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**GEOPHYSICAL PROPERTIES AND DEPOSIT RESERVE ESTIMATE OF
KPAUTAGI KAOLIN DEPOSITS IN MOKWA AREA, NORTH-CENTRAL
NIGERIA**

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ABSTRACT

A geophysical survey using the Vertical Electrical Sounding (VES) technique was carried out to evaluate Geotechnical properties of Kaolin mineral deposit in Kpautagi village, Mokwa local government area of Niger State in Bida Basin, North-central, Nigeria. Twenty five (25) Schlumberger vertical electrical soundings (VES) were acquired at five different profiles to delineate the lithological-unit across the selected portions within the Kpautagi-Kaolin deposit area. The data obtained was interpreted using IP2WIN software to characterize the outcropped Kaolin deposits of the area via the geophysical field data acquired. The result revealed that the average thickness of the Kaolin deposit across the study location was 30.11 m with an average resistivity value of 51.33 Ω m. all the investigated profiles indicated presence of the Kaolin deposit with Profiles 3 and 4 having the highest deposit thickness of 60 m each. The Kpautagi kaolin deposit-reserve for the investigated portion was estimated at 3.9×10^5 t. This study has established that the investigated area within Kpautagi is rich in Kaolin deposit which could be economically exploited. More detailed geological and geochemical characterization to ascertain the quality and other influential professional and legal exploitability parameters!

Keywords: VES, Bida Basin, Kaolin, Reserve Estimate, Kpautagi

INTRODUCTION

Kaolin or China clay is an economic mineral having a texture of soft powder and whitish in colour. It is a rock that is rich in kaolinite and is among the group of industrial minerals having high economic value. The chemical composition of Kaolin is $Al_2Si_2O_5(OH)_4$ or



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$H_2Al_2Si_2O_8H_2O$ or $Al_2H_4O_9Si_2$ with a melting point of $1750\text{ }^\circ\text{C}$. It occurs in form of Kaolinite clay in a very large quantity in soils formed from the chemical weathering of rocks in tropical rainforest areas which has a hot and moist climate (Gbenga et al., 2017). Naturally, kaolin can also be found in other minerals in various quantities such as muscovite, quartz, feldspar, etc. (Akinniyi et al., 2019).

It has a lot of industrial and commercial uses in Nigeria and globally due to its chemically inert nature which made it a versatile industrial economic mineral with wide applications in the cosmetics, pulp and paper, chalk, paints and agro allied industries and in pharmaceutical formulations (Akinniyi et al., 2019). Nigerian government in an effort to promote the growth of its local industries within the country banned the importation of the Kaolin mineral resources (Hussaini, 2018). Yet, many kaolin deposits are yet to be identified and many of the industrial properties attributed to most of the identified kaolin deposits appear to be influenced by the deductions from comparable deposits in other global kaolin-rich places. Thus, the seeming gap in the local knowledge on the kaolin deposits and grades may have contributed to the unappealing appreciation of the economic and industrial values of the small-scale explored and the unexplored kaolin deposits. The consequence of which made the local industries to be mostly dependent on the imported kaolin while dismissing small-scale local sources as not meeting the required industrial demands or specifications.

An estimated three billion metric tons of kaolin deposits in various parts of Nigeria has been reported (Gushit et al., 2010; Hussaini, 2018). Recently, the Katsina deposit has been discovered as one of the best for pharmaceutical purposes because of its chemical composition (Gbenga et al., 2017) with the Kankara deposit regarded as one of the largest deposits in the country (Osumeje & Lawal 2021). The estimated annual national demand for kaolin has been over 360,000 tons, out of which the only available local production is



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just about 125,000 tons, which leaves a wide gap of about 235,000 tons and hence the need to explore more potential kaolin deposits.

Bakari and Zauro (2015) evaluated the suitability of kaolin deposits at Kaoje, Nigeria for local industries by studying their geochemical and geological characteristics. The physical (grain size) analysis revealed a moderate proportion of clay and silt size particles for the samples analyzed while chemical result revealed that SiO_2 and Al_2O_3 are the main constituents, making them suitable for local industrial usage. Akhireubulu et al. (2010) also reported the presence of clay deposits with 44% kaolinite minerals at Kutigi, Nigeria which are suitable for local ceramic and pharmaceutical industries. Badmus and Olatinsu (2009) estimated the thickness of the Lakiri kaolin deposit to be between 0.4 and 17 meters and apparent resistivity values ranging between 1099 Ωm and 22037 Ωm using the vertical electrical sounding (VES) geophysical method. Kaoline deposits in parts of the northern Anambra Basin were estimated by Yahaya et al., (2018) to have thickness of between 10 and 63 meters and apparent resistivity between 421.8 Ωm and 583.15 Ωm using VES. Akinsunmade et al., (2019) delineated the kaolin deposits of Ikare-Ekiti, southwestern Nigeria as having a thickness of 0.2 to 48 meters with resistivity range of 1 to 150 Ωm while deploying the VES method.

The study area lie within the Kpautagi Kaolin deposit site in North-central Nigeria and is confined within the latitudes $9^\circ 21' 40'' \text{N}$ - $9^\circ 21' 55'' \text{N}$ and longitudes $5^\circ 12' 50'' \text{E}$ - $5^\circ 12' 34'' \text{E}$ within the northern Bida Basin. The electrical resistivity and thickness of the subsurface kaolin units were thus delineated using the vertical electrically sounding (VES).

The study area being one of the identified areas with unknown Kaolin Deposit Reserve by Gushit et al., 2010 (Table 1), intimated the attempt to fill the knowledge gap. Therefore, quantitatively the depth, thickness and reserve estimate of the of the kaolin deposit within



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the investigated portion of the Kpautagi Kaolin Deposit area were geophysically determined to update the existing Kaolin deposit reserve database.

Table 1: Major Kaolin Deposits in Nigeria and Estimated Reserves (Modified after Gushit et al., 2010)

State	Major Locations	Estimated Reserve (million tonnes)
*Abia	Isikwuato, Nneochi, Obingwa, Umuahia Area, Ikwuano	Very large
Anmbra	Anambra-East, Ayamelum, Ekwusigo, Njikoka, Aguata, Ihiala, Nnewi-South	4.2
Bauchi	Alkaleri, Bauch, Damban, Darazo, Ganjuwa, Kirfi, Misau, Ningi	18
Benue	Obi, Ogbadibo, Apa, Oturkpo	10
*Borno	Gwoza, Chibok, Damboa	Large
*Edo	Esan, Ovia And Etsako Areas, Ikpobaokha, Akoko-Edo, Egor, Igueben, Oredo, Orhionmwon, Uhummwonde, Owan-East	Very large
Enugu	Enugu	50
Kaduna	Maraban-Rido	5.5
*Kastina	Batagarawa, Batsari, Dan-Musa, Danja, Dutsin-Ma, Ingawa, Kankara, Kankia, Safana, Malumfashi, Musawa.	Very large
*Kebbi	Bagudo, Suru, Wasagu/Danko	Very large
*Kwara	Baruten, Edu, Ifelodun, Ilorin, Ilepodun, Isin, Kaiama, Pategi	Large
*Niger	Bosso, Edati, Gbako, Katcha, Lapai, Lavun, Mashegu, Mokwa, Paikoro, Shiroro, Wushishi	Very large
*Ogun	Abeokuta Area, Ado-Odo/Ata, Idarapo, Ifo, Igbado Area, Ijebu Area, Ipokia, Obafemi-Owode, Odeda, Odogbolu, Remo-North	Large
*Ondo	Irele, Odigba	Not available
Oyo	Atisbo, Ifedayo, Iseyin, Saki West And East.	1.5
Plateau	Barkin-Ladi, Bassa, Bokkos, Jos-North, Kanke, Pankshin	8.0
*Zamfara	Gumi, Gusau, Kaura-Namoda, Maradun, Maru, Talata-Mafara, Zurmi	Not available

* Areas with unknown reserve.

Geology of the Study Area

The study area (Figure 1) lies within the NE-SW trending intracratonic Bida Basin which has its limit at Kontagora to the North and slightly beyond Lokoja to the south (Obaje, 2009). The basin is a gently down-warped trough whose origin is closely connected with Santonian orogenic movements in SE Nigeria and the Benue valley. The four mappable stratigraphic units of the northern Bida Basin are the Bida Sandstone, Sakpe Ironstone,

Enagi Siltstone and Batati Ironstone formation, which are correlatable with the formations in the southern Bida Basin and Anambra Basin.

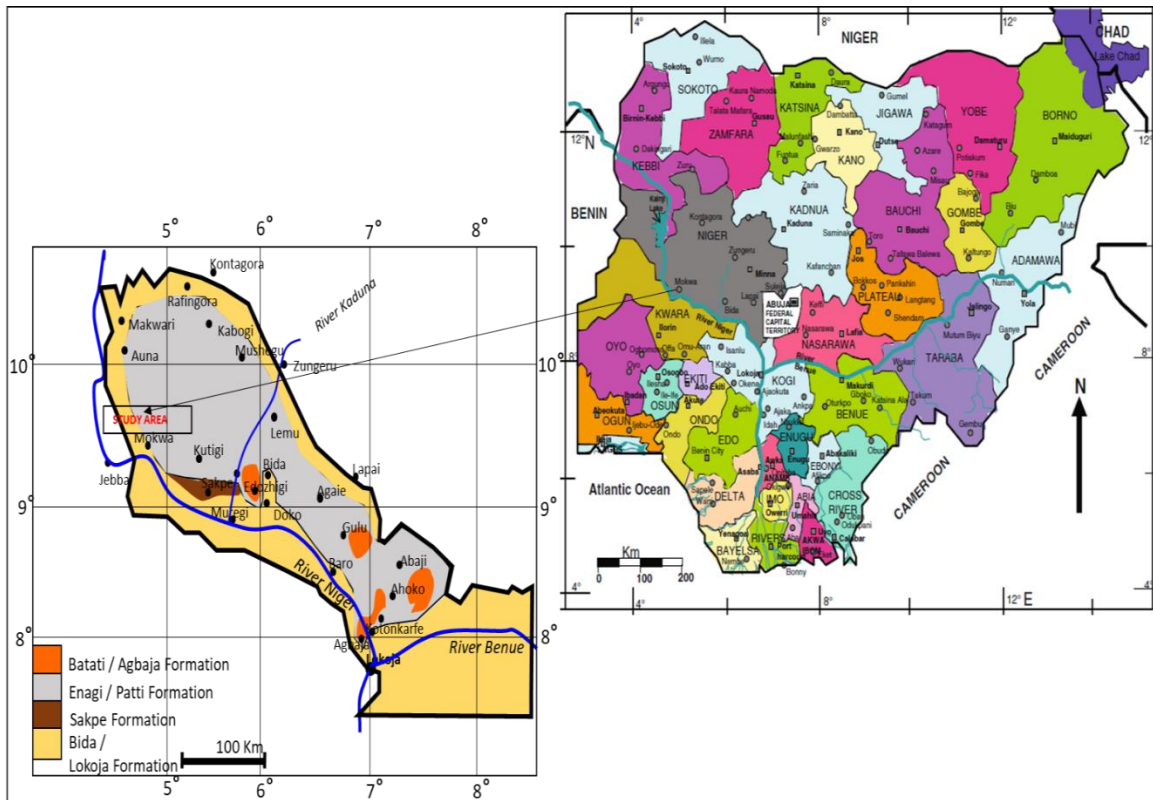


Figure 1: Location and Geological Map of the Study Area (modified after Obaje et al., 2019)

METHODOLOGY

Schlumberger electrode configuration was employed for the field data collection using the Allied Ohmega resistivity meter. In this method, four electrode arrays are used (Figure 2); two of which is used to inject current into the ground referred to as the current electrodes (A and B), while the other two electrodes (M and N) are used to measure the potential difference between the current electrodes. A total of twenty-five (25) vertical electrical sounding (VES) stations, designed along five profiles, with maximum half current electrode



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spacing, $AB/2$, between 50 and 70 meters was covered in this study. The obtained field resistance for each data reading was multiplied by the calculated geometric factor, K , to obtain the respective apparent resistivity values of the earth material. The obtained apparent resistivity values were qualitatively interpreted using the graphical method of curve matching with master curve and by computer iteration using the IP12win software to delineate the geo-electrical layers. The layer apparent resistivity and thickness were used to generate resistivity pseudo-sections along the five profiles so as to have a quick visual understanding of how the resistivity and thickness changes laterally which was used in estimating the local reserve of the kaolin.

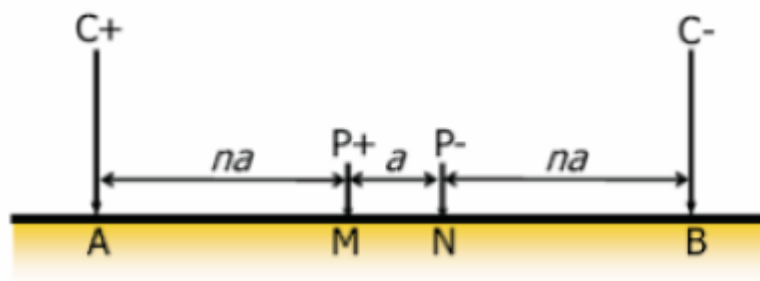


Figure 2. Electrode Configuration of the Schlumberger Array

RESULTS AND DISCUSSION

Three geo-electric sections were delineated from the resistivity section of profile 1 as presented in figure 3 and table 2. The topmost layer has a resistivity value of $438 \Omega\text{m}$; it is 2.56 m thick at a depth of 2.56 m and interpreted as sandstone. This is observable around VES point 1. The second layer is 13.10 m thick cutting across VES points 2 to midway after VES point 4 characterized by low resistivity value of $57.60 \Omega\text{m}$ and interpreted as the Kaolin clay deposit. The third layer with a thickness value of 18.20 m relatively having the highest resistivity value of $546 \Omega\text{m}$ observed at surface around VES points 65 and 6 was interpreted as sandstones.

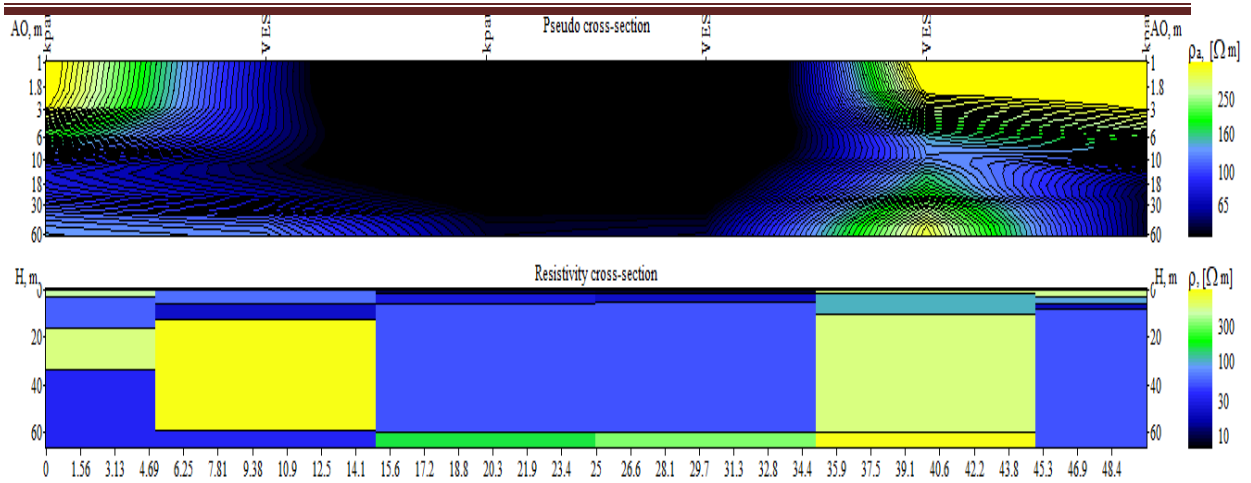


Figure 3: Pseudo-section and Resistivity Cross-section of Profile 1

Table 2: Delineated Three Geo-electric Sections Across Profile 1

N	p	h	d	Alt
1	438	2.65	2.65	-2.655
2	57.6	13.1	15.8	-15.79
3	546	18.2	33.9	-33.95
4	35			

The topmost layer interpreted from the geo-electric section at profile 2 (figure 4 and table 3) has a resistivity of 66.82 Ω -m and a thickness of 5.52 m. This is interpreted as the outcropping section of the kaolin deposit which is expected to have high level of impurities because of its exposure to surface processes. The next layer was also characterized by a lower resistivity value of 24.17 Ω -m, with relatively thicker value of 6.58 m. It is interpreted as the extension of the Kaolin deposit. However, the variation in their resistivity values across the layers could be attributed to the decrease in the amount of impurities with the depth. The third layer has a very high resistivity and thickness values of 878.50 Ω -m and 47.32 m respectively. It is interpreted as sandstones and conglomerate. This occurs at a depth of 59.42 m. Layers one and two are delineated as Kaolin deposit and they have an



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accumulated thickness of 12.10 m. Are you suggesting that the same Kaolin have different range of resistivity base on depth, if yes the you need to justify.

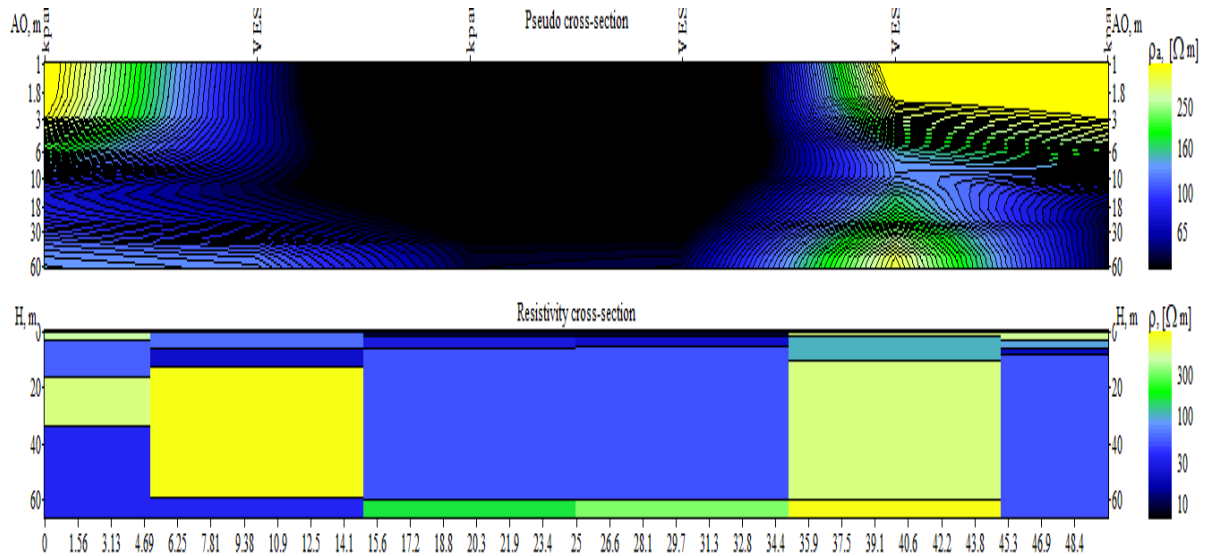


Figure 4: Pseudo-section and Resistivity Cross-section of Profile 2

Table 3: Delineated Three Geo-electric Sections Across Profile 2

N	p	h	d	Alt
1	66.82	5.516	5.516	-5.5157
2	24.17	6.584	12.1	-12.1
3	878.5	47.32	59.42	-59.422
4	35.02			

The Geo-electric Section at Profile 3 (Figure 5 and Table 4) also has three layers considered. Their apparent resistivity values are between 11.18 Ωm and 53.64Ωm and corresponds to a massive deposit of kaolin which outcrops at parts of the profile. The clay unit within this profile 3 has a total thickness of 60 m.

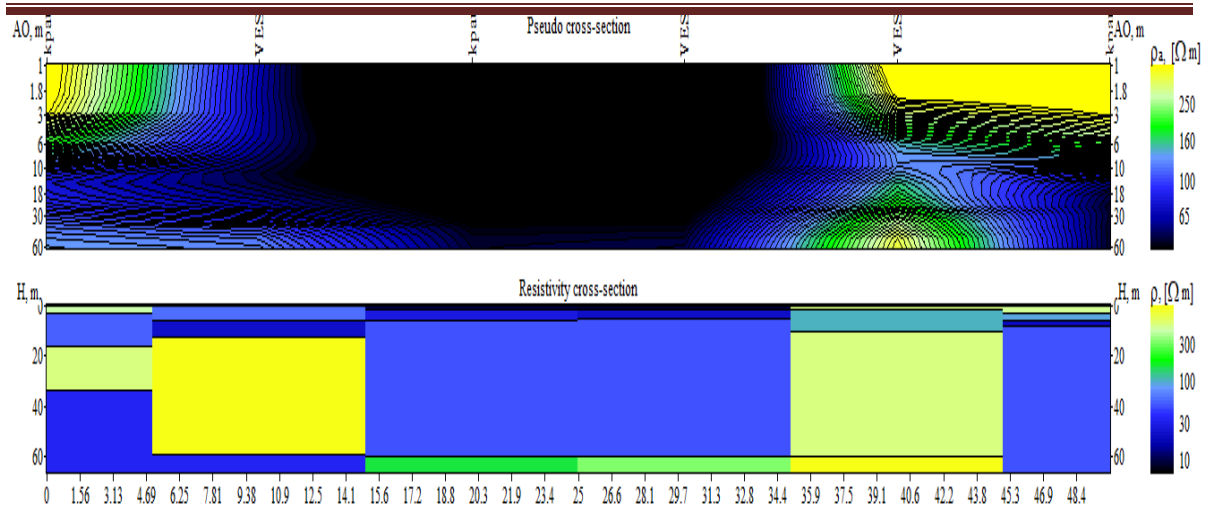


Figure 5: Pseudo-section and Resistivity Cross-section Along Profile 3

Table 4: Delineated Three Geo-electric Sections for Profile 3

N	p	h	d	Alt
1	11.18	1.445	1.445	-1.4454
2	28.24	4.096	5.541	-5.5414
3	53.64	54.46	60	-60
4	162.4			

The Geo-electric Section at profile 4 (Figure 6 and Table 5) displayed similar characteristics as that of profile three and has layer resistivity between 10.99 Ωm and 54.81 Ωm for the three layers which is also interpreted to be an extensive kaolin unit of about 60 meters thickness.

Figure 6: Pseudo-section and Resistivity Cross-section of Profile 4

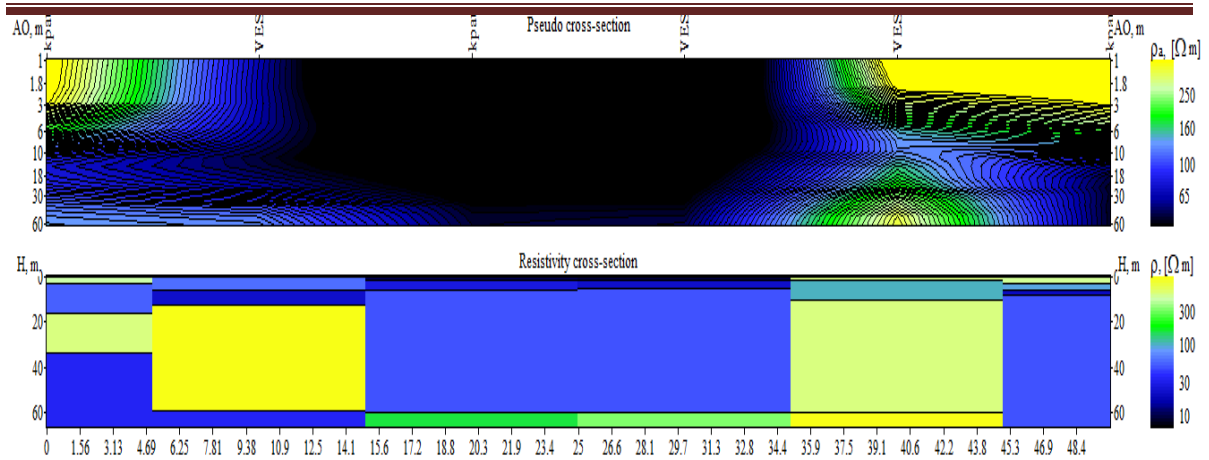


Table 5: Delineated Three Geo-electric Sections Across Profile 4

N	p	h	d	Alt
1	10.99	1.315	1.315	-1.3148
2	24.58	3.624	4.939	-4.9392
3	54.81	55.06	60	-60
4	321.3			

Profile 5 has a slightly higher apparent resistivity relative to other profiles. An apparent resistivity value of 467 Ωm was obtained for the first layer which is interpreted to be a silty sand layer with a layer thickness of 2.58m. The resistivity of the second layer is 92.40 Ωm and thickness of 3.56m. This layer is interpreted to be a kaolin layer which probably contains some silt. The third layer is a 1.78 meters thick, low (22 Ωm) resistivity layer which is interpreted as kaolin.

Figure 7: Pseudo-section and Resistivity Cross-section of Profile 5

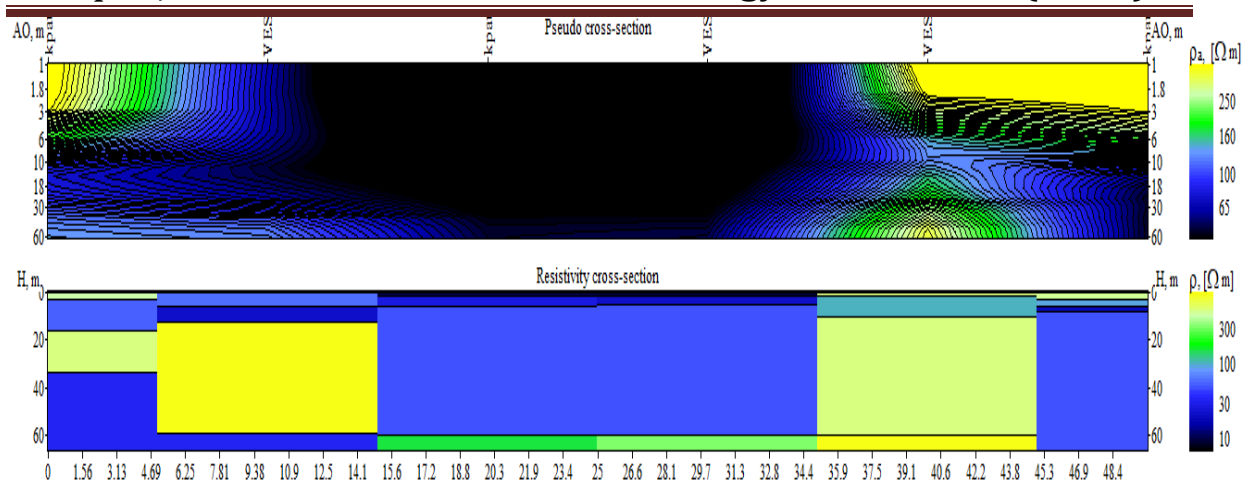


Table 6: Delineated Three Geo-electric Sections Across Profile 5

N	p	h	d	Alt
1	467	2.58	2.58	-2.579
2	92.4	3.56	6.14	-6.137
3	22	1.78	7.92	-7.917
4	50.8			

Comparison of the Kaolin Potentials across the Profiles

The correlation of the interpreted geo-electric units across all the profiles (Table 7), showed a strong correlation between the five profiles. The average resistivity values of the Kaolin across all the profiles showed a linear relationship between the sounding points indicative of the continuity of the anomaly (Kaolin Deposit). The average thickness of the kaolin deposits exhibited that the kaolin unit has the greatest thickness of 60 m at profiles 3 and 4 which implied the most potential and focal points for further details investigations. The profile 5 has the least Kaolin unit of thickness 5.34 m.



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Table 7: Resistivity and thickness of the kaolin deposits across the five profiles probed

Profiles	Average Resistivity (Ω m)	Kaolin Thickness (m)
1	57.60	13.10
2	45.50	12.10
3	31.02	60.00
4	30.13	60.00
5	92.40	5.34

The Interpreted field data and analysis of the electrical resistivity measurements for assessing both the lateral, vertical extent and thickness of kaolin occurrence in this work have indicated the lateral continuity of the kaolin occurrence from the central portion of the study site towards the south-eastern portion of the Kpautagi Village (Table 7). On the west flank of the study location has also a portion of the kaolin occurrence. The results have demonstrated that the adopted method of investigation (vertical electrical sounding) can be used swiftly as part and compliment of mineral exploration methods. The study has also shown that subsurface investigations with emphasis on mineral assessment are achievable when integrated with geophysical and geological information. This type of evaluation can be precursor to detail mineral exploration stages.

Reserve Estimation

The reserve estimate (RE), in tons, for the kaolin deposit at the investigated portion of the Kpautagi Deposit area was determined using the formula by Yusuf (2021). The average thickness of the deposit is 30.12m, covering an area of only about 4900 m² and Kaolin density is 2.65 g/m³ (Kayode, et al., 2015).

$$RE = \text{Area} \times \text{Thickness} \times \text{Density} \quad (1)$$

Where: RE is reserve estimate

$$RE = 4,900 \text{ m}^2 \times 30.12 \text{ m} \times 2.65 \text{ g/m}^3$$

$$RE = 3.9 \times 10^5 \text{ tons}$$



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The reserve of the investigated portion of the Kpautagi Kaolin deposit in Mokwa, northcentral Nigeria is estimated to be approximately 3.9×10^5 tons with overburden thickness of about 6 meters. This thus by extension established that the entire area of Kpautagi is rich in kaolin deposit which could be economically exploited when quantitatively compared to the similar estimated value by Bakari and Zauro (2015).

CONCLUSION

A portion of the Kpautagi kaolin deposits area has been studied using geophysical tools. Influential physical parameters have been measured and correlated with the works of other authors and inferences also drawn to confirm the results of the study and economic viability of the Kpautagi Kaolin deposit. The results revealed that the average thickness of the kaolin unit across the study location is 30.11 meters with the corresponding average resistivity value of $51.33 \Omega\text{m}$, for which the profiles 3 and 4 had the greatest thicknesses. A huge amount of the kaolin deposit reserve of magnitude 3.9×10^5 tons was estimated at just small part out of the entire Kpautagi Kaolin deposit of the area which is an indication of the high potential area for kaolin deposits with good economic exploitability. Further research is recommended in understanding the spread of the entire reserve in the area as well as investigating the geochemical and mineralogical composition of the kaolin deposit so as to understand the percentage of kaolinite present therein.

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