	2.57	2.26	2.36	2.14	1.84	1.21	1.41	1.83	1.84	1.20	1.56
MnO	0.017	0.029	0.029	0.031	0.009	0.022	0.02	-	0.019	0.007	0.003	0.009	0.025	0.01
V_2O_5	0.12	0.089	0.077	0.14	0.13	0.13	0.11	0.061	0.082	0.093	0.065	0.082	0.075	0.08
Cr_2O_3	0.028	0.022	0.019	0.036	0.039	0.033	0.03	0.018	0.018	0.020	0.022	-	0.017	0.02
SO_3	-	-	-	0.25	-	-	0.25	-	-	-	-	-	-	-
LOI	7.08	8.26	3.04	8.04	8.62	9.92	7.49	2.04	6.42	5.01	2.63	1.95	7.84	4.31
Al_2O_3/SiO_2	0.41	0.37	0.26	0.37	0.37	0.37	0.35	0.20	0.35	0.27	0.17	0.18	0.29	0.24
SiO_2/Al_2O_3	2.46	2.70	3.89	2.73	2.73	2.69	2.87	5.12	2.90	3.71	5.66	5.71	3.43	4.42
Al_2O_3/TiO_2	12.33	13.72	8.98	8.44	9.78	9.24	10.15	7.22	17.77	13.12	7.16	7.39	15.91	10.69
CIA	-	-	-	-	-	-	88.50	-	-	-	-	-	-	87.02
TOTAL	99.897	99.464	100.96	99.648	99.995	99.968	100.56	99.999	98.721	99.974	99.992	99.923	99.899	95.99

Table 4. *Continue.*

OFE-JIJI CLAY DEPOSIT*									
BB13	BB14	BB15	BB16	BB17	BB18	Mean Value	1	2	3
54.70	70.23	53.74	61.76	78.99	76.06	65.91	63.20	67.79	64.29
25.1	18.2	23.3	20.0	14.1	15.8	19.42	25.61	17.81	13.02
4.78	0.933	2.73	0.958	0.525	0.781	1.78	1.52	1.67	7.9
3.26	2.11	2.28	2.74	1.7	2.11	2.37	0.05	0.13	1.73
0.223	0.218	0.492	0.387	0.237	0.537	0.349	0.10	0.08	2.15
2.54	2.72	2.76	3.01	0.89	1.04	2.16	0.29	0.07	1.25
0.381	0.280	0.667	0.20	0.051	0.049	0.271	1.75	1.63	3.79
2.09	2.16	3.05	1.74	1.38	1.51	1.99	0.22	2.42	0.94
0.023	0.023	0.008	0.034	0.026	0.008	0.02	0.01	0.02	0.23
0.12	0.073	0.18	0.100	0.040	0.067	0.10	-	-	-
0.025	0.014	0.041	0.028	0.018	0.025	0.03	-	-	-
-	-	-	-	-	-	-	-	-	0.01
6.4	2.03	10.64	9.03	2.04	2.01	5.36	-	7.8	-
0.46	0.26	0.43	0.32	0.18	0.21	0.29	-	-	-
2.18	3.86	2.31	3.09	5.60	4.81	3.64	-	-	-
12.01	8.43	7.64	11.49	10.22	10.46	9.76	-	-	-
-	-	-	-	-	-	87.50	-	-	-
99.642	98.991	99.888	99.987	99.997	99.997	101.75	63.20	99.42	64.29

* This study
1) Ibadan residual kaolin [7]
2) Bida claystone [15]
3) Ashenge basin clay [10].

7. Conclusion

Clays from Ofe-Jiji, Aloji and Udane-Biomi, Northern Anambra Basin have been studied using XRF method of analysis. From the results obtained, the following conclusions have been drawn:

1. The chemical compositions indicate that Ofe-Jiji, Aloji and Udane-Biomi clays are chemically composed mainly of silica (65.91wt%, 61.53wt% and 70.59wt%, respectively) and alumina (19.42wt%, 21.72wt% and 16.67wt%, respectively). There was close correlation between the chemical compositions of the 3 clay deposits studied. This similarity in chemical compositions reflects the homogeneity of the Formation which the clay deposits belong to; this may be attributable to uniform depositional conditions for the sediments.
2. Using geochemical parameters, such as Al_2O_3/TiO_2 and SiO_2/Al_2O_3 ratios suggested that the 3 kaolin deposits studied might have been derived from intermediate source rock and the Silica-Alumina ratios indicated that Udane-Biomi kaolin deposit is the most siliceous out of the 3 deposits studied.
3. Results from the geophysical interpretation show that the average thickness of the clay unit at Ofe-Jije, Aloji and Undane Boimi is 62.7 meters, 14.1 meters and 9.7 meters respectively and the average resistivity values of the clay unit in each of the location are 554.33 Ωm, 583.15 Ωm and 421.77 Ωm.
4. A comparison of the geochemical composition of Ofe-Jiji, Aloji and Udane-Biomi clays with [10 and 13] indicate that the deposits in the study area are useful in the ceramic and brick clay industries.

References

[1] Akaegbobi, I. M. (2005). The crab eye view of the organic sedimentological evolution of the Anambra Basin, Nigeria: Hydrocarbon source potential and economic implications. Faculty of Science Lecture University of Ibadan, Ibadan, 42.

[2] Akhirevbulu, O. E., Amadasun, C. V. O., Ogunbajo, M. I. and Ujuanbi O. (2010). The Geology and Mineralogy of clay occurrences Around Kutigi Central Bida Basin, Nigeria. *Ethiopia Journal of Environmental Studies and Management* 3 (3), 49-56.

[3] Badmus, B. S and Olatinsu, O. B. (2009). Geophysical evaluation and chemical analysis of Kaolin clay deposit of Lakiri Village, south Western Nigeria. *International Journal of Physical sciences*. 4 (10) 592-606.

[4] Emufurieta, W. O. (1988). A Comparative Study of two Kaolin Deposits in South Western Nigeria. *Journ. Min. and Geosc. 24, 15-20.*

[5] Ezeh, C. C., 2008. Hydrogeoelectrical estimation of aquifer parameters in Enugu State Nigeria. Unpubl. PhD dissertation, University of Nigeria, Nsukka.

[6] Fatai, O. A., Kenneth, K. A., Peter A. O and Joseph O. B (2014). Characterization of some clay deposits in South West Nigeria. Leonardo Electronic Journal of Practices and Technologies. Issue 25, p. 46-57

[7] Henriet, J. P., 1977. Direct Application of Da- Zarrouk Parameters in Groundwater Surveys. *Geophysical Prospecting*. vol. 24, pp 344-353.

[8] Ibrahim, A. G., Okoli, O. G and Dahiru, D (2016). Comparative Study of the Properties of Ordinary Portland Cement Concrete and Binary Concrete Containing Metakaolin Made from Kankara Kaolin in Nigeria. ATBU Journal of Environmental Technology 9 (5) P 53-59

[9] Keller, G. V. and Frischnechk, F. C., 1979. *Electrical Methods in Geophysical Prospecting.* Program Press: New York, NY. Pp 91-135.

[10] Kurkura *et al*., (2012). Mineralogical and geochemical characterization of clay and lacustrine deposits of Lake Ashenge Basin, northern Ethiopia: Implication for industrial applications. *Momona Ethiopia Journ. Of Sc.(MJS), 4 (2); 111-129.*

[11] Mark, U. and Onyema Obi, O. O. (2009). Assessment of the Industrial Potentials of some Nigerian Kaolinitic Clay Deposits. *Inter. Res. E. Journal of clay deposits.*

[12] Mongelli, G., Cullers, R. L., Muelheisen, S., (1996). Geochemistry of Late Cretaceous- Oligocenic shales from Varicolori Formation, southern Apennines, Italy: Implication for mineralogical, grain-size control and provenance. *Eur. J. Mineral. 8, 733-754.*

[13] Nwajide, C. S. and Reijers, T. J. A. (1996). Geology of the Southern Anambra Basin. In: Reijers, T. J. A. (Ed), Selected chapters on Geology, SPDC, Warri, pp. 133-148.

[14] Obaje, N. G. (2009). Geology and mineral resources of Nigeria. 1st edition Springer Books, Heidelberg. 60-62.

[15] Okunlola, O. A and Olubunmi. I (2012). The geochemistry of claystone-shale deposits from the Maastritchian Patti formation, Southern Bida basin, Nigeria. *Earth Sci. Res. S. J. 16 (2), 57-67.*

[16] Reijers, T. J. A and Nwajide, C. S. (1998). Geology of the Southern Anambra Basin. Unpublshed Report for Chevron Nigeria Limited, Field Course Note 66p.

[17] Short, K. C. and Stauble, A. J. (1968). Outline of Geology of Niger Delta. Bul. Amer. Ass. Petr. Geol. Vol. 54 (5) 761-779.

[18] Taylor, J. H. (1951). Clay Minerals and the Evolution of Sedimentary Rocks. Paper Read 2nd November 1951.

[19] Umeji, P. O. (2005). Palynological study of the Okaba coal section in the Anambra Basin, Southern Nigeria, *Journ. of Mining and Geol. 41 (2), pp. 194.*

[20] Weaver, C. E., (1953). Mineralogy and petrology of some Ordovician K-bentonites and related limestones: Geol. Soc. Amer. Bull. V. 64, Pp. 921-943.