African Journal of Environment and Natural Science Research
ISSN: 2689-9434
Volume 6, Issue 1, 2023 (pp. 90-102)
www.abjournals.org

EVALUATION OF KAOLIN MINERAL EMPLACEMENT AT AMAIHE-UKPOR, ANAMBRA BASIN, SOUTHEASTERN NIGERIA USING SPATIAL LAYER ELECTRICAL RESISTIVITY TOMOGRAPHY

Egwuonwu Gabriel Ndubuisi, Nwafor Ernest Kelechukwu

and Kalu Ugo Egbu

Department of Physics and Industrial Physics, Nnamdi Azikiwe University, Awka Anambra State, Nigeria

gn.egwuonwu@unizik.edu.ng, nwaforernest93@gmail.com, meetugo4good@gmail.com

Corresponding Author: gn.egwuonwu@unizik.edu.ng

Cite this article:

Egwuonwu G.N., Nwafor E.K., Kalu U.E. (2023), Evaluation of Kaolin Mineral Emplacement at Amaihe-Ukpor, Anambra Basin, Southeastern Nigeria Using Spatial Layer Electrical Resistivity Tomography. African Journal of Environment and Natural Science Research 6(1), 90-102. DOI: 10.52589/AJENSR-JM6ISZZV

Manuscript History

Received: 20 Feb 2023

Accepted: 2 April 2023

Published: 18 April 2023

ABSTRACT: *Spatial layer Resistivity tomography was carried out at a Kaolin Mining site in Amaihe-Ukpor of Anambra Basin, southeastern Nigeria. The tomograms were obtained at various depths with the aim of assessing the depths of emplacement of the Kaolin at the site. Firstly, apparent resistivity data Schlumberger-B electrode configuration was obtained from Seventy-five (75) Vertical Electrical Tomography (VES) along 6 transverses at the site. Using the VES data, tomographic plots of spatial distribution of the Kaolin minerals at depths were obtained. Interpreted tomograms showed the occurrence of Kaolin minerals bearing apparent resistivity values in the range of about (900 - 28,900 Ωm) occurrence within the depth range of 0.5 m at layer 2 to 115 m at layer 4 of the site. The tomograms show that layers 2 to 5 indicate traces of the occurrence of Kaolin, layers 2, 3 and 4 particularly showed prominence of the Kaolin. Layers 1 and 6 show no trace of the Kaolin formation enrichment on them. The spatial layer tomograms showed that the prominence of the Kaolin remains at the site occur mostly at the northern and southern zones of the surveyed site. Further mining at the site could lead to tertiary exploitation of the mineral. The site is therefore in threat of gross depletion of the environment. Hence, there is need for suspension of the ongoing extraction of the Kaolin at the site to give room for deposition and sufficient formation of the target mineral.*

KEYWORDS: Kaolin, Spatial Resistivity, Tomograms, depletion, exploitation

Article DOI: 10.52589/AJENSR-JM6ISZZV
DOI URL: https://doi.org/10.52589/AJENSR-JM6ISZZV

INTRODUCTION

Rapid depletion of high grade mineral deposits has become common in recent times due to high rate of exploitation during mining. The ever rising demands of most solid minerals compel miners to carry on with extraction even from deposits of lower grades hence causing environmental damage. Beyond the ecological, destruction of natural flora and fauna, pollution of land, air and water and radiation hazards; high rate of exploitation commonly lead to instability of soil and rock masses, landscape degradation (Aigbedion and Iyayi (2007). Particularly, rapid exploitation of mineral resources leads to partial or complete alteration of the original recognizable image of soil and landscape. Sequel to the thriving environmental setback caused by mineral exploitation, there is need establish control over indiscriminate mining of mineral resources and emphasize on environmental protection of the mineral reserves (Zeman, 2020).

The target mineral in this study is Kaolin, a whitish hydrated aluminum silicate is a fine grained clay mineral having non-abrasiveness and chemical stability (Keller, 1978; Murray, 1988). It is a natural component of soil which occurs widely in most sedimentary Basins either as a product of weathering or hydrothermal alteration of rocks containing Alumino Silicate minerals. Its occurrence is commonly during the decomposition of alumino silicate minerals, especially feldspar and hydrothermal alteration (Singh and Gilkes, 1991). Kaolin occurrence also takes place when rocks undergo hydrothermal alteration through the agency of recirculating hot water. Its deposit is either primary or secondary; the primary deposits originate at site by alteration of minerals while the secondary deposits are sediments which result from transportation from their place of formation. The extensive Kaolinisation in Southern Nigeria has been linked to the prevalence of warm humid climate, which elevates the potentials for development of secondary minerals through enhanced chemical weathering (Akudinobi, 2006). The Kaolin at Amaihe-Ukpor as a secondary Kaolin deposit predominantly. As secondary Kaolin formation site, is purer and relatively of lesser in brightness than the primary formation (Ries, 1927; Keller, 1978; Bristow, 1980; Ekosse, 2005). The purification of the Amaihe-Ukpor secondary deposit most likely occur when they are transported from the place of their primary formation (Murray, 1988). Kaolin has a very wide application; it is of valuable use in construction, textile, paper, agricultural, pharmaceutical, ceramics, electrical, paint, nuclear energy and polymer industries (Murray, 1963; Heckroodt, 1991; Ekosse, 2010; Obaje *et al.*, 2013 and Tassongwa *et al*., 2014). According to Murray (2002) Percentage distribution of Kaolin application is highest in paper industry (45%), then refractory and ceramics (31%), fiber glass (6%), cement (6%), rubber (5%), paint (3%) and others (4%). Before the current stage of exploitation of most Kaolin deposits in Ukpor town; the extracted Ukpor Kaoline was known to be most useful for production of ceramics products. Particularly, one of the ceramic industries in Anambra State was located at Ukpor town but it is currently folded up. To a great extent, there is uncertainty and questions about what the emplacement and quantity the Kaolin remains in the subsurface is at Ukpor town is. The uncertainties call for response. Therefore, it is important to delineate the extent of the depletion of minerals has advanced in most geologic environs. It is hoped that if relevant geo-scientific information is provided at mineral reserve sites; the rate of extraction, safety and conservation of mining would be well controlled.

Geophysical methods would provide information about the subsurface features. Most of geophysical techniques have been proven to be non-invasive, non-destructive, fast, and cost effective. Geophysical information could be linear (vertical or horizontal), two-dimensional

Article DOI: 10.52589/AJENSR-JM6ISZZV
DOI URL: https://doi.org/10.52589/AJENSR-JM6ISZZV

or three-dimensional. However, beyond three dimensional, fourth fifth or more variables could be factored in. The two dimensional geophysical subsurface images (tomograms) could be vertical or horizontal. The horizontal (spatial) images at depths depending on the resolution of the results could delineate the distribution of solid minerals in the subsurface. Hence, the capacity of field layout and it resultant image to distinguish responses of solid mineral deposits from their host geologic environments is vital in the choice of survey method(s). Particularly geophysical technique considered most adequate for delineation of the Kaolin deposits is Electrical Resistivity method. The method is based on the contrast between the electrical properties between the target mineral and its host environment. There is need for geophysical survey in the recent few years at Kaolin enriched mine of Amaihe Nnewi, located in cretateous Anambra Basin, southeastern Nigeria.

This paper is therefore aimed at producing a sequence of downward subsurface layers tomograms generated from measurements of electrical vertical resistivity sounding (VES) to delineate Kaolin mineral remains at the site. In other words, this paper aims at showing tomographic layer maps at depths in order to view the current status Kaolin reserve at various depths at the site. Hence, the uncertainties on where and at what depths of the occurrences are the mineral deposits, quality and shape to certain reasonable extent, would be cleared.

THE STUDY AREA AND SITE

The study site is Amihe in Ukpor town at Nnewi-South Local Government Area, Anambra State, southeastern Nigeria. It is bounded by latitudes $05°55'0''N$ and $05°57'0''N$ and longitudes $06°52'30''E$ and $06°55'0''E$ at average elevation of about 133.52 m above mean sea level. Ukpor town is one of the three famous towns in Anambra state, Nigeria known for Kaolin enrichment. The town spans to about 14 km^2 Area in land mass. The site falls within the tropical rainforest vegetation of Nigeria (Balogun, 2009). The vegetation signature of the area has been altered due to prolong anthropogenic activities such as bush burning and agricultural practices changing the vegetation to that of guinea savanna. Geographically, the area belongs to the tropical rainforest vegetation of Nigeria characterized by thick evergreen tall trees with thick undergrowth ((Balogun, 2009; Iloeje, 2004). Ukpor town and environs experience high rainfall which occurs between April and October having its peak in September (1520 mm to 2020 mm). The area's dry season scarcely characterized by little dusty dry harmattan in December and January wind from Sahara desert falls between November and March having its hottest period between February and April with temperatures range of 25^oC to 32^oC (Iloeje, 1981). The temperature is slightly lowered during the harmattan with associated features such as excessive evaporation, low humidity, arid-natured rainfall and general dryness. The annual pressure in the area ranges from 1010.0 millibars to 10792.9 millibars (Monanu and Inyang, 1975).

The physiographic feature of the area is prominent and known as the Awka-Oraukwu-Orlu Cuesta, characterized by undulating topography. The highlands of the undulating topography are made up of sandstone, siltstone, and pebbles in some areas while the lowlands are mainly shaly terrain covered by clayey overburden, laterites with intercalation of mudstones. Having tropical climate, the rocks are susceptible to weathering hence characterized by various formation of soil horizons. The area's horizonation (horizon formation) is a function of a range of geological, chemical and biological processes and occurred over a long periods of

Article DOI: 10.52589/AJENSR-JM6ISZZV
DOI URL: https://doi.org/10.52589/AJENSR-JM6ISZZV

time (Talabi *et al*., 2012). The lowlands in the area generally less than 100 metres above mean sea level with regional slope of about 20 westwards whereas the uplands are known to be commonly separated from one another by rivers, streams and dry valleys (Okpoko, 2018). The drainage system at the area is dominated by rivers namely; River Ulasi, Ubu, Eze and Ofala which are dendritic (Iloeje, 2004). Figure 1 shows the map of Nigeria showing Ukpor Town in Anambra State, Nigeria.

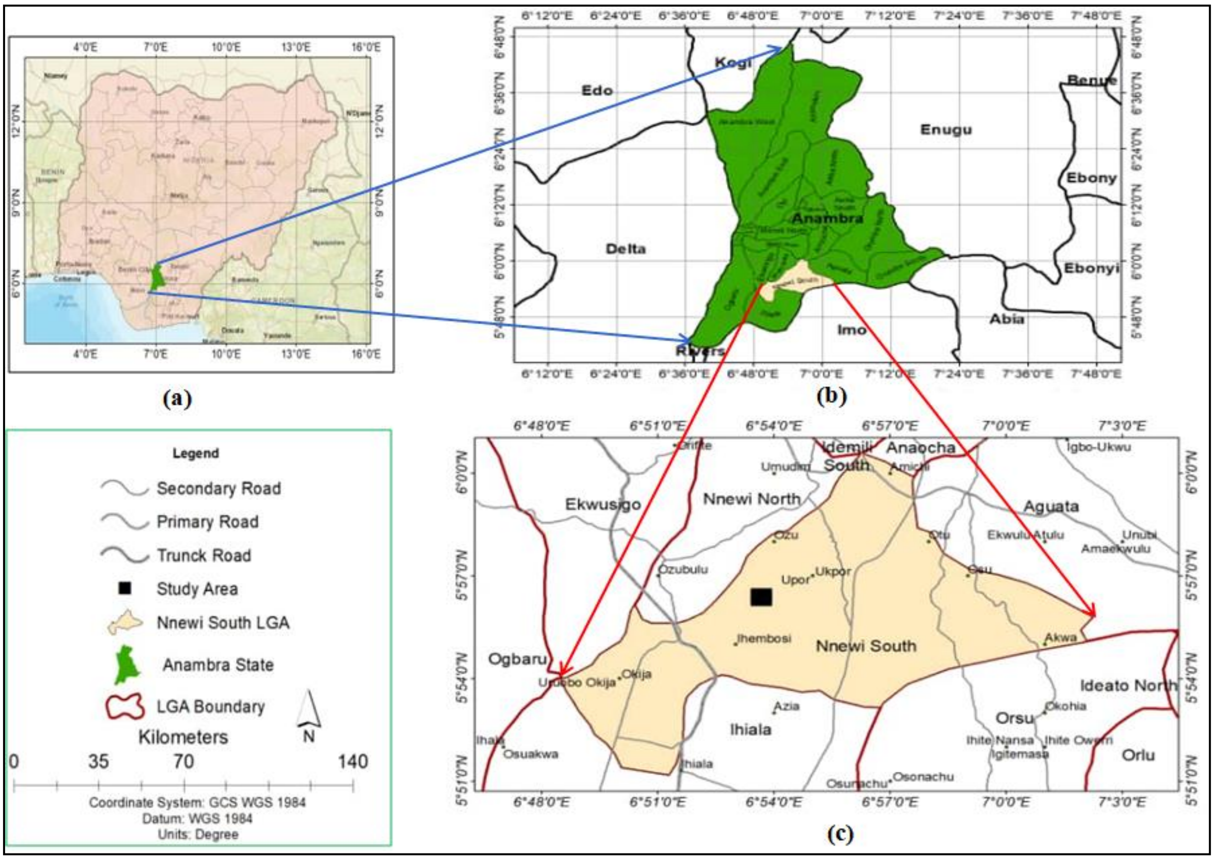

Figure 1: Map of Nigeria showing the study Area and Ukpor Town in Anambra State, Nigeria.

(a) Map of Nigeria showing Anambra State (b) Map of Anambra State showing the Study Area Ukpor-Town in Anambra State, Nigeria.

The Geological Setting of the Study area and site shows that Ukpor town falls within the Anambra cretaceous Basin. The Basin is bounded by Bida Basin at its North, Benue Trough at its East, African Massif at its West and Niger Delta complex at its South (Obaje, 2009). It bears structural synclinal depression and one of the intracratonic Basins in Nigeria. It has roughly triangular shape with sedimentary thickness of about 9.0 km and area of about 40,000 km^2 (Reyment, 1965). The formation of Anambra Basin was due Sanitonian tectonic pulse on a sub-basin by the differential subsistence of the fault blocks in the Southern of Benue trough. It was a Deltaic complex filled with lithostratigraphic unit akin to those of the Cenozoic Niger Delta (Reijers, 1996), and characterized by enormous lithologic

Article DOI: 10.52589/AJENSR-JM6ISZZV
DOI URL: https://doi.org/10.52589/AJENSR-JM6ISZZV

heterogeneity in both lateral and vertical extensions derived from a range of paleoenvironmental settings (Nwajide and Reijers, 1996; Akaegbobi, 2005). Anambra Basin is directly underlain Alluvial plain sands, Ogwashi-Asaba Formation, Ameki/Nanka sands and Imo shale, with varying water storage and yielding capacities. At the current study site's vicinity (Amihe village Ukpor) there is majorly Ameki/Nanka sand formation. Figure 2 shows the base map of the study site superimposed on the site's geological setting.

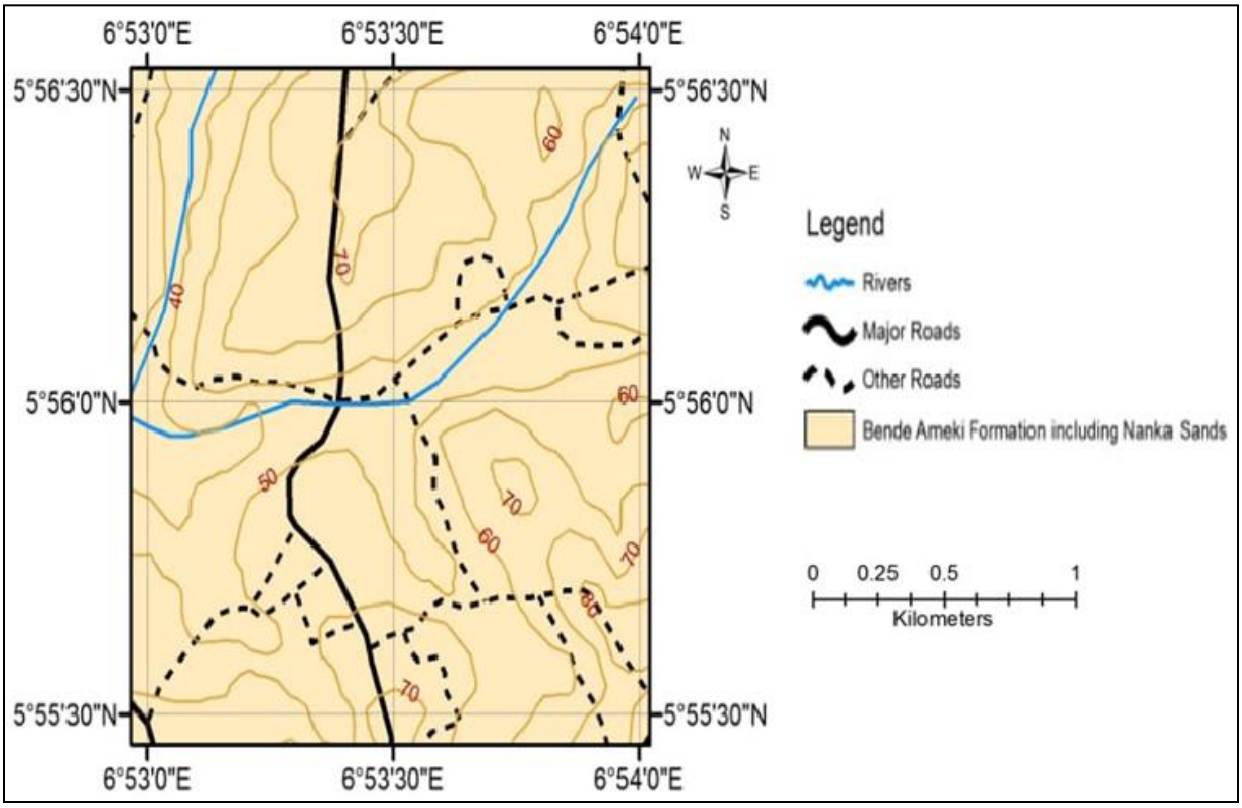

Figure 2: Base Map of the Study Site Superimposed on the Site's Geological Setting

METHODOLOGY

Application of electrical methods in geophysics such as resistivity, self-potential (SP) and induced polarization (IP) are eminent in solid mineral exploration (Sultan *et al.*, 2009). In this study, electrical resistivity method is applied using Vertical Electrical Sounding (VES) technique. The layout geometry used for VES survey (Figure 3a) is Schlumber-B. The geometry was chosen in order to obtain sufficient penetration good signal to noise ratio even at high depths while registering the responses of the subsurface materials to the flow of electric current through it. During the survey, the field crew of five personnel (Figure 3a) ensured adequate symmetrical expansion of the current electrodes about the centre of the spread and commensurate increase of the potential electrode spacing when the potential difference in noticed to has become too small to be measured with sufficient accuracy (looping). The looping was ensured in order to have the measurement detect the near surface in homogeneities in the subsurface. The crew also ensured that all checks and precautionary

Article DOI: 10.52589/AJENSR-JM6ISZZV
DOI URL: https://doi.org/10.52589/AJENSR-JM6ISZZV

measures while taking all measurements at all the transverses. An automated Terrameter namely; *PASI 16GL*, powered by 12V, 60Ah battery with its relevant accessories was used for data acquisition (Figure 3b). Also, precision Global Positioning System (GPS) namely *Garmin-12* was used for the measurement of the coordinates each VES point in terms of longitude and latitude in the national grid and height above the mean sea level of the site. As the spacing between the current electrodes was increased about the centre of spread, the total volume of earth being measured invariably increase as required in the Schlumber-B technique (Figure 3c) configuration (Telford *et al*., 1990; Okwueze *et al*., 1995). Noting that the depth of penetration is proportional to the separation between the electrodes, the variations in the separation of the electrodes delineates the conductivity with which the geoelectric interpretation of the subsurface stratification is made.

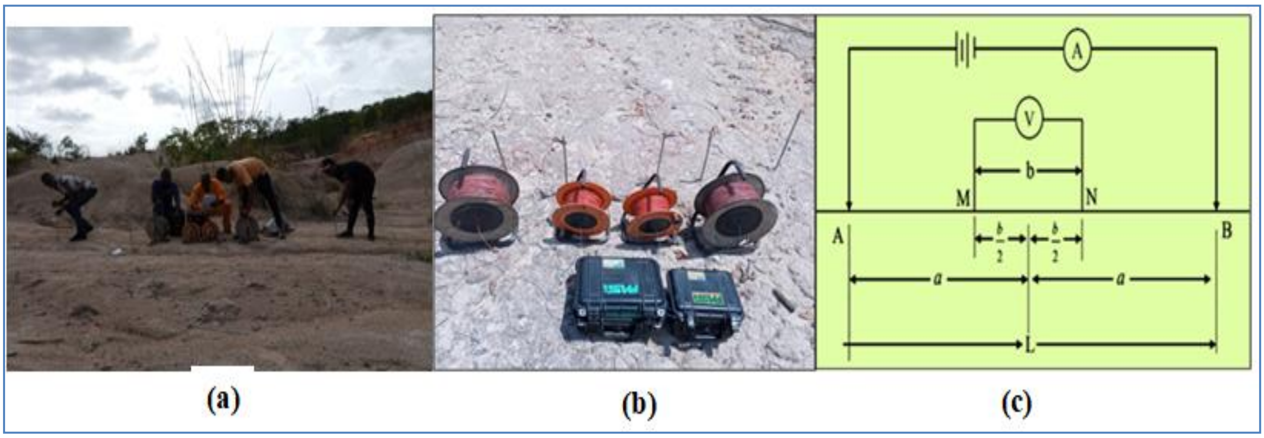

Figure 3: (a) The Field Survey (b), the *PASI 16 GL* Terrameter and Cable Reels (c) Schlumberger Electrode Configuration (Array) Used for Data Acquisition

The Instrument automatically recorded the current and the corresponding potential difference, stacks the results, computes the resistance in real time and digitally displays it. The Slumber-B was carried out at Seventy-five (75) point at the Amihe-Ukpor Kaolin mineral site. A total of seventy five (75) VES stations were acquired points along six (6) transverses. Ten (10) station points of 10.0 m interval were established along three (3) traverses trending in North-South direction and fifteen (15) station points of 10.0 m interval were also established along the other three (3) traverses trending in East-West direction. Figure 4 shows the Seventy-five (75) VES points along the survey transverses showing.

Article DOI: 10.52589/AJENSR-JM6ISZZV
DOI URL: https://doi.org/10.52589/AJENSR-JM6ISZZV

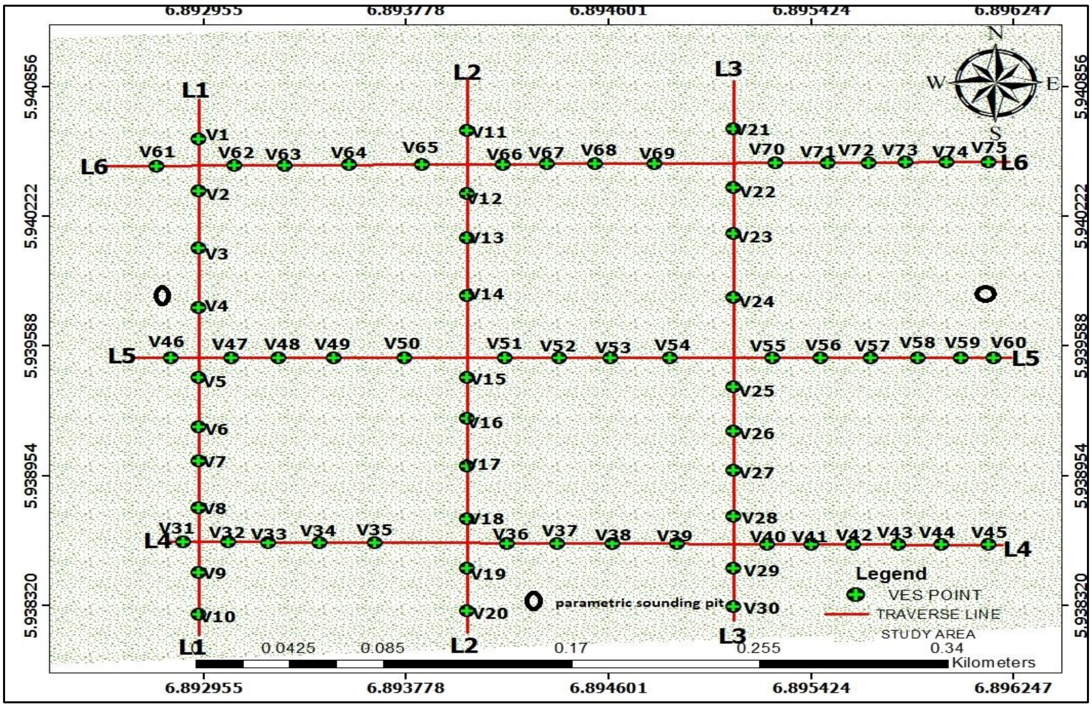

Figure 4: Survey Transverses showing the Seventy-five (75) VES Points.

Readings were taken with specified electrode spacing where current ‘I’ flows through its two current electrodes (AB) for potential difference ‘ΔV’ record between its two potential electrodes (MN) potential. Hence, the geometric factor of Schlumberger Array ‘K’ was applied to the registered data resistance reading was converted to an apparent ground resistivity (Equation 1).

$$\boldsymbol{\rho_a = \pi \frac{\left[\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2\right]}{MN} . \frac{\Delta V}{I}} \quad \textbf{or} \quad \boldsymbol{\rho_a = K . \frac{\Delta V}{I}} \qquad 1$$

The current electrode separation (AB) was varied from a minimum of 2.00 m to 260.00 m while potential electrode separation varied from 1.00 m to 7.00 m. The calculated geometric factor obtained ranges from 6.28 to 14024.97.

Data Processing and Results

Two-dimensional DC electrical resistivity at various depths was acquired for layers using the data acquired from the 75 VES points. Six layer model tomograms bounded by Latitudes Longitudes were obtained from the VES model results. The Schlumberger VES data was modeled into layers using *Resist Graph* software hence the 45th Schlumberger VES model at the survey site is shown (Figure 5). The modeled data were separated into six (6) files for the layers 1 to 6 respectively in *Microsoft Excel-2007*. With the aid of *Surfer-9* software, the 75 layer-1 active data was read, gridded on elapsed time for gridding of 0.05 seconds to obtain

Article DOI: 10.52589/AJENSR-JM6ISZZV
DOI URL: https://doi.org/10.52589/AJENSR-JM6ISZZV

3,100 gridded data mesh (100 rows x 31 columns) whereat the apparent resistivity values of each layer map were plotted. The gridding method used in the *Surfer* software is *Kringing method* of point type upon the gridding geometry range of 6.89 E to 6.90 E longitude and 5.91N to 5.95N latitude. Hence each 2D-tomography map for the layers as defined in the VES interpretation was iteratively plotted.

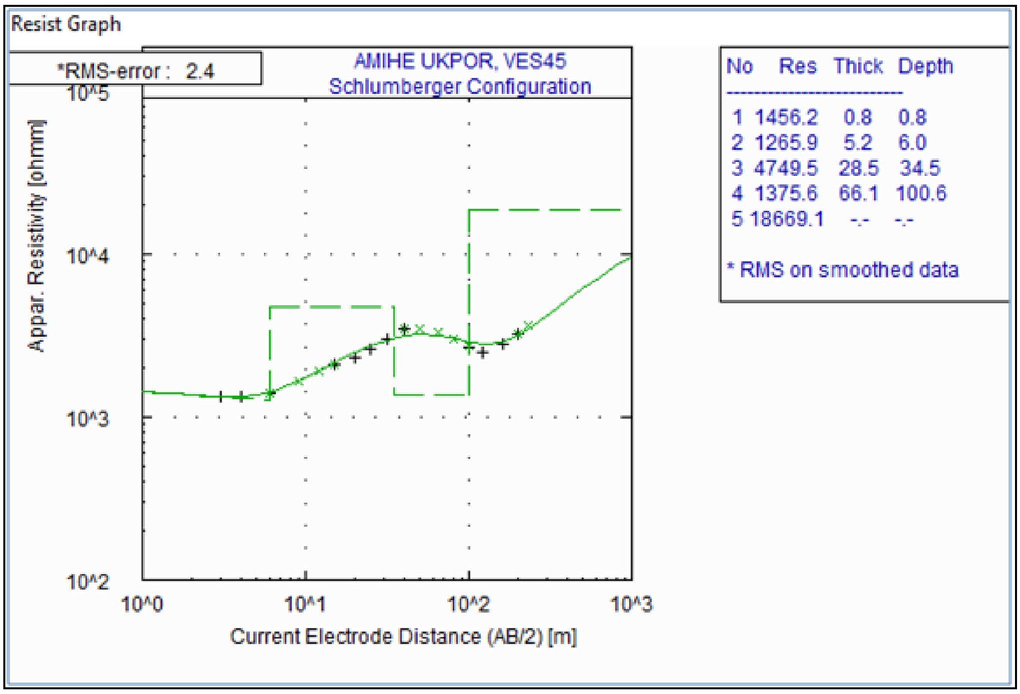

Figure 5: Schlumberger VES Model Plot of the 45th at the Survey Point at the Site

Interpretation of Layers 1 and 2 Tomographic Maps

Figure 5a shows the spatial electrical resistivity tomography map of layer-1 with contour interval of 500 Ωm. This occurs between the depths of 0.5 m and 1.10 m of the Amaihe-Ukpor Kaolin mineral site. The model was generated with apparent resistivity data in the range of 473.60 Ωm to 8786.50 Ωm. This range of layer-1 resistivity is the topmost layer or soil at the Kaolin site (topsoil) encompassing the occurrence of topsoil/laterite (473.60Ωm to 8786.50 Ωm). Figure 5b shows the spatial electrical resistivity tomography map of layer-2 also with contour interval of 500 Ωm. This occurs between the depths of 1.6 m and 18.1 m of the Amihe-Ukpor Kaolin mineral site. The model was generated with apparent resistivity data in the range of 464.60 Ωm to 8160.0 Ωm. This range of layer-2 resistivity is the second layer or soil delineated at the Kaolin site encompassing the occurrence of sandy-clayey (464.6 - 875.6Ωm), Kaolin (899.6 – 4728.2 Ωm) and dry sandstone (6001 – 8160.0Ωm). The layer's map shows Kaolin formation deposit is at the northcentral, southeastern, and southwestern zones of the site. However, most prominently, the Kaolin deposition could be observed to have been deposited most at the southcentral, northwestern and northcentral zones of the site. Occurrence of dry sandstone formation is shows least on the layer.

Article DOI: 10.52589/AJENSR-JM6ISZZV
DOI URL: https://doi.org/10.52589/AJENSR-JM6ISZZV

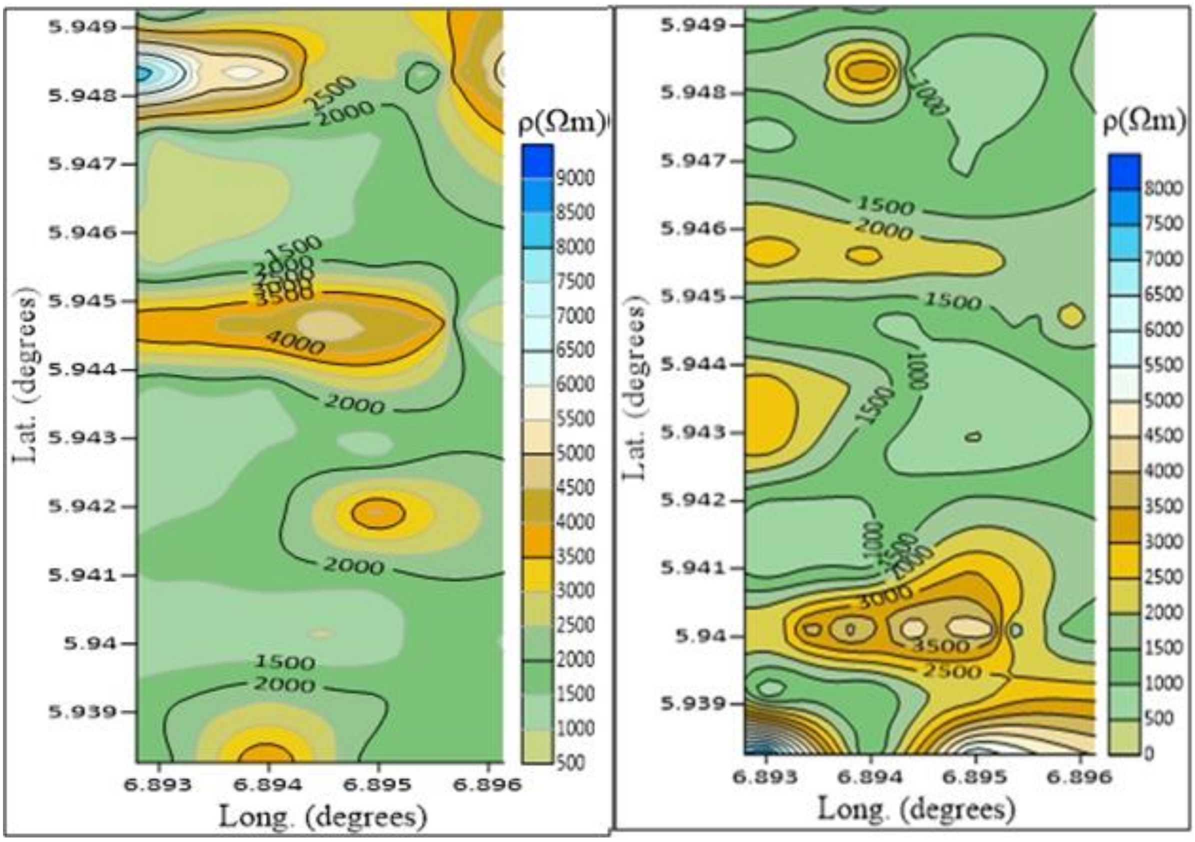

Figure 5: Resistivity Relief Plot for Layer 1 and 2 at Amihe-UkporKaolin Mineral Mine Site

Figure 6a shows the spatial electrical resistivity tomography map of layer-3 with contour interval of 1000Ωm. This occurs between the depths of 6.4 m and 89.4 m of the Amihe-Ukpor Kaolin mineral site. The model was generated with apparent resistivity data in the range of 204.5 Ωm to 21190.6 Ωm. This range of layer-3 resistivity is the third layer or soil delineated at the Kaolin site encompassing the occurrence of Kaolin (927.7-4442.4 Ωm), dry sandstone (5018.5-21190.6 Ωm), sandstone (3091.0 – 5098.3 Ωm), sandy-clay (534.1 Ωm) and clayey sand (279.9 – 634.1 Ωm). The layer's map shows that Kaolin formation is predominant at the northcentral, northeastern, southeastern and southwestern zones of the mine site whereas sandy-clay formation shows least occurrence. Kaolin deposition could be observed to be prominent at the northeastern and southeastern zones of the site. Figure 6a shows the spatial electrical resistivity tomography map of layer-4 with contour interval of 2000 Ωm. This occurs between the depths of 19.7 m and 114.6 m of the Amihe-Ukpor Kaolin mineral site. The model was generated with apparent resistivity data in the range of 364.9 Ωm to 28864.3 Ωm. This range of layer-4 resistivity delineated at the Kaolin site encompasses the occurrence of dry sandstone (5052.5 -28864.3Ωm), water saturated sand (364.9-3144.5Ωm), sandstone (2834.0-5750.6Ωm), Kaolin (1755.9- 4307.1Ωm), sandy-clay (871.9Ωm) and clayey sand (377.9Ωm). The layer's map shows water saturated sandstone formation is predominant and the central northern, eastern and southeastern zones of the site whereas clayey sand and sandy-clay formation shows least occurrence. Kaolin deposition could be

Article DOI: 10.52589/AJENSR-JM6ISZZV
DOI URL: https://doi.org/10.52589/AJENSR-JM6ISZZV

observed to be prominent at the north central, northeast, southeast and mid southern zones of the mineral site.

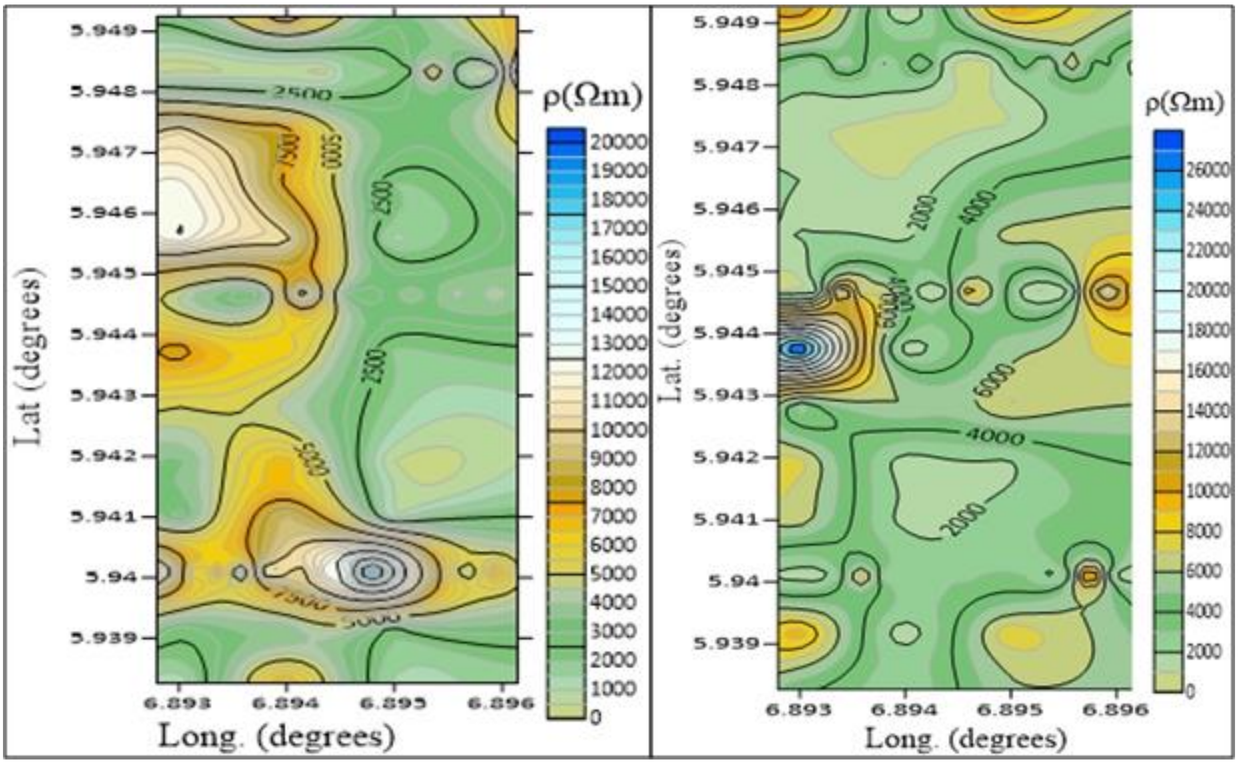

Figure 6: Resistivity Relief Plot for Layer 3 and 4 at Amihe-Ukpor Kaolin Mineral Mine Site.

Figure 7a shows the spatial electrical resistivity tomography map of layer-5 with contour interval of 2000Ωm. This occurs between the depths of 22.5 m and 69.1 m or infinity of the Amihe-Ukpor Kaolin mineral site. The model was generated with apparent resistivity data in the range of 216.4 Ωm to 35040.3 Ωm. This range of layer-5 resistivity is the third layer or soil delineated at the Kaolin site encompassing the occurrence of sandstone (1817.4 -4862.6 Ωm), sandy-clay (469.5-1710.2 Ωm), dry sandstone (5526.0-35040.3 Ωm), water saturated sandstone (216.4-3475.2 Ωm) and Kaolin (2629.0). The layer's map shows dry sandstone formation is predominant and the northwest, southeastern, and southcentral zones of the site whereas Kaolin formation shows least occurrence. Kaolin deposition could be observed at the northcentral and southern zones of the mineral site. Figure 7b shows the spatial electrical resistivity tomography map of layer-6 with contour interval of 1000 Ωm. This occurs at infinity depths of the Amihe-Ukpor Kaolin mineral site. The model was generated with apparent resistivity data in the range of 1079.3 Ωm to 9754.2 Ωm. This range of the sixth layer or soil delineated at the Kaolin site encompasses the occurrence of sandstone (1753.1 Ωm), dry sandstone (9754.2 Ωm) and water saturated sand (1079.3Ωm). There is no trace of the Kaolin formation at this depth.

Article DOI: 10.52589/AJENSR-JM6ISZZV
DOI URL: https://doi.org/10.52589/AJENSR-JM6ISZZV

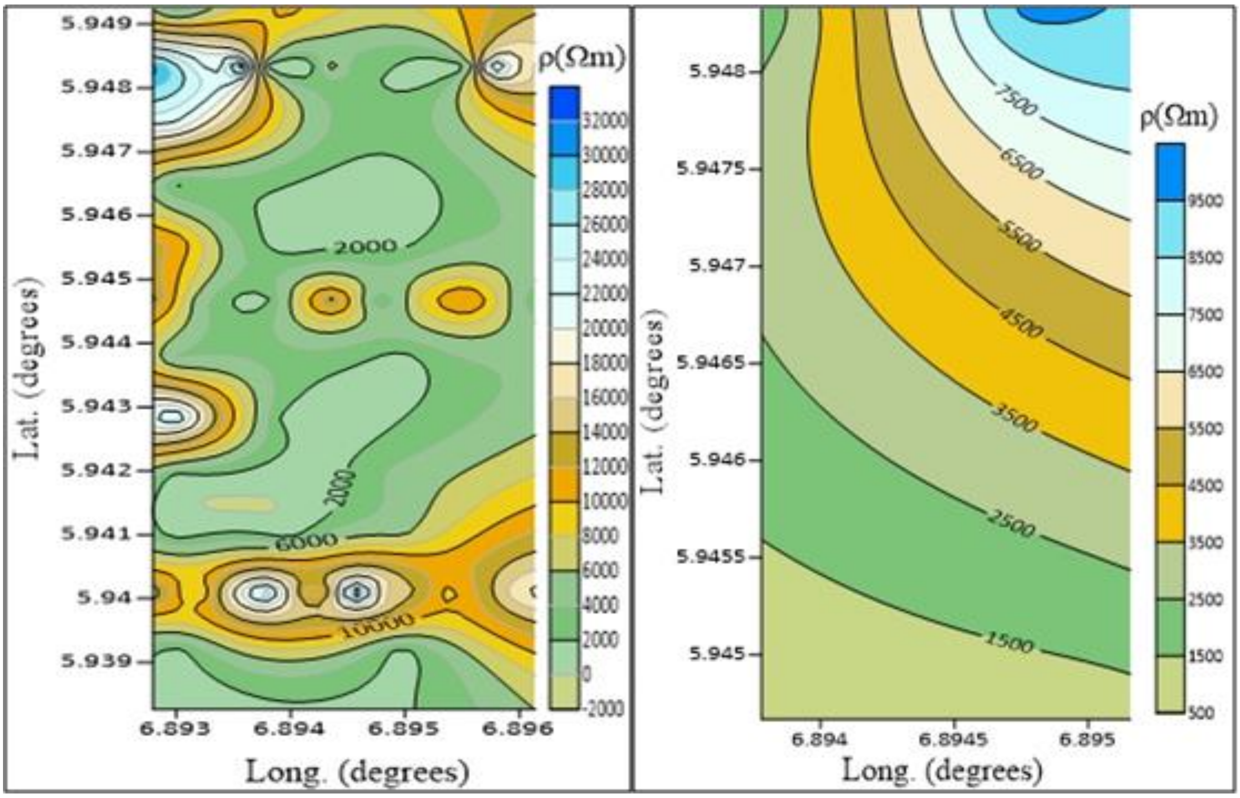

Figure 7: Resistivity Relief Plot for Layer 5 and 6 at Amihe-UkporKaolin Mineral Mine Site.

CONCLUSIONS

The spatial layer resistivity tomography maps have provided downward view of the variations of lithological emplacements of the target Kaolin minerals at the site. It is observed that the apparent resistivity range indicating the formation or occurrence of the target mineral, Kaolin show its prominence at various portions of the Layers. Layers 2, 3 and 4 showed prominence of the mineral at the northern and southern zones of the site. It is also observed that as from the fifth layer at depth range of about 22.50 m to 69.10 m downwards, the occurrence of the Kaolin mineral at the site is very scanty whereas its prominence completely diminishes. The exploitation of mineral resources by surface mining has direct effects on the environment. Owing to the environmental sensitivity of the site, a control mechanism is required in future mining of the Kaolin. Hence, it is suggested that regular suspension of mining activities is required be adopted. This would help in curtailing the physical devastation and degradation of the mineral reserves at the Amaihe-Ukpor in terms of relief change, landslide occurrence, and loss of vegetation, soil subsidence and mining leading to degradation. Boundaries could be set at the exploitation fields on mining taken into account the current and future quantity of the Kaolin mine in place as an industrial raw material at Amaihe-Ukpor, southeastern Nigeria.

Article DOI: 10.52589/AJENSR-JM6ISZZV
DOI URL: https://doi.org/10.52589/AJENSR-JM6ISZZV

REFERENCES

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, 42.

Akudinobi, B. E. B. (2006). Aspects of Chemical and Mineralogical assessment of the Ukpor clay, Nnewi South Local Government Area, Anambra State, Nigeria. *Journal of Raw Materials Research*, 3(1), 56-67.

Aigbedion, I., & Iyayi, S. E. (2007). Environmental effect of mineral exploitation in Nigeria. *International journal of physical sciences*, *2*(2), 33-38.

Balogun, O. Y. (2009). Senior Secondary Atlas (2nd Edn.). Lagos, Longman Nigeria PLC, Nigeria pp; 123.

Bristow, C. M. (1980). World Kaolins: genesis, exploitation and application; Ind. Miner, 238, 45-49.

Ekosse, G. I. E. (2005). Fourier transform infrared spectrophotometry and x-ray power diffractometry as complimentary techniques in characterizing clay size fraction of kaolin. *Journal of Applied Science and Environmental Management*, 9(2), 43-48.

Ekosse, G. E., Dejager, L. & Ngole, V. (2010). Traditional mining and mineralogy of geophagic clays from Limpopo and Free State provinces, South Africa; *African Journal of Biotechnology*, 9(47), 8058-8067.

Heckroodt, R. O. (1991). Clay and clay materials in South Africa. *Journal of the Southern African Institute of Mining and Metallurgy*, *91*(10), 343-363.

Iloije, N. P. (1981). A new geography of Nigeria.

Iloeje, N. (2004). A New Geography of Nigeria. Longman Nigeria Limited 221.

Keller, W. D. (1978). Flint-clay facies illustrated within one deposit of refractory clay; Clays and Clay Minerals in press.

Monanu, S. & Inyang, F. (1975). Climatic regimes. *Nigeria in Maps. Ethiope Publication House, Benin*, 27-29.

Murray, H. H. (1963). Industrial applications of kaolin, Swineford ed., clays and clay minerals; National Conference, Macmillian, New York, vol. 10, pp. 291-298.

Murray, H. H. (1988). Kaolin minerals. Their genesis and occurrences. In; (S. W. Bailey, editor), Hydrous Phyllosilicates (Exclusive of Micas). Reviews in Mineralogy, Mineralogical Society of America, Washington, DC, 20006, USA, 19; 67-90.

Nwajide, C. S. & 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.

Obaje, N. G. (2009). Geology and mineral resources of Nigeria. Ist edition Spring Books. Heidelberg. 60-62.

Obaje, S. O., Omada, J. I. & Dambatta, U. A. (2013). Clays and their industrial applications: Synoptic Review, *International Journal of Sciences and Technology*, 3(5), 264-270.

Okpoko, E. I. (2018). Physico-chemical and microbial analysis of groundwater from the upper cretaceous deposits underlying parts of Udi and Ezeagu areas of Southeast Nigeria. *Afr J Environ Res* 1; 25-41.

Okwueze, E. E., Selemo, A. & Ezeanyin, V. I. (1995). Preliminary lithologic deduction from a regional electrical resistivity survey of Ogoja, Nigeria. *Niger J. Phys*. 7: 43-46.

Reyment, R. A. (1965). Aspects of the geology of Nigeria. University of Ibadan Press. 145pp.

Ries, H. (1927). "*Clays: Their occurrence, properties and uses*" 3rd edition, John Wiley, N. Y.

Article DOI: 10.52589/AJENSR-JM6ISZZV
DOI URL: https://doi.org/10.52589/AJENSR-JM6ISZZV

Sharma, P. (1997). *Environmental and engineering geophysics*. Cambridge University press, pp.207-261.

Singh, B. & Gilkes N. (1991). Alteration of Cr-muscovite to kaolinite in a weathered quartzite, clays and clay minerals 39, 571-579.

Talabi, A. O., Ademilua, O. L. & Akinola, O. O. (2012). Compositional features and industrial application of Ikere kaolinite Southwestern Nigeria. *Res. J. Eng. Appl. Sci*, *1*(5), 327-333.

Tassongwa, B., Nkoumbou, C., Njoya, A., Tchop, J. L., Yvon, J. & Njopwouo, D. (2014). Geoelectrical and mineralogical characteristics of the Mayouom Kaolin deposit, West Cameroun, Earth Science Research, 3(1), 94-107.

Telford, W. M., Geldart L.P. & Sheriff R.E. (1990): *Applied geophysics. 2nd edition, Cambridge University Press, Cambridge 770pp.*

Zeman, S. (2020). Exploration and Exploitation of Mineral Resources in Environmental Protection. 9th International Scientific Symposium: Discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/349662272 Conference Paper; June 2020

Article DOI: 10.52589/AJENSR-JM6ISZZV
DOI URL: https://doi.org/10.52589/AJENSR-JM6ISZZV