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Research Article

DISCOVERING THE RABBA POTENTIAL FOR KAOLIN DEPOSIT WORTH OF OPTIMAL RETURN ON INVESTMENT: A GEOPHYSICAL PERSPECTIVE

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Abstract

Essentially, this study was aimed at establishing the spatial-extent and average thickness occurrence of the kaolin deposit in part of Rabba, Northern Nigeria using geophysical method. Twenty five VES measurements were made within Rabba area in Mokwa Local Government Area of Niger State which lies within the Bida Basin, Northern Nigerian. The geophysical interpretation of the results using IP2WIN software revealed three geo-electric layers mostly across all the five profiles and that the Kaolin mineral lies within the investigated subterranean. The Kaolin deposit was overlain by the weathered layer of the sandstone unit. The average delineated Kaolin thickness ranged between 12.05 and 58.69 m, while the depth ranged from 3.40 to 60.01 m, cutting across both the first and the second geo-electric layers. The apparent resistivity values of the Kaolin clay unit within the location ranged between 1.23 and 389.30 Ωm. The estimated Rabba Kaolin Reserve was up to 4.8 x 10^6 t which is capable of producing an optimal return on Kaolin mining investment. Further detailed geological and geochemical investigation is thus recommended for the area considering the estimated economy of the discovered Kaolin deposit.

Keywords: Spatial-extent, Sandstone, Kaolin, Mineralization, geo-electric layers.

INTRODUCTION

Kaolin (hydrated Aluminium Silicate, ($Al_2Si_2O_5$ $(OH)_4$), commonly known as china clay, is fine-grained white clay whose physical properties make it ideal for an assortment of industrial applications. Individual grains of kaolin usually occur in a plate-like form, or stacks of such plates (Akinniyi, *et al.,* (2019)). These plates are very small, often being less than two microns in diameter. Kaolin derived its economic importance from being used extensively in a number of industries including paper, plastics, adhesives, rubber, paint, refractories, cement, bricks and ceramics. Kaolin is also a natural ingredient used for the short-term symptomatic treatment of various conditions including diarrhoea, skin dryness and minor skin bleeding (Joseph *et al.,* 2021). Impliedly, Nations well-blessed in abundance of such Natural mineral resources have therefore identified it to be the most important foundation and key to the viability and sustainability of their national economy and industrial developments. Nigeria has been described also as one of such African nations richly blessed with abundant mineral resources such as petroleum and various solid minerals which include the Kaolin, coal and bitumen (Obaje, 2009). Non-metallic rocks and minerals which include gnesis, marble, granite and limestone occur in large amounts in many parts of Nigeria. They are being exploited for the purpose of satisfying the raw materials requirements for the national industries and infrastructural development as well as for and international markets. Such has checkmated the level of importation of such raw materials. The global economy has been sustained from the mining proceeds being a valuable means of export and a major contributor to the GDP of these nations. The alarming activities of unlicensed mineral exploiters (artisan miners) have also been responsible for the increased smuggling of some of these natural resources as well as lack of government comprehensive attention on the creation and encouragement of manufacturing industries for the benefit of the state or nation (Baba, *et al.,* (2018). Olade, (2019) has reported that due to the Nigerian weak regulations and increasing number of artisan mining, only about 5.3 billion naira was recorded from mining in 2019, while quite substantial amount of both gold and Kaolin, as well as other minerals worth hundreds of millions of dollars exploited by artisanal mining are being smuggled out of the country accounting for very high amount of revenue being eroded away. The youths' poverty level, escalated rise in prices and increasing demand of these minerals has also accelerated such incessant artisanal mining activities and these have dominated most of the local activities in the mineralized areas of Niger State, most especially, the study area and the entire nation at large. As these youths become self-employed with little monies and knowledge, go into fields and gather distinct stone and minerals from the earth surface or from shallow depths to sell to interested black marketers as against the state laws. Such illegal activities have been responsible for environmental pollutions and contamination of soil which has even caused poisoning in some states within Nigeria (Anka *et al.,* 2020). Although to the best of our knowledge so far, there have not been any reported geophysical exploration for Kaolin within the study site, however, a previously reported geophysical works at Takowangwa area by (Yusuf, 2021), some distance away from the present site, estimated the occurrence of vast limestone deposits of the magnitude 2.0 x 10^6 t . This revealed the high mineralized potential of the Mokwa area which can be of very much state economic importance for domestic, mining and industrial purposes. Scanning through some other related geophysical works on Kaolin exploration in other fields, such as that conducted around Kankara Local Government Area of Katsina State (Joseph *et al.,* 2021; Ajayi and Adefila, 2012; and Christian *et al.,* 2018) have all shown that Kaolin exists in Kankara affirming the efficacy and influence of the

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geophysical perspective in Kaolin explorations. While, Hussaini *et al.,* (2016), also used geophysical electrical resistivity method to delineate the Kaolin layer with estimated thickness range of between 1.25 m and 39.4 m at Dajin Gwamna also in Kastina state. Badmus and Olatinsu (2009) also used theVertical Electrical Sounding (VES) method to estimate Kaolin deposit with thicknesses between 0.4 and 17 m covering 80% of the investigated VES stations in Southwest Nigeria. Akinniyi, *et al.,* (2019) also deployed the Vertical Electrical Sounding (VES) method to estimate the average thickness of the kaolin layer to range from 0.8 to 46 meters in part of Ikere-ekiti, south western Nigeria. In the light of all the above, this study was therefore designed with the sole aim of establishing the occurrence and economic viability of the kaolin deposit for exploration and exploitation within Rabba area in Mokwa Local Government Area of Niger State, Bida Basin, Northern Nigeria using geophysical method. Twenty five VES measurements were made within the study site with the objective of measuring the spatial-extent, average thickness and reserve estimation using the relevant computer software to model and interpret the delineated geophysical parameters influential to Kaolin exploration and exploitations.

Study Area

The study area (Rabba Village) is located at Latitude 9^{o}12' N and Longitude 5^{o}1' E with elevation of 89 m with open location code 6FX7626H+CV. It is surrounded by localities like Koshaba Village (100 m), Gbere Locality (4.5 Km) west, Lafiagi Village (8 Km) Northwest and Mokwa town (10 Km) North. The landmarks surrounding Rabba are Lake Wako (10 Km) Southwest, Tatabu Railroad Station (12 Km) west, Lake Ndakalowu (12 Km) west and Lake Laka Dada (15 Km) west. Rabba is also surrounded by four Rivers; River Dingi (100 m), River Gusheko (12 Km) South, River Gwadaku (12 Km) West and River Lentela (16 Km) West. Geologically, it 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, 2008). 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).

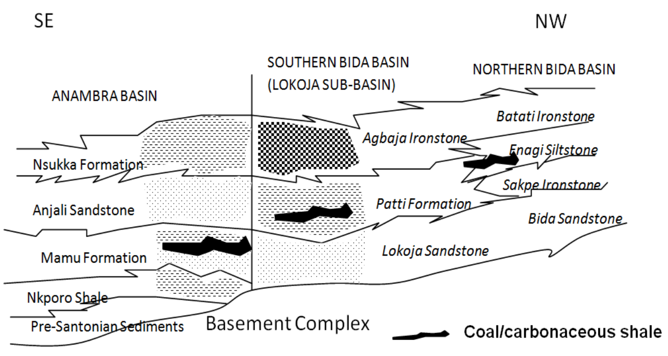

Figure 1. Formations in the Northern and Southern Bida Basin correlatable with the Anambra Basin (After Obaje, 2013)

From Rabba to Mokwa, the lithic fill consists mainly of arkosic to quartzose, angular to sub-rounded poorly to well sorted greyish to whitish sandstones that becomes better sorted upwards. The sandstones are medium to very coarse and contain irregular pebbly quartz and feldspar grains. The coarser quartz grains have smooth flat surfaces that look like vein quartz. The sandstone also becomes more clayey and less angular which is underlayed by Kaolin which outcrop in some locations within the study site (Figure2). The arkosic sandstone are argillaceous, colour mottled, forming the basal units at the locations and are highly bioturbated in some places. Siltstone and mudstone pebbles, and some thin, indurated, ferruginized, dark-brown sandstone bands are present in some localities (Obaje, 2008) as well as presence of thin interbedded grey to whitish claystones.

Figures 2. Outcrop of some Kaolin deposit at Rabba Village in Mokwa Local Government area of Niger State, Nigeria

METHODOLOGY

Geophysical investigation using the method of Vertical Electrical Sounding (VES) and Schulumberger electrode configuration was conducted at the study area to delineate the sub-surface lithology and map the thickness of the Kaolin deposits within the study area. This method was applied at this stage to facilitate in measuring the subsurface resistivity distribution from the surface by using a Resistivity meter (OMEGA from Allied Associates Geophysical Ltd. Serial No. 0080). This was achieved by injecting electrical current via current electrodes (AB) into the subsurface and measuring the potential field generated by the injected current through the potential electrodes (MN) all of which were connected to the Resistivity Meter in accordance with Schulumberger electrode configuration (Figures 3 and 4). The maximum half-current electrode spacing (AB/2) ranges from 1 to 60 m.

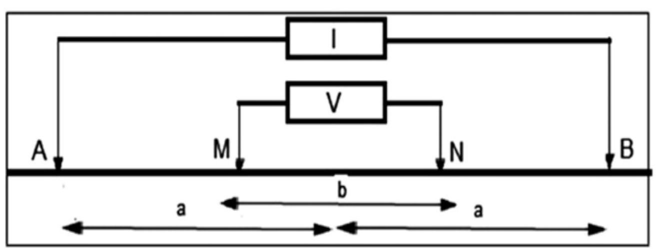

Figure 3. Electrode arrangement in the field - VES Schlumberger electrode array

Figure 4. Field Survey using Omega Resistivity Meter in Schulumberger Electrode Configuration

GEOPHYSICAL RESULTS AND DISCUSSION

In the present work, the results of the VES soundings at each of the five profiles (apparent resistivity values) obtained from the field were geophysically processed using computer iteration techniques thereby producing modelled parameters for quantitative interpretation. The pseudo-sections and Resistivity cross-section obtained from the computer software (IP2WIN) facilitated the interpretation of the various VES points across all the profiles.

Rabba Profile 1

The Geo-electric Section at profile 1 around Rabba sandstone mining site revealed three geo-electric sections delineated (Figure 5 and Table 1). The topmost layer has a resistivity value of 633 Ω-m, it is 1.64 m thick and interpreted as outcropped sandstone which is presently observed to be mined illegally. The second layer is 16.30 m thick with a lower apparent resistivity value of 222 Ω-m and interpreted as clayey Kaolin deposit. The next layer with thickness value of 17.10 m with relatively high conductivity is also interpreted as Kaolin deposit at the average depth range of 18 to 35.10 m. The total estimated possible Kaolin deposit thickness in this profile is 33.40 m with overburden thickness of 1.64 m.

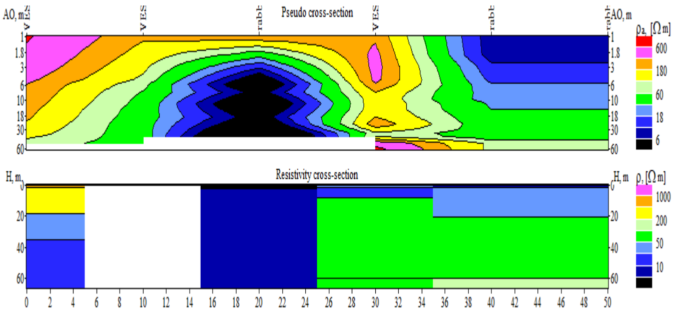

Figure 5: Pseudo cross-section and Resistivity cross-section for Profile 1 at Rabba across 5 VES points

Table 1. The three geo-electric sections for Profile 1 across 5 VES points

N	ρ	h	d	Alt
1	633	1.64	1.64	-1.64
2	222	16.3	18	-17.98
3	49.5	17.1	35.1	-35.11
4	15.2			

Rabba Profile 2

At the second Profile within the same site, the revelation was also that three geo-electric sections were delineated (Figure 6 and Table 2). The topmost layer has a resistivity value of 201 Ω-m, it is 1.51 m thick and interpreted also as the outcropped sandstone. The second layer with a thickness of 3.05 m exhibited a lower apparent resistivity value of 61.60 Ω-m and interpreted as clayey Kaolin. The next layer with a huge thickness value of 45.40 m having relatively lower resistivity value of 36.90 Ω-m is also interpreted as probable Kaolin deposit at the average depth range of 4.55 to 50.00 m. This amounted to a total estimate of possible Kaolin deposit along this profile to be 48.45 m.

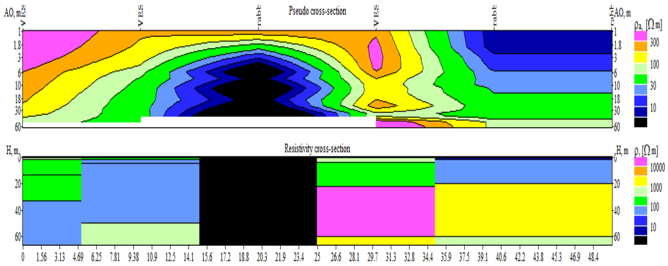

Figure 6. Pseudo cross-section and Resistivity cross-section for Profile 2 at Rabba across 5 VES points

Table 2. The three geo-electric sections for Profile 2 across 5 VES points

N	ρ	h	d	Alt
1	201	1.51	1.51	-1.509
2	61.6	3.05	4.55	-4.555
3	36.9	45.4	50	-50
4	787			

Rabba Profile 3

Profile 3 revealed the possible presence of Kaolin litho-face mainly across VES points 2, 4 and 5 as exhibited by low resistivity values across the second and third geo-electric layers (Figure 7 and Table 3). The resistivity ranged from 1.23 to 50.08 Ωm. The estimated possible Kaolin deposits thickness in this profile is 12.05 m with resistivity ranged from 1.23 to 14.36 Ωm. The delineated possible Kaolin deposit was overlain by an overburden thickness of 1.21 m as shown in Table 3.

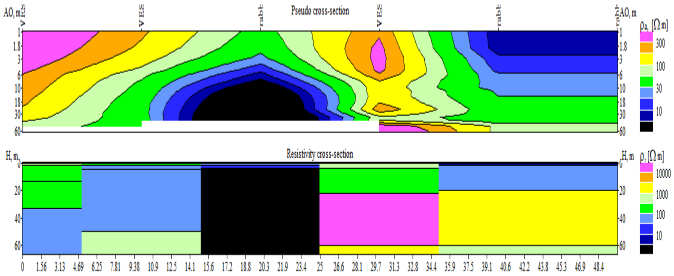

Figure 7. Pseudo cross-section and Resistivity cross-section for Profile 3 at Rabba across 5 VES points

Table 3: The three geo-electric sections for Profile 3 across 5 VES points

N	ρ	h	d	Alt
1	50.08	1.208	1.208	-1.2082
2	14.36	2.189	3.397	-3.3972
3	1.228	9.858	13.26	-13.255
4	0.2832			

Rabba Profile 4

The situation in Profile 4 (Figure 8 and Table 4) provides a more promising revelation of the possible presence of Kaolin litho-face mainly across the same vein (VES points 2, 4 and 5) with indication of lesser overburden thickness of 3.46 m compared to the larger delineated Kaolin deposit estimated thickness of 56.55 m with resistivity values ranged from 109.10 to 389.30 Ωm. as exhibited by the observed low resistivity values across the second and third geo-electric layers. The resistivity ranged from 49.5 to 633 Ωm.

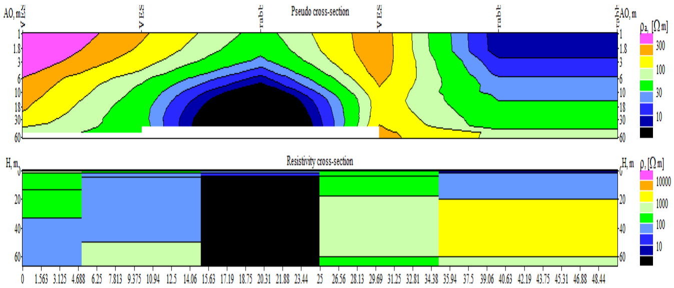

Figure 8. Pseudo cross-section and Resistivity cross-section for Profile 4 at Rabba across 5 VES points

Table 4. The three geo-electric sections for Profile 4 across 5 VES points

N	ρ	h	d	Alt
1	275.9	3.462	3.462	-3.4616
2	109.1	13.8	17.26	-17.26
3	389.3	42.75	60.01	-60.01
4	144.5			

Rabba Profile 5

The situation in Profile 5 (Figure 9 and Table 5) provides a most promising inference quantitatively. The exhibited very low resistivity values that ranged between 27.40 and 57.70 Ωm across both the second and the third layers can be inferred as the Kaolin Deposits. This Kaolin deposits trend was still observed along the same vein (VES points 2, 4 and 5). It has an overburden thickness of just 1.35 m with a possible delineated Kaolin deposits thickness estimated at 58.69 m.

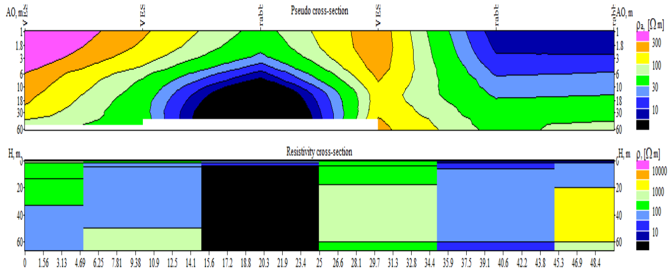

Figure 9. Pseudo cross-section and Resistivity cross-section for Profile 5 at Rabba across 5 VES points

Table 5. The three geo-electric sections for Profile 5 across 5 VES points

N	ρ	h	d	Alt
1	6.76	1.35	1.35	-1.349
2	27.4	4.29	5.64	-5.64
3	57.7	54.4	60	-60
4	21.4			

Summarily, from Table 6 it is deducible that profile 5 offers a more economic potential for Kaolin deposit with least overburden thickness of just 1.35 m in addition to the shallowness of the depth range of (5.64 – 60.00) m. This is followed by profile 2 which also has less overburden and almost close depth range with the fifth profile. Then the order is followed by Profiles 4, 1 and 3 with the least thickness of 12.05 m even though it has also the least overburden.

Table 6. Estimated possible Kaolin Deposits at Rabba Village in Mokwa LGA, Niger State, Nigeria

Profile	Kaolin Deposits Thickness (m)	Overburden Thickness (m)	Depth Range (m)	Apparent Resistivity Range (Ω-m)
Profile 1	33.40	1.64	18.00 – 35.10	49.50 – 222.00
Profile 2	48.45	1.51	5.55 – 50.00	36.90 – 61.60
Profile 3	12.05	1.21	3.40 – 13.26	1.23 – 14.36
Profile 4	56.55	3.46	17.26 – 60.01	109.10 – 389.30
Profile 5	58.69	1.35	5.64 – 60.00	27.40 – 57.70

Kaolin reserve estimation (KRE)

The Kaolin deposit reserve estimation for the probed location in Rabba area of Mokwa for which the dimension was 200 m by 200 m, covering an area of 40,000 m^2 was determined using equation (1) (Yusuf, 2021). The average thickness of the Kaolin deposits was estimated at 46.10 m and Kaolin Density is 2.65 g/m^3 (Telford *et al.,* 1990).

KRE = Area x Thickness x Density (1)

$40,000\ m^2 \times 46.10\ m \times 2.65\ g/m^3 \approx 4.8 \times 10^6$ t.

Conclusion

The outcropped sandstone illegal exploitation site at Rabba area of Mokwa, in Bida Basin has been geophysically investigated using method of Vertical Electrical Sounding. From the perspective of the geophysical results obtained, the following conclusions have been drawn:

1. That this research work has revealed the occurrences of Kaolin deposits to the tune of economic interest across all the five profiles probed. This is in addition to the already discovered massive sandstone outcrop which is being mined freely and illegally by the Artisan Miners. The highest estimated vein with probable Kaolin deposits with a thickness of about 58.69 m was estimated at a depth range of between 5.64 and 60.00 m at Profile 5 across VES points 2, 4 and 5. These natural resource discoveries have placed the Rabba Village among the highly mineralized and good economic potential zone if and only could be professionally and legally fully exploited!
2. This possible occurrence of huge Kaolin deposits over an area characterized by flat topography with plain land-covers can be of very much economic importance for mining and industrial purposes to the immediate communities, the LGA and the State/Nation at large.
3. The geophysically surveyed area was just about only 40,000 m^2, for which this huge amount of Kaolin deposits (4.8×10^6 t) was estimated with a clear indication of the possibility of its extension both vertically and laterally beyond the investigated area.
4. This study has thus provided a discovery on the high potential of the investigated area (Rabba area) for Kaolin deposits with good economic exploitability.
5. The results quality has also demonstrated that this method of geophysical investigation (VES) is suitable for usage swiftly as part and complimentary to other mineral exploration methods. It also revealed that subsurface investigations with emphasis on mineral assessment are achievable when integrated with geophysical and geological information. Impliedly, this type of proxy evaluation being a non-invasive and economic-friendly should always be adopted as precursory to other detail mineral exploration stages.

Acknowledgement

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Data availability statement

The root data underlying this article shall be made available on reasonable request to the corresponding Author.

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