



## Electrical Resistivity Investigation of Kaolinitic and Laterite Deposits within Birnin and Environs, NW Nigeria

<sup>1\*</sup>Adamu, A., <sup>1</sup>Fahad, A., <sup>1</sup>Ologe, O., <sup>2</sup>Sagagi, Y.M. and <sup>3</sup>Shamsudeen, A.

<sup>1</sup>Department of Applied Geophysics, Federal University Birnin Kebbi, Kebbi State, Nigeria

<sup>2</sup>Department of Physics with Electronics, Federal University Birnin Kebbi, Kebbi State, Nigeria

<sup>3</sup>Department of Physics, Federal College of Education, Zaria, Nigeria

### ABSTRACT:

The interpretation of 15 Vertical Electrical Soundings (VES) and Electrical Profiling data was carried out within Birnin Kebbi and Environs NW, Nigeria. This is an attempt to investigate the possibility of anomalous location for Kaolinitic-Clay and Laterite deposit as essential solid minerals and the geologic characteristics of the subsurface within the study area. Terrameter (SAS) model 300 was the instrument used. No booster was used as the expected depth is within the range of penetration of the instrument. The interpretation was performed using computer softwares (AGI EarthImager 1D and Surfer). The interpreted results were used to produce geoelectric section and specialized map. The survey results indicate that the area is underlain by three to four subsurface layers namely: Topsoil, Weathered lateritic-overburden, Fractured and fresh bedrock. The results of the interpreted VES data showed that the saturated bearing layer (aquifer) lie within the weathered and fractured basement of the predominantly four-layered geoelectric structure. The thickness of the overburden varied from 3.2-11.3m with an average of 7.6m. VES points 06, 10, 11 and 12 were found to be suitable locations to exploit industrial minerals such as laterite and kaolin.

**Keywords:** Vertical Electrical Sounding (VES); Electrical Profiling; Geopulse Terrameter; Duku-Tarasa and Birnin Kebbi Metropolis

### INTRODUCTION

Mineral exploration in Nigeria dates back to the geological expeditions by the colonial masters in the early part of 20<sup>th</sup> century (Ajayi, 2000, and Olowu, 1967). It has resulted in revenue accruing earnings and economic development in the Sokoto Basin NW Nigeria, especially the northwestern part of Kebbi State. Solid mineral exploration is an everyday activity that is currently going on, but, on a 'wild cat' basis. The ministry of Solid Minerals of Kebbi State asserted that rearnings from these resources can contribute to the economic growth of the region and can attract foreign direct investment thereby boosting the country's economy (Okline *et al.*, 1992). Mineral resources are an important source of wealth for a nation, but before they are harnessed, they have to pass through the stages of exploration, mining and processing (Badmus *et al.*, 2005; Okline *et al.*, 1992). For example, kaolinitic rocks are mainly constituted by clayey minerals and carbonates (calcite and/or dolomite), among others, and so to get kaolin (China clay) commodity there must be exploration, mining and processing.

Geophysical investigations of the earth involve studying the physical properties of the earth, thereby providing vital information on subsurface material conditions for numerous practical applications. Physical property measurements on the earth's surface are influenced by the properties of the earth's near-surface which may vary vertically and laterally reflecting the subsurface geology. Alternatively, another method of investigating subsurface geology is by pitting and drilling which provide information only at discrete locations and can be expensive (Burger, 1992). Geophysical investigations can

cover large areas rapidly and optimize the targeting of necessary intrusive inspections (Shemang, 1990). Geophysical techniques are often useful for discovering unknown subsurface conditions; most of these techniques are classified as passive and active. The methods employed are electrical (active), gravity (passive), magnetic (passive), seismic (active), electromagnetic (active) etc. The methods can be cost effective and capable of detecting and delineating local features of interest (Kearey and Brooks, 1988).

Electrical prospecting involves the detection of surface effect produced by electric current flow in the ground (Telford *et al.*, 1976). Exploitation of mineral resources has assumed a prime importance in several developing countries including Nigeria (Barker, 1989). Nigeria is endowed with abundant mineral resources, and can contribute immensely to the nation's wealth with associated socio-economic benefits.

The electrical properties of earth materials, consolidated and unconsolidated, vary widely. Various types of unconsolidated materials differ significantly in voids and contain fluids. For example, sandstone and granite may differ in porosity and fluid content. These differences affect the conductivity of the rocks. The contrasts between consolidated and unconsolidated materials are usually significant as far as electrical properties are concerned. Hence electrical exploration for depths of consolidated material is generally successful in mineral or subsurface investigation.

In this study an electrical sounding of geophysical investigation was carried out using Vertical Electrical

Sounding (VES) and Electrical Profiling (EP) making an attempt to delineate the possibility of anomalous zones of Kaolinite and Laterite deposits over Gwandu Ridges, of Birnin Kebbi area NW, Nigeria.

#### Location and Accessibility of the Study Area

Bulassa-Unguwan Naraba via Kangiwa Federal road is situated within Birnin Kebbi Local Government Area

LGA of Kebbi State NW Nigeria. The survey area is bounded by latitudes  $12^{\circ} 27' - 12^{\circ} 45' N$  and longitudes  $04^{\circ} 12' - 04^{\circ} 12' E$  with an average elevation of 250 m above sea level. The accessibility to the Bulassa-Unguwan Naraba village is only by the Birnin-Kebbi road (Fig. 1).

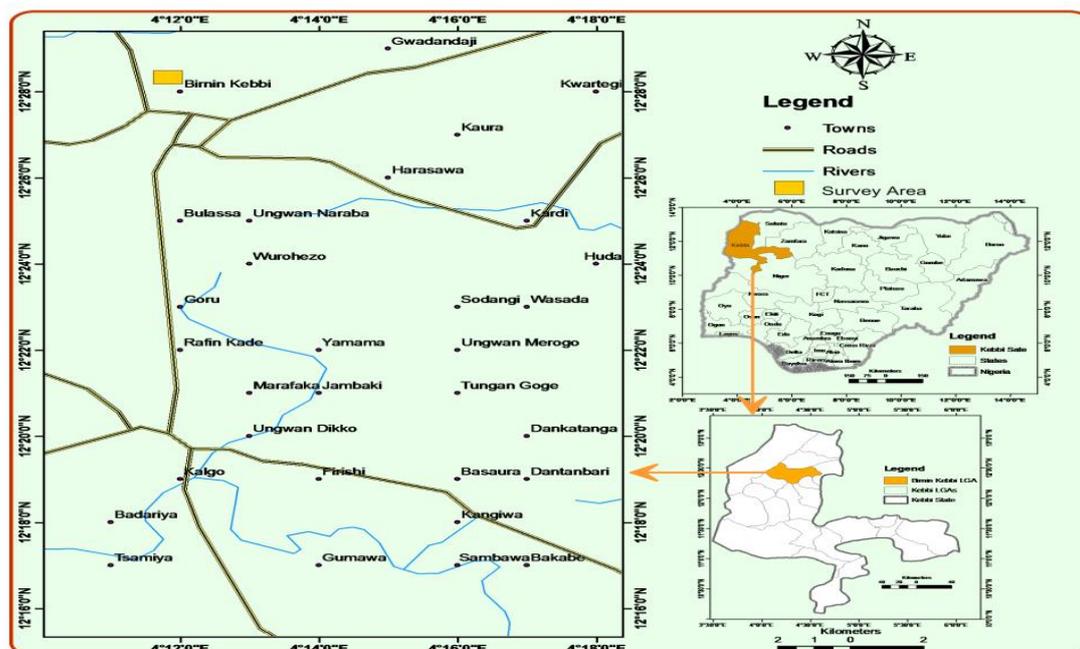


Fig. 1: Location map of the study area adopted from Google Earth, (2018).

#### General Geology of the Study Area

Nigeria lies in the pan African mobile belt which has been affected by pan African events through cycles of orogenic, epierogenic, tectonic and metamorphic episodes. The geology of Nigeria is classified into two parts, the basement complex and the sedimentary basin. The Duku-Tarasa village area of Birnin LGA of Kebbi State lies on a plain which forms part of the vast gentle undulating plain with an average elevation varying from 250 m to 450 m above the sea level. The plain is occasionally interrupted by low mesas and other escarpment features. The geology of the Sokoto Basin has been adequately described by various authors (Kogbe, 1979; Obaje *et al.*, 2013).

Birnin Kebbi is a part of the Sokoto basin which is the Nigerian sector of the larger Iullemeden basin. The Iullemeden basin itself is a broader sedimentary basin covering most part of Niger and Benin Republics and parts of Mali, Algeria and Libya. The sediments of the Iullemeden Basin were accumulated during four main phases of deposition:

- (i) The Illo and Gundumi Formations (made of grifts and clays) unconformably overlay the Pre-Cambrian Basement Complex.

- (ii) This is the so-called pre-Mastrichtian 'continental intercalaire' of West Africa.
- (iii) The Maastrichtian (66 – 72 Ma) Rima Group (consisting of mudstones and friable sandstones (the Taloka and Wurno Formations) separated by the fossiliferous, calcareous and shaley Dukamaje Formation overlay the Illo and Gundumi Formations unconformably.
- (iv) Next on top of the sequence are the Dange and Gamba Formations (mainly shales separated by the calcareous Kalambaina Formation constituting the Paleocene (56 – 66 Ma) Sokoto Group.
- (v) The sequence cover is the Gwandu Formation of the Eocene (33 – 56 Ma) age forming the continental terminal.

These sediments dip gently and thicken gradually towards the northwest with maximum thicknesses attainable towards the border with Niger Republic.

The Gwandu group consists of massive clay interbedded with alluvium sandstone (Fig. 2). Minerals that can be found within Gwandu formation includes quartz, kaolin, photolytic bauxite, clay, potassium, silica, sand and laterite deposits (Kogbe, 1979, 1981 and Obaje, 2009).

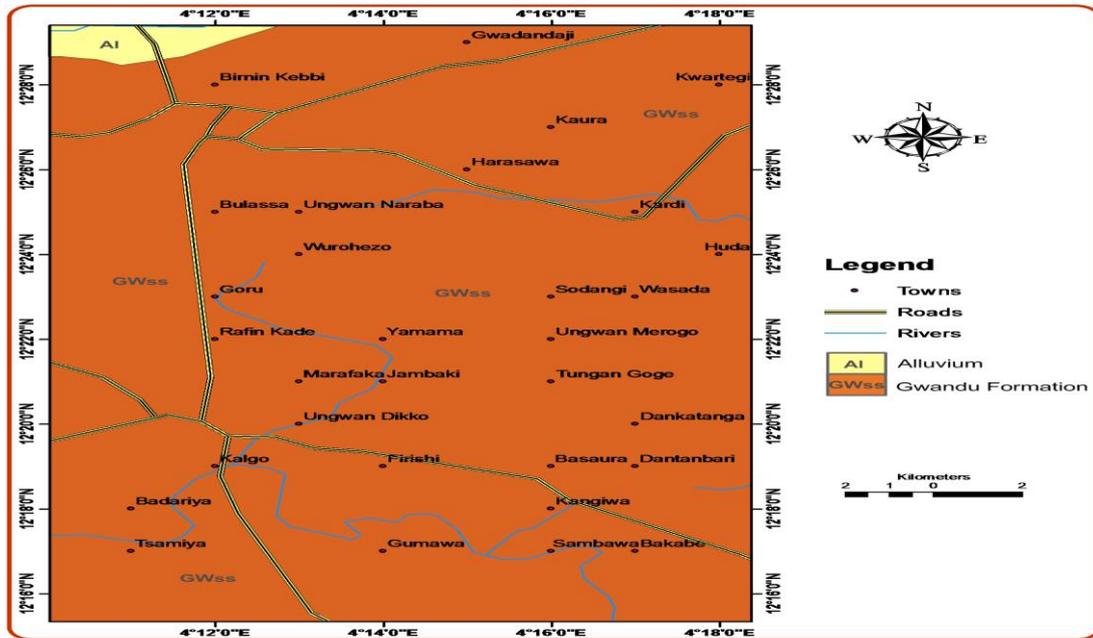


Fig. 2: Geological Map of the Study Area (Modified after Obaje *et al.*, 2013).

**MATERIALS AND METHODS**

The electrical resistivity method was employed to investigate the mineral resources deposit of the subsurface features beneath the Duku-Tarasa via Kangiwa road in Birnin Kebbi LGA of Kebbi State, NW Nigeria. This method was used to identify different subsurface layers that may yield various geoelectric sections that will give the probable zones of anomalous locations of mineral deposit.

**Instrumentation and Field Layout**

The instrument used in this study is **GEOPULSE Terrameter SAS 300**. The Schlumberger electrodes configuration was used in carrying out the Vertical Electrical Soundings (VES) at a separation of 50 m

covering an area of 300 km<sup>2</sup> apart (Fig. 3). A maximum current electrode spacing (AB) of 100m was used which might give a probing a depth of at least 25m of AB (Gholam and Nad, 2005). A profile with a total of 3.VES stations was established on each of the five profiles. Data collected from the VES were processed using AGI EarthImager 1D software for interpreting Vertical Electrical Sounding) and the results were used to determine the thickness of the overburden and other regolith information within the area of study. The horizontal electrical profiling was carried out along the pre-selected profiles and data collected from this were displayed using the Surfer (Golden software version 13) and the result assisted in locating anomalous areas of interest.

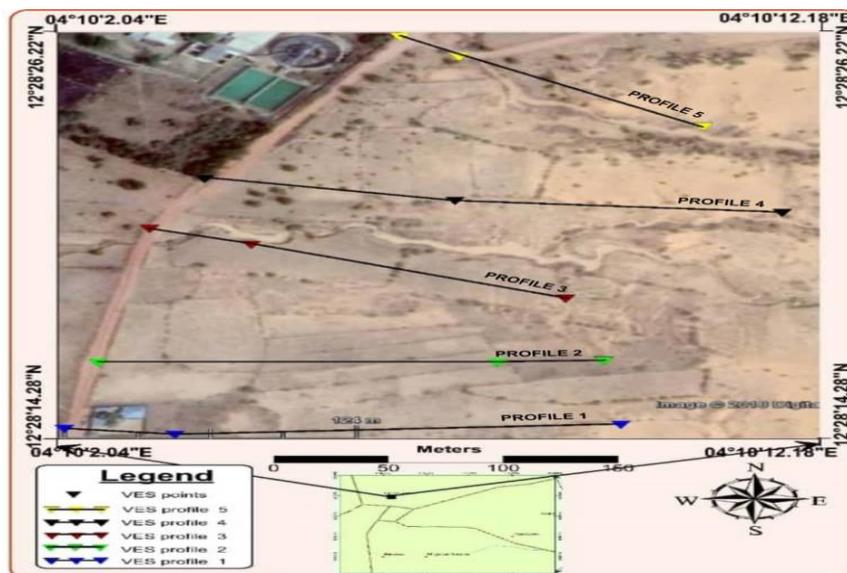


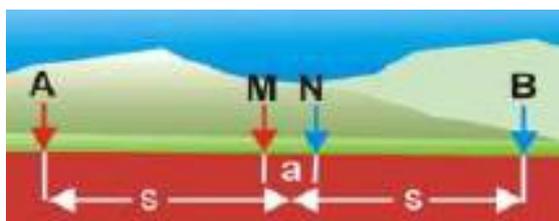
Fig. 3: Profiles on Google Earth map within the study Area. Profiles are tagged P<sub>1</sub>, P<sub>2</sub>, P<sub>3</sub>, P<sub>4</sub> and P<sub>5</sub>

**Schlumberger Electrode Configurations**

In this array, the current electrodes are spaced much further apart than the potential electrodes (Fig. 4). The

$$\rho_a = \pi \left( \frac{l^2}{b} - b \right) \frac{\Delta V}{I} \dots\dots\dots (1)$$

Where *l* is the distance of the current electrodes, and *b* is the potential electrodes distance. We have adopted the conceptual technique in which the potential electrodes are fixed while the current electrode separation is increased symmetrically about the centre of the spread, Schlumberger soundings were carried out under the



**Fig. 4:** The Schlumberger array (A and B are current electrodes while M and N are potential electrodes, and S is the array spacing). Note that *l* = 2*s* and *b* = *a*

**The Wenner Electrode Configuration (Horizontal Profiling)**

The Wenner electrode geometry is illustrated in Figure 5. Spacing between all electrodes is equal and conventionally denoted by letter 'a'. The horizontal

$$\rho_a = 2\pi a \frac{\Delta V}{I} \dots\dots\dots (2)$$

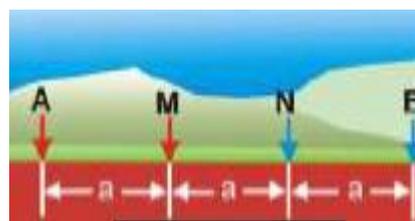
In this case, the survey was carried out along the profiles on the same VES profiles. The electrodes spacing remained constant and moved along a profile of 100 m. This method is widely employed to locate faults or shear zones and detect localized bodies of anomalous conductivity. It is also used in geotechnical surveys to determine variations in bedrock depth and can also indicate the presence of potentially unstable ground conditions (Kearey *et al.*, 2002).

**Interpretation of Resistivity Data**

An exclusively quantitative interpretation of apparent resistivity data is often difficult because of the wide variation in resistivity possessed by geological materials and the difficulty in developing theoretical expressions for apparent resistivity of each simplest geometries (Burger and Burger, 1992). There are so many interpretation methods which include cumulative resistivity (Moore, 1945) Barnes layer method and analytical method, that also include curve matching, and other computer aided techniques (Barnes, 1950; Zohdy, 1989). Recently due to the advancement in modern technology, different computer programmes have been designed to ease the ambiguity in the interpretation of resistivity data. However, because of the problem of equivalence and suppression and because of the many factors that affect curve details, a thorough knowledge of resistivity principles and interpreter's experience must go hand-in-hand with the results from computer-derived solutions of the field measurements (Burger and Burger, 1992).

electric field is measured approximately. The apparent resistivity  $\rho_a$  is given as

constraint potential electrode spacing (MN) which is small compared to the current electrode spacing (AB) i.e.  $MN < AB/2$ . The ratio  $\Delta V / I$  is that the potential difference (measured by the potential electrodes) to the current injected through current electrodes.



**Fig. 5:** The Wenner Electrode Configuration

electrical profiling technique allows the electrodes to move along a straight line or between the selected profiles after every reading such that the spacing between electrodes remains equal, taking on certain preselected values (Badmus *et al.*, 2005). The general equation for the apparent resistivity in this configuration is given by

Available geological controls such as borehole data, hand dug wells, exposed sections of the rock formations and resistivity values of earth materials compiled are used in order to have a meaningful interpretation (Saleko Ltd, 2013). The assumption usually made in the interpretation of VES data that are: (a) the various geoelectric layers delineated electrically homogeneous and isotropic. However, because of the existence of lateral variation in resistivity within a layer, possibility of error in interpretation is present, (b) the principle of equivalence that is, non unique solution for which a typical three layer curve is only distinguished by the resistivity value of its second layer in a relation to the value of either the first or third layer. Typical examples are type A ( $\rho_1 < \rho_2 < \rho_3$ ) and type H ( $\rho_1 > \rho_2 < \rho_3$ ) curves.

**RESULTS AND DISCUSSION**

The VES data were interpreted using AGI EarthImager an automatic interpretation tool box for sounding data. This method was used to obtain the model for the apparent resistivity of each sounding. The resulting true resistivity layer model from the application is shown in Figure 6 where the true resistivity under the sounding points were used to produce geoelectric section along VES profiles 1, 2, 3, 4 and 5. These profiles are parallel to observe and investigate continuity of the subsurface structures. All the geoelectric sections were correlated with the borehole section (Fig. 7) to produce hydrogeologic/resource sections for the study area

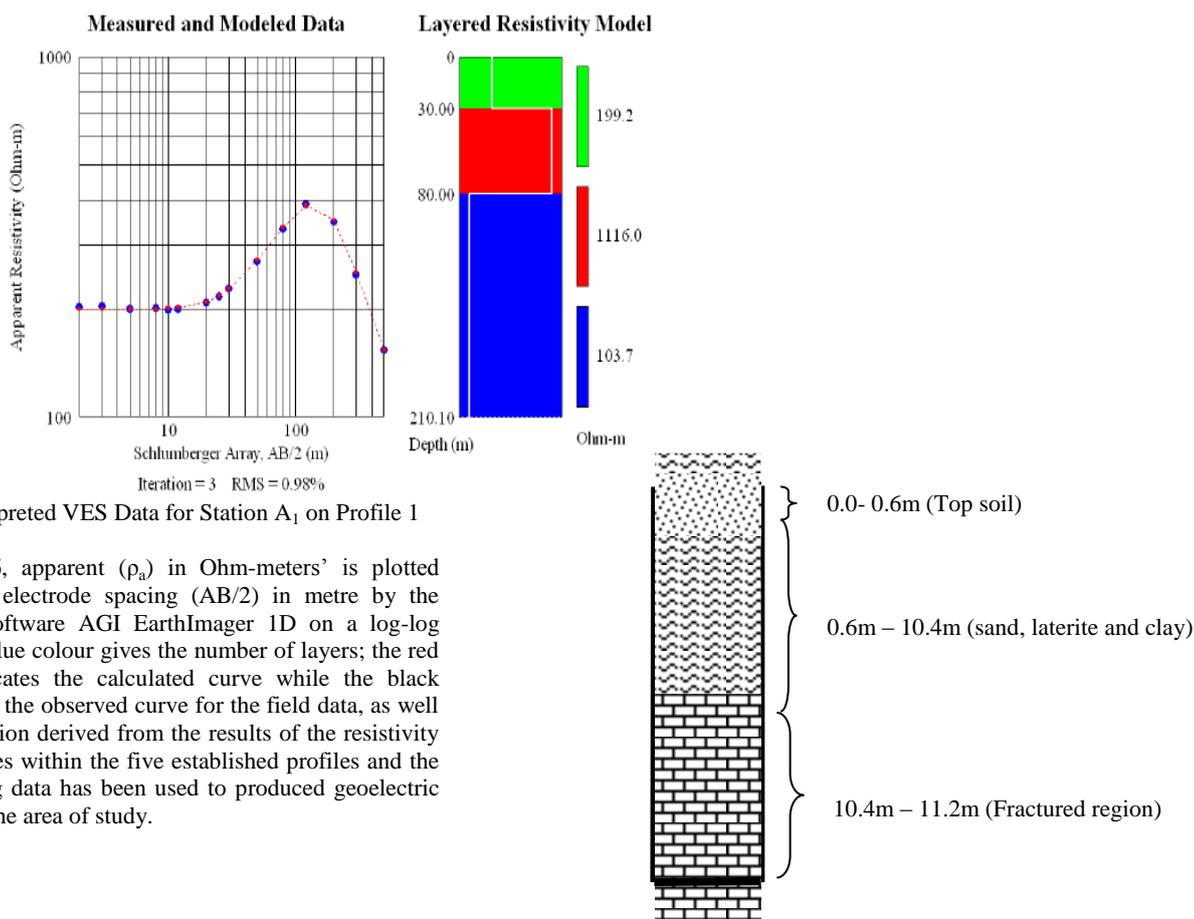
**Vertical Electrical Sounding (VES) Interpretation**

The resistivity data for station A<sub>1</sub> (Table 4.1) were interpreted using AGI EarthImager (1D software) and

displayed on Figure 6. This is a 3-layer case; other field data were similarly interpreted.

**Table 4:** VES Data for Station A<sub>1</sub> on Profile I

AB/2 (m)	MN/2 (m)	K factor (m)	Resistance, R (Ω)	Apparent Resistivity, ρ <sub>a</sub> (Ωm)
1	0.5	2.4	86.5	207.60
1.5	0.5	6.0	47.1	282.60
2	0.5	12.0	30.5	366.00
3	0.5	27.0	17.34	468.18
5	0.5	78	7.29	568.62
5	1	38	14.06	534.28
7	1	75	8.02	601.50
10	1	156	3.37	525.02
10	3	48	8.71	418.08
15	3	113	2.69	303.97
20	3	205	1.08	221.40
25	3	323	0.61	197.03
30	3	467	0.35	163.40
30	10	126	1.78	224.28
35	10	177	1.08	191.16
40	10	236	0.70	165.20
50	10	377	0.30	113.10



**Fig. 6:** Interpreted VES Data for Station A<sub>1</sub> on Profile 1

In Figure 6, apparent (ρ<sub>a</sub>) in Ohm-meters' is plotted against the electrode spacing (AB/2) in metre by the computer software AGI EarthImager 1D on a log-log scale. The blue colour gives the number of layers; the red colour indicates the calculated curve while the black colour gives the observed curve for the field data, as well as the information derived from the results of the resistivity master curves within the five established profiles and the borehole log data has been used to produced geoelectric sections in the area of study.

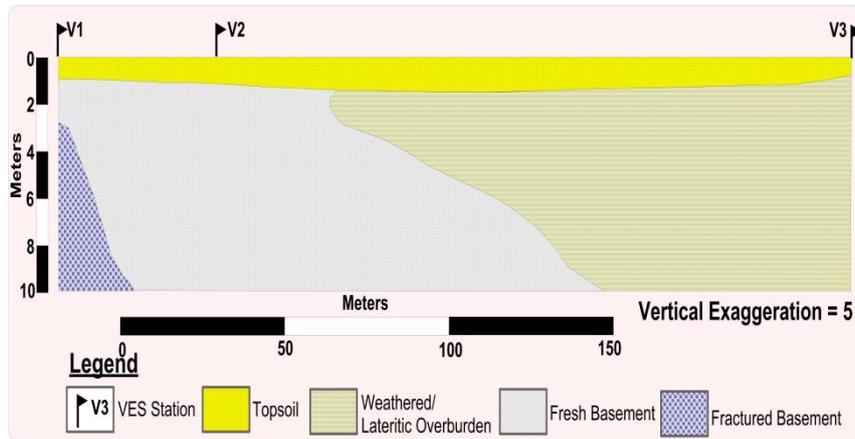
**Fig. 7:** Borehole log data drilled near the study area, (after Saleko Ltd, 2013)

**Geoelectric Sections along Profiles**

**(a) Profile 1**

Geoelectric section along the profile 1 (Fig. 3) has four subsurface layers (Fig. 8). The topsoil has resistivity value ranging from 56 to 346 ohm-m and average thickness of 1.5 m. The presence of laterites around VES 02 on profile 2 may be responsible for the low resistivity value. The second layer is the lateritic overburden with a resistivity varying from 22 to 568 ohm-m and of average

thickness of 2.4 m to 8 m (Saleko Ltd, 2013). The low resistivity values may be associated with kaolinitic clay. The third layer whose resistivity values range from 120-500 ohm-m is likely the fractured basement with the probable zone of mineral deposit lying within the survey area. The fourth layer with a resistivity value greater than 750 ohm-m with undefined thickness is probably the fresh basement.

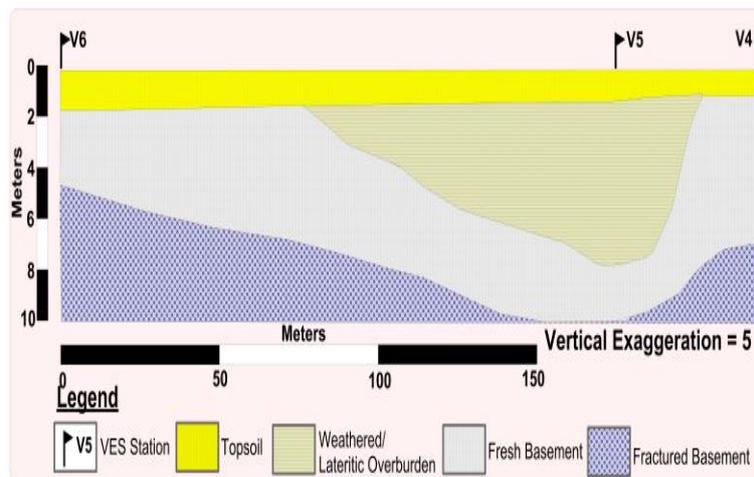


**Fig. 8:** A Geoelectric section along profile 1

**(b) Profile 2**

Figure 9 shows the geoelectric section along profile 2. Four subsurface layers are identified. The topsoil has a resistivity ranging from 72-200 ohm-m and with an average thickness of 1.2 m. This layer consists of laterite, sandstone and silt. Underlying the above layer is a formation where resistivity is in the range of 96-488

ohm-m and average thickness of 3.5 m. this is likely the weathered/lateritic overburden region. The third layer is probably weathered basement layer having resistivity range of 134-706 ohm-m and thickness varying from 2.5 m to 8.2 m (Saleko Ltd, 2013). The last layer of thickness 6.2 to 10 m has a resistivity greater than 700 ohm-m. This is probably the fresh basement and most likely the place where mineral deposit can be found (Eduvai, 2000).



**Fig. 9:** A Geoelectric section along profile 2

**(c) Profile 3**

This profile suggests that the region is underlined by four subsurface layers; the superficial cover (topsoil layer) having resistivity values ranging from 171 ohm-m to 624 ohm-m (Fig. 10). The thickness varies from 1.2 m to 2 m this layer probably is made up of sandy, clay and silt (lateritic) soil. The second layer has resistivity values between 21 ohm-m and 138 ohm-m with an average thickness of 11.3 m, this layer is probably the

weathered/overburden layer. The third layer has resistivity value ranges of 70 ohm-m to 727 ohm-m and likely the weathered region with an average thickness of 7.6m. This region is most likely the layer that has the kaolinitic clay, silts and sandstone deposits. The third layer has resistivity value ranges of 98 ohm-m to 1078 ohm-m which and is likely a fractured basement around VES 07, 08 and a fresh basement around VES 09 with an average thickness each of 5m.

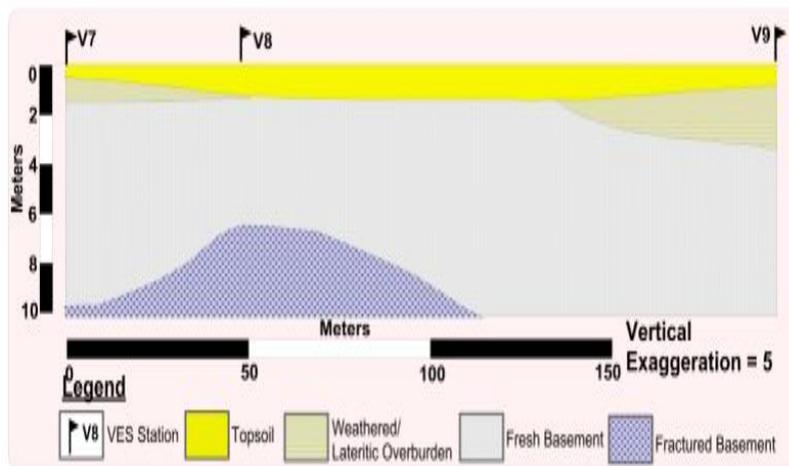


Fig. 10: A Geoelectric section along profile 3

(d) Profile 4

Figure 11 depicts the geoelectric section derived from the resistivity VES curves. The profile suggests four subsurface layers; the first layer has an average resistivity value of 110 ohm-m with an average thickness of 2.5 m. This layer contains a sandy, loam, and silt and kaolin clay. Beneath this layer is the second layer with resistivity value ranging from 35 ohm-m to 304 ohm-m

which most likely is the weathered overburden. The third layer has an average resistivity value of 2719 ohm-m and the thickness about 4 m. The fourth layer is the fresh basement with the thickness not fully penetrated with resistivity value ranging from 66 ohm-m to above 1000 ohm-m.

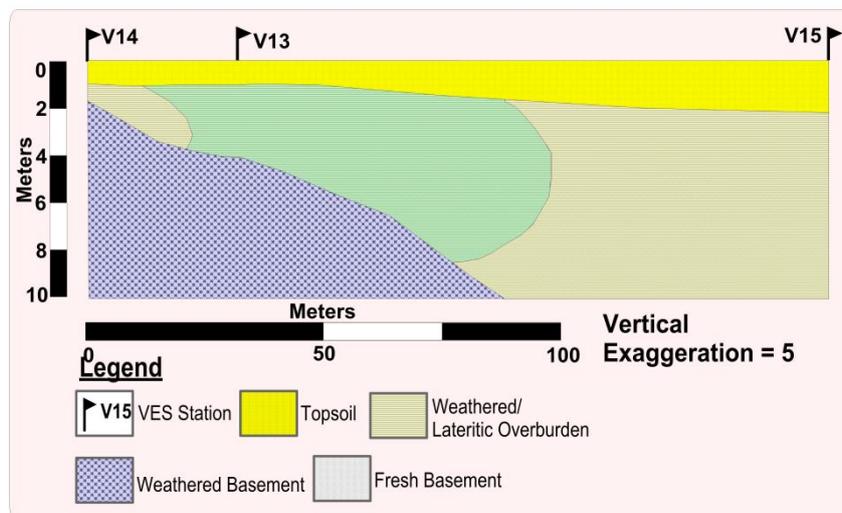


Fig. 11: A Geoelectric section along profile 4

Map Produced from Interpreted Data

In order to look at some subsurface structural trends in the study area and to reveal the lithological sequence of the formation, specialized maps were produced from the interpreted resistivity data were obtained for the whole VES stations. The essence of this map is to show the lateral variation of resistivity over a horizontal plane at

certain depth. This has been produced for a depth of 10m (Fig. 12).

The map (Fig. 12) was produced by contouring the resistivity values of the top soil at fifteen (15) points along all the locations of the five (5) profiles within the study area. The resistivity values vary between 500 to 1500 ohm-m. The higher resistivity values are noticed around VES06, VES10, VES11 and VES12.

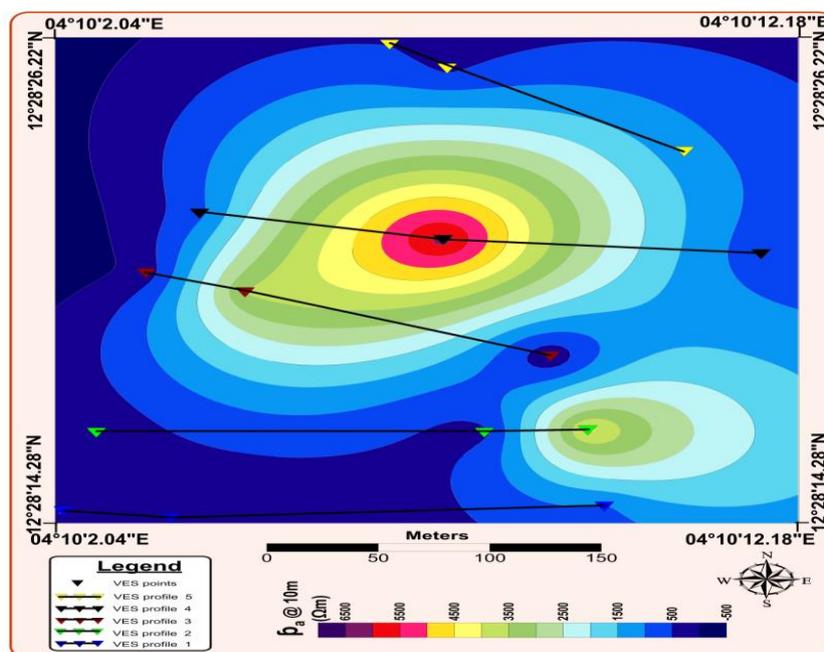


Fig. 12: Iso- resistivity map of surface layer at 10 m on the study area

## CONCLUSION

Generally, the VES data and Electrical Profiling techniques employed in this work have revealed the possible location of Kaolin (China clay) and Laterite deposit at Duku-Tarasa Area of Birnin Kebbi NW, Nigeria. The investigation showed that Kaolin (China clay) and laterite deposit could be found with dominant clay/shale/Iron-ore/limestone within the Gwandu Formation in Kebbi State. It was also discovered that the mineral of interest, Kaolin (China clay) and laterite could be found within a possible depth in the range of 3.2 m to 11.3 m which fall largely within the second layer and possibly beyond the hydrogeologic/resources sections of the five profiles in the area of study. However, it is uniquely important to undertake at least two more geophysical techniques to add value to this assertion.

## Recommendation

The electrical resistivity method is a reconnaissance tool. However it can also suitable for detailed study of a prospect when other techniques, such as gravity, electromagnetic (EM) or some other passive methods have been used. Finally future work should be extended beyond the limit of the profiles and better understanding of the target area and also 2-D and 3-D resistivity survey should be undertaken within the area under investigation.

## REFERENCES

- Ajayi, C.O. (2000). "The Ajayi-Makinde Two Electrode D.C. Resistivity Array", A Brief Brochure to the Patent Office Abuja.
- Barker, R.D. (1989). Depth of Investigation of a Generalized Collinear Four Electrode Array. *Geophysics*, 54, 1031 – 1037.
- Burger, R.H. (1992). *Exploration Geophysics of the Shallow Subsurface* Prentice Hall, U.S.A pp. 30-56.

- Badmus, B.S., Ayolabi, E.A., Olowofe, J.A., Adisa, S.A., and Oyekunle, T.O. (2005). Current Variation in Electric Resistivity Probing using Wenner and Schlumberger Arrays in Basement Terrain. *Journal of Geophysics*, Volume 2, pp118-125.
- Barnes, H.E., (1950). *Soil mechanics in Road construction* Butter and Tenner publishing company, Great Britain, pp23-25.
- Burger, D.C. and Burger H.K., (1992). *Exploration Geophysics for shallow subsurface*, prentice Hall, pp 445-446.
- Eduvai, M.O. (2000). Groundwater Assessment and Development in the Bima Sandstone: Case Study of Yola-Jimeta Areas "Water Resources", *Journal of Nigerian Association of Hydrogeologists*". Vol. 11, Nov. 2000.
- Gholam, R.L. and Nad, M.N. (2005). Geoelectrical investigation for the assessment of groundwater condition. Volume 48(6) pp 937-944.
- Kearey, P. Michael, B. and Ian H. (2002). *An Introduction to Geophysical Prospecting* Pergamon Press Inc. Oxford.
- Kearey, P. and Brooks, M. (1988). *An Introduction to Geophysical Exploration*. Blackwell Scientific Publication, London.
- Kogbe, C. A., (1979). Geology of southeastern portion of the Iullummeden Basin (Sokoto Basin), *Bull. Dept. Geology, Ahmadu Bello University, Zaria, Nigeria*, Vol. 2, 420p.
- Kogbe, C. A., (1981). Cretaceous and Tertiary of the Iullummeden Basin in Nigeria (West Africa), *Cretaceous Research* 2, 129 – 186.
- Moore, W. (1945). An Empirical Method of Interpretation of Earth Resistivity Measurement, *Transaction of American Institute, of Mining and Metallurgical Engineers* Volume 164, pp197-223.

- Obaje, N.G, (2009). Lecture Notes in Earth Science, Vol.120. Geology and mineral resources of Nigeria springer, con/series/772.
- Obaje, N. G., Aduku, M. and Yusuf, I. 2013, The Sokoto Basin of northwestern Nigeria: a preliminary assessment of hydrocarbon prospectivity, *Petroleum Technology Development Journal* **3** (2), 66-80
- Okline, E.T., Ndinwa, K.R, and Olorufemi, M. O. (1992).Electrical resistivity investigation of a typical basement complex area.Journal of Mining and Geology, *27*(2), 63– 68.
- Olowu, J (1967). Preliminary Investigation of the Groundwater Condition in Zaria sheet 102 SW, Geological Survey of Nigeria report, No.1-62.
- Saleko Hydrological Drilling Company Nigeria Limited, 2013.
- Shemang, E.M. (1990). Electrical Depth Sounding at selected well sites within Kubanni River Basin, Zaria unpublished M.Sc. Thesis, A.B.U Zaria, Nigeria
- Telford, W.M. Geldart, L.P. Sheriff, R.E, and Keys, D.A., (1976). Applied Geophysics Cambridge University Press, London. 860pp.
- Zohdy , A.A.R. (1989). A new Method for the Automatic Interpretation of Schlumberger and Wenner Sounding Curves, Geophysics, Volume 54, pp 9-39.