International Journal of Applied Environmental Sciences
ISSN 0973-6077 Volume 14, Number 2 (2019), pp. 197-210

http://www.ripublication.com

Geoelectric Assessments of the Bauxite Ore Deposit at Orin-Ekiti, Southwestern Nigeria

***Eluwole Akinola Bolaji; [1]Ademilua Oladimeji Lawrence; [1]Oyinloye Akindele; [1]Adebayo Olajide Femi; [1]Obasi Romanus Ayoola; [1]Talabi Abel Ojo and [1]Olaolorun Olusola Amos**

[*] *Department of Geophysics, Federal University, Oye-Ekiti, Nigeria.*

[1] *Department of Geology, Faculty of Science, Ekiti State University, Ado-Ekiti, Nigeria.*

Abstract

A portion of Orin-Ekiti, Southwestern Nigeria has been investigated with the aim of delineating bauxite ore deposit as well as estimating its lateral and depth extents. The electrical resistivity method of geophysical prospecting was adopted for the investigations. The resistivity measurements were taken along four (4) approximately southeast – northwest traverses using the 1-D Vertical Electrical Sounding (VES) and 2-D Electrical Resistivity Tomography (ERT) techniques. The Schlumberger and Dipole-dipole electrode configurations were adopted for the two techniques respectively. The observed data from Eighteen (18) VES stations were subjected to partial curve matching and forward modelling, while the ERT data obtained from the four traverses were interpreted by inversion with the aid of the Finite Element Modelling (FEM) algorithm. Geoelectric sections were generated from the VES interpretations and 2-D subsurface electrical resistivity images were produced from the 2-D data. The VES technique delineated a total of five (5) subsurface layers, and these include the topsoil/lateritic hardpan; the bauxite ore; the weathered layer/bauxitic clay; the partly weathered/fractured bedrock and the fresh bedrock. On the 2-D images, the contrasting resistivity regimes which are somewhat directly proportional to lithological contrasts were seen to possess appreciable semblance as those observed on the geoelectric sections. The subsurface regions within the 2-D images observed to manifest the resistivity characteristics of the bauxite ore were further classified in order of increasing resistivity and specific depth of occurrence as clayey bauxite; mottled bauxite, granular bauxite and pisolitic bauxite. The average thickness of the bauxite ore is greater than 5 m; however thicknesses greater than 20 m are present in some areas. The ore was observed to possess a northeast – southwest orientation, with its bulk occurring in the central parts of the study area. The results of the geoelectric assessments therefore suggest the presence of an economically viable bauxite ore at Orin-Ekiti.

Keywords: bauxite ore, geophysical prospecting, lithological contrasts, economically viable bauxite ore)

INTRODUCTION

Alumina, the key component in aluminium production has bauxite as its primary ore. Approximately 85% of bauxite are considered to be aluminium (Qadrouh *et al.*,2015). Such high percentage has attracted governments and industrialists to invest in bauxite exploration due to its high economic potentials. This is so, because aluminium is used in a huge variety of ways. In transportation, aluminium is used in the production of automobiles, aircrafts, marine vessels, bicycles, space craft etc. Aluminium is also used in the production of beverage containers, cans, and foils because of its high resistance to corrosion.

Bauxite is found in lateritic areas at or near the surface of elevated terrain. As of 2016, Guinea, Australia, Brazil, China, and India were respectively listed as the top five (5) countries with largest bauxite reserves in the world (Dipanwita, 2016). Other countries known for the production of bauxite include Spain, Italy, Hungary, Greece, Ghana and Sierra Leone (Talabi *et al.,* 2013). Although Nigeria is not listed among the world's producers of bauxite, researchers (e.g. Talabi *et al.,* 2013) suspects that the numerous crystalline rocks covering about 50% of the country and which are known to be rich in aluminium oxides possess the potential for the production of bauxite.

Because geophysical methods are responsive to the resistivity, density, dielectric, thermoelectric andother physical properties of bauxite, geophysical methods have been successfully used for bauxite exploration. Some of such successes have been reported. For example Tsourlos *et al.,* (2005) used electrical tomography and Ground Penetrating Radar (GPR) in search of bauxitic lenses in galleries. Neishtadt *et al.,* (2006) differentiated rocks such as bauxites and kimberlites from host rocks based on their piezoelectric and seismoelectrokinetic properties. Bing-Kun (2009) applied the Induced Polarization (IP) sounding and high density resistivity methods to prospect for concealed bauxite deposits.

In Nigeria, Talabi *et al.,* (2013) adopted the Vertical Electrical Sounding (VES) technique of the electrical resistivity method to investigate the possible occurrence of bauxite at Orin-Ekiti, Southwestern Nigeria. The preliminary investigation which indicated the presence of bauxite however covered a limited area. This study therefore aimed at expanding the scope of geophysical exploration for bauxite deposit at Orin-Ekiti by deploying the 1-D VES and 2-D Electrical Resistivity Tomography (ERT) field techniques. This was with a view to delineating the geoelectric parameters (resistivities and thicknesses) of subsurface lithologies and specifically estimating the bauxite ore's lateral and depth extents.

Location and Accessibility

Orin-Ekiti is located within Latitude 7^{o} 48.5^{1} – 7^{o} 50.4^{1} and Longitude 5^{o} 13.7^{1} – 5^{o} 14.5^{1} (Figure 1). It is 2.7 km from Ora-Ekiti, a neighbouring town and about 30 km from Ado-Ekiti the State Capital. The topography of the area is undulating, with an average elevation of about 560 m.

Geology

Geologically, Orin-Ekiti lies within the Precambrian Crystalline Basement Complex of Southwestern Nigeria (Rahaman, 1988). The main rock outcrops are migmatite gneiss and charnockite (Figure 2). The rock outcrops are predominantly coarse in terms of texture (Talabi *et al*., 2013). The boulders of charnockite which are indiscriminately scattered around the study area make the terrain rugged.

Methodology

A total of four (4) approximately southeast – northwest geophysical traverses were established within a0.34 sq km area, with inter-traverse separation varying from 180 m to 390 m (Figure 3). The traverse lengths varied from 120 m to 320 m. The 1-D Vertical Electrical Sounding (VES) and 2-DElectrical Resistivity Tomograpy (ERT) techniques of the Electrical Resistivity method of geophysical prospecting were adopted for the study. The Schlumberger and the dipole-dipole electrode configurations were adopted for the 1-D and 2-D measurements respectively.

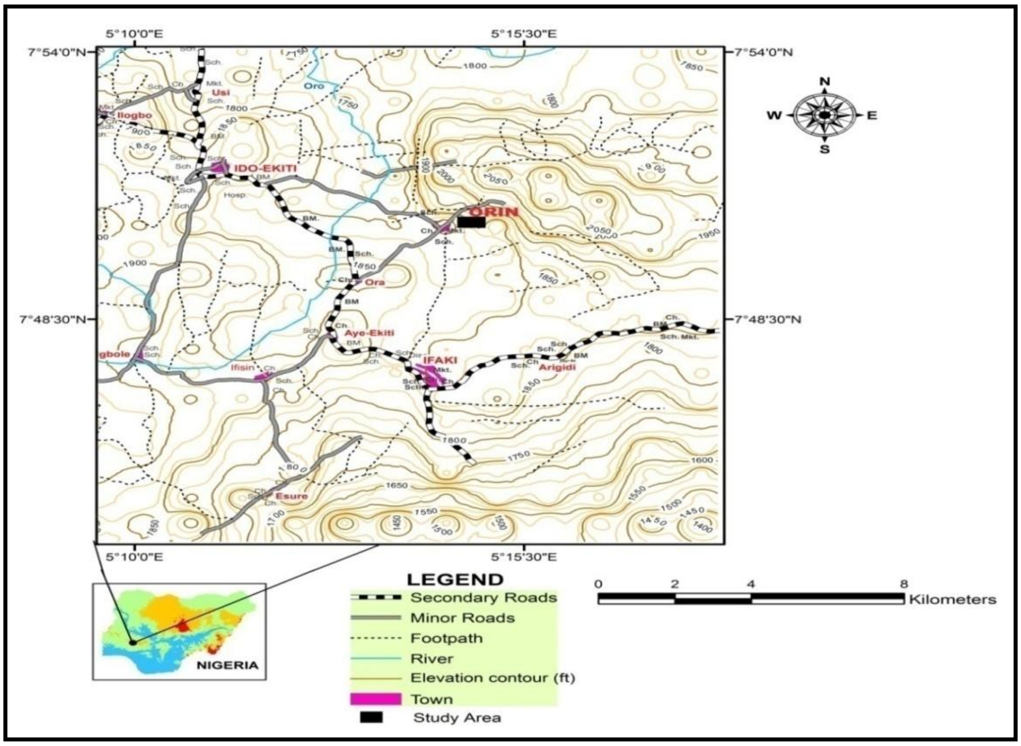


Figure 1: Topographical Map of the Study Area

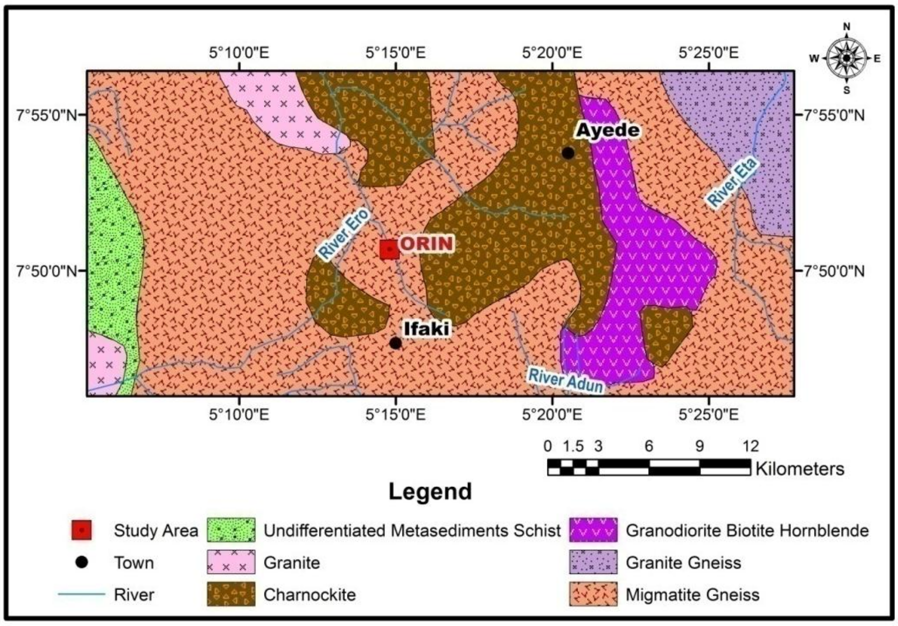


Figure 2: Geological Map of the Area around Orin-Ekiti
(modified after Bayowa, 2013)

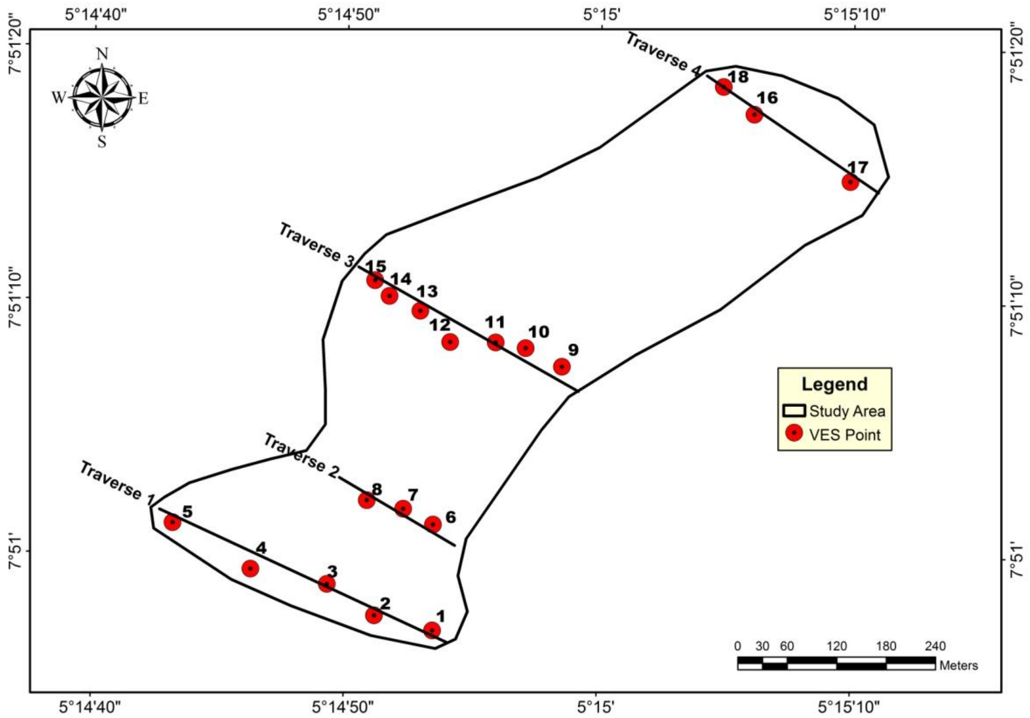


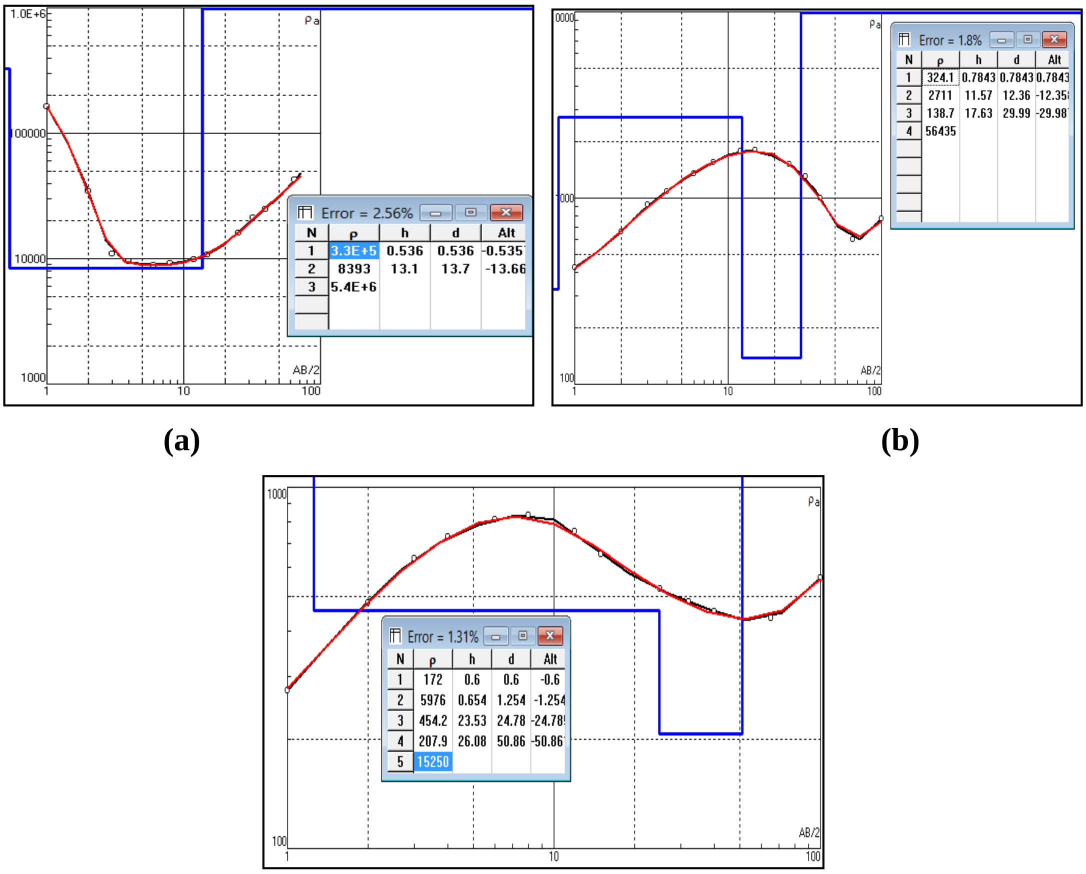
Figure 3: Geophysical Data Acquisition Map

The VES technique was purposely engaged to determine the general stratification/layering within the investigation grid to serve as a calibration guide for the 2-D imaging. Eighteen (18) VES stations were occupied with inter-VES separation varying from 50 m to 100 m on the four traverses (see Figure 3). Half current electrode spacing (AB/2) was varied from 1 m to a maximum of 100 m for the VES locations. The 2-DERT which gave continuous resistivity characteristics of the subsurface along and beneath the four traverses was calibrated in a traverse-specific manner, guided by the VES results. As such, inter-electrode spacing (a) of 5 m and 10 m, and expansion factor (n) varying from 1 – 4 and 1 – 7 m respectively were administered. Over one hundred and twenty (120) stations were so-occupied. VES data were interpreted quantitatively by partial curve matching and computer assisted forward modelling using the IPI2Win(R) software (Bobachev, 1990). The geoelectric paramaters (thicknesses and resistivities) obtained from the VES interpretation were used to generate Geoelectric sections beneath the four traverses. The parameters were also subjected to spatial analyses to determine their spatial distributions. The ERT data were processed and interpreted quantitatively by inverse modelling with DIPRO for Windows software from which 2-D subsurface Electrical Images were obtained. The results of the resistivity measurements served as guide for the siting of test holes from which samples were collected for further geochemical analyses. However, the texture of cuttings obtained from the test holes were logged and used to constrain the geoelectric lithological classifications, most especially those of the 2-D resistivity images.

RESULTS AND DISCUSSION

Geoelectric Lithologic Sequence

The depth sounding curves obtained from the study area were the 3-layer (A- and H-types, e.g. Figure 4a); the 4-layer (KH, KQ, and QH types, e.g. Figure 4b) and the 5-layer (KHA, HKH, KQH, AKH and HKQ-types, e.g. Figure 4c). As presented in Table 1, the 5-layer types have the highest frequency of occurrence in the study area. The spatial geoelectric lithologic model (Figure 7)describes the spatial distribution of the geoelectric lithologic system of the study area. Areas under the brown colour band are characterised by four geoelectric lithologies, zones within the white colour band are associated with four geoelectric lithologies while the blue colour band depicts the areas having five geoelectric lithologies.



(a) **(b)**

(c)

Figure 4: Typical Depth Sounding Curves. (a) 3-layer H-type, (b) 4-layer KH-type and (c) 5-layer KQH-type.

Table 1: Summary of the VES Curves Distribution

Number of Layers	Curve Type	Frequency of Occurence	VES Number
3	H	1	11, 12
	A	1	16
4	KH	4	2, 3, 5, 9
	KQ	1	8
	QH	1	13
5	KHA	1	1
	HKH	2	4,10
	KQH	3	6, 14, 17
	AKH	2	7, 18
	HKQ	1	15

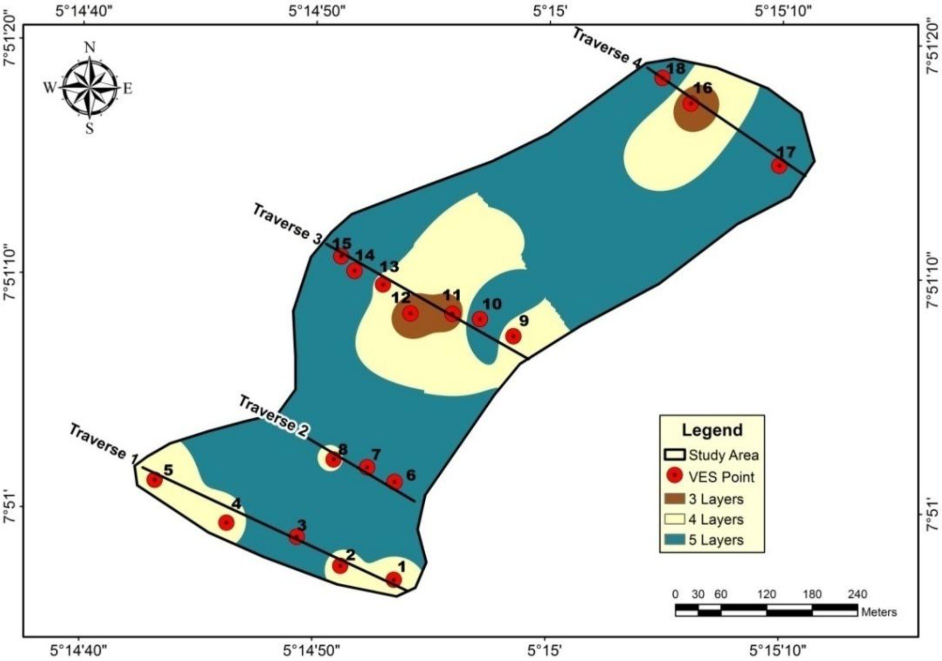


Figure 5: Spatial Geoelectric Lithologic Model of the Study Area

Geoelectric Sections

Geolectric sections were evolved by correlating the geoelectric parameters (thicknesses and resistivites) obtained from the eighteen VES points. The section beneath Traverse 1 (Figure 6) delineates five (5) layers. The first layer is the topsoil/lateritic hardpan. The resistivity and thickness of the layer ranges from 324 to 4819 ohm-m and 0.7 to 5.6 m respectively. The bauxite ore which lies directly beneath the topsoil/lateritic layer constitutes the second layer. It is characteristically relatively resistive (resistivity values are between 2711 and 20776 ohm-m). Talabi *et al.*, (2013) also delineated the bauxite ore beneath the topsoil and lateritic layer.

Such relatively high resistivity characteristics is attributable to the insulating nature of alumina – a major constituent of bauxite whose resistivity range is of the order of 1 x 10^{12} ohm-m. Underlying the bauxite ore are the weathered layer/bauxitic clay; the partly weathered/fractured bedrock and the charnockitic bedrock. The weathered layer/bauxitic clay respresents the mottled bauxite zone with a correspondingly low resistivity ranging between 70 – 1098 ohm-m when compared to the other layers, and a thickness range of 2.9 – 24 m. The partly weathered /fractured bedrock is only present beneath VES 2 and it extends to the depth of about 43 m. The bedrock is characterised by relatively high resistivity ranging between 7389 – 140600 ohm-m with undulating topography.

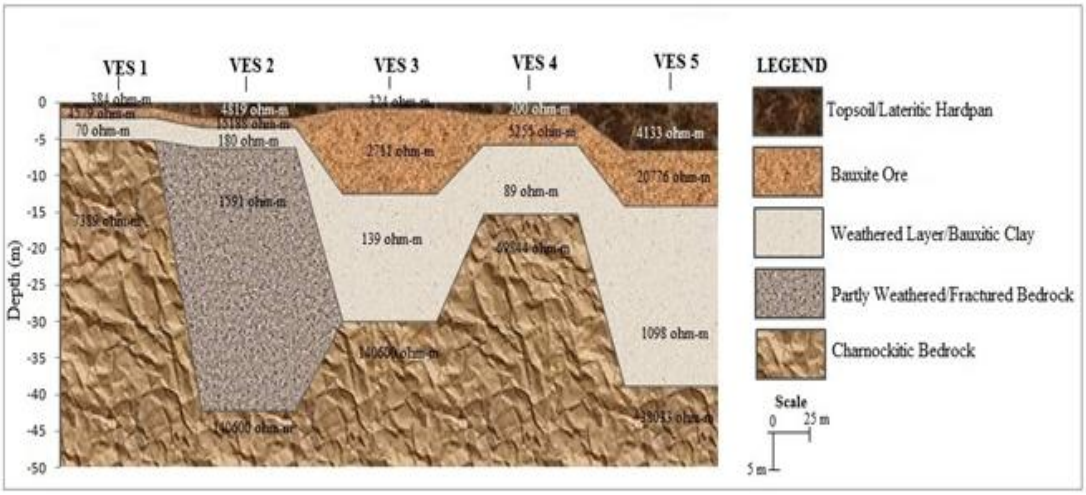


Figure 6: Geoelectric Section Beneath Traverse 1

If not for the absence of the partly weathered/fractured bedrock, the geoelectric sections obtained from Traverses 2 – 4 (Figure 7 – 9) would have been said to exhibit similar geoelectric characteristics as Traverse 1. The topsoil/lateritic hardpan which constitutes the overburden of the bauxite ore is generally thin (< 3 m) along the traverses, especially on Traverse 3 (Figure 8) where the ore has a surface exposure. The bauxite ore beneath Traverse 2, 3 and 4 is moderately thick (generally > 5 m).

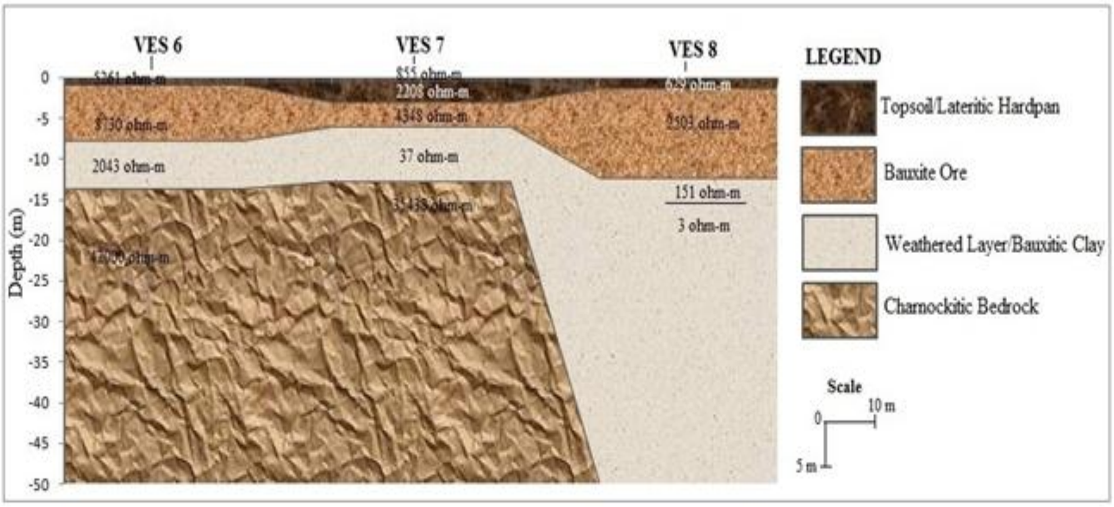


Figure 7: Geoelectric Section Beneath Traverse 2

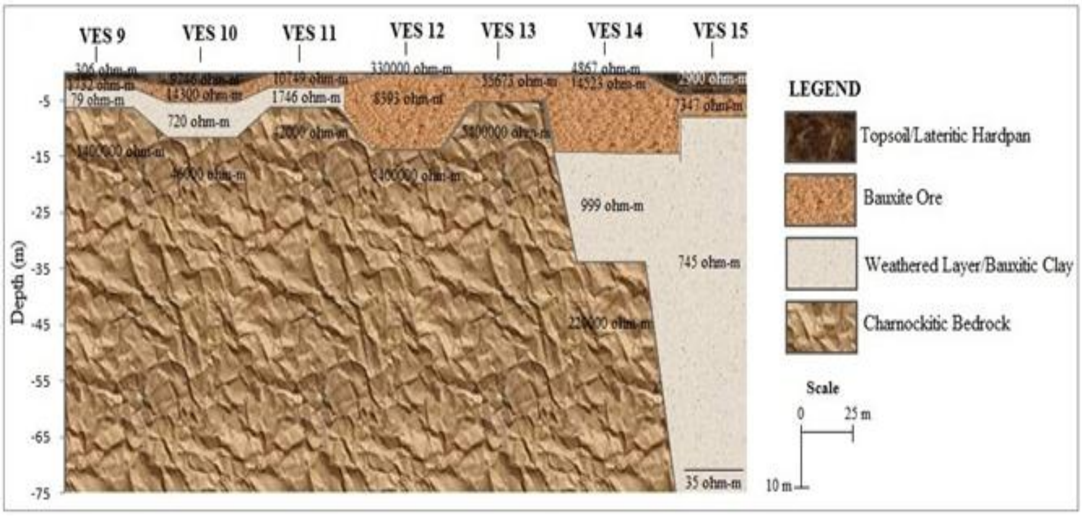


Figure 8: Geoelectric Section Beneath Traverse 3

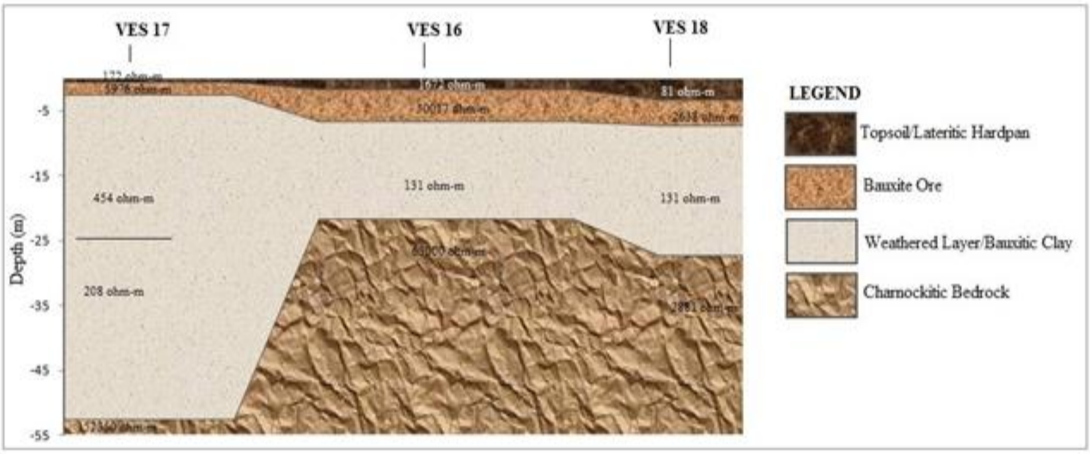


Figure 9: Geoelectric Section Beneath Traverse 4

2-D Resistivity Images

The 2-D subsurface electrical resistivity images (Figures 10 – 13) were obtained from the four traverses. The images display the continuous resistivity regimes beneath the traverses with distinguishable colour spectrum. The blue colour band represents resistivity values generally less than 1500 ohm-m. The yellow/green colour bands are characterised by resistivity values greater than 1500 ohm-m but less than 3000 ohm-m. However, areas under the red colour band depicts resistivities generally greater than 3000 ohm-m but less than 7000 ohm-m, while resistivity values greater than 7000 ohm-m are represented by the purple colour band.

The bauxite samples obtained from the test holes were pisolitic, granular, mottled and clayey respectively in terms of texture. Physical examinations showed that the moisture contents increased in the above order, with the pisolitic bauxite having the least moisture content. The 2-D images were interpreted vis-a-vis the textural characteristics and the earlier discussed colour regimes.Areas under the blue/green colour bands within the upper 2.5 m of each image constitutes the topsoil/lateritic layer, while similar zones present beneath the depth of about 10 m represents the bauxitic clay zones. The zones under the purple colour band are indicative of the pisolitic bauxite ore. However such zones are seen to merge into the bedrock at depths generally greater than 15 m on Figures 11 and 12. The reddish colour band in the vicinities of the purple colour band are suggestive of the resistivity characteristics of the granular bauxite ore. Meanwhile areas under the yellowish/greenish colour bands especially those beneath the depths of about 10 m and directly beneath the earlier identified pisolitic and granular bauxites are suspected to emanate from the friable/mottled bauxite ore.

Table 2 serves as the interpretation Legend of the 2-D electrical resistivity images obtained from the four traverses.

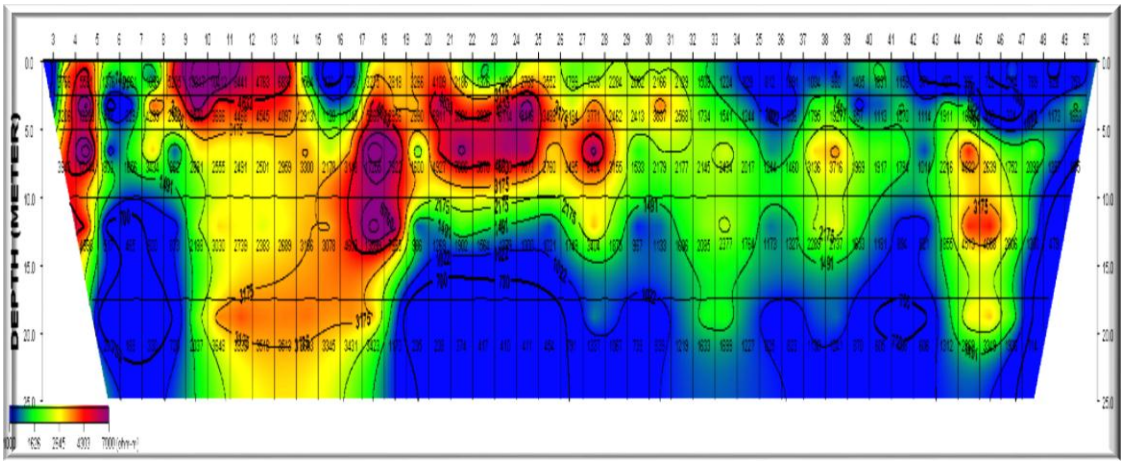


Figure 10: 2-D-Electrical Resistivity Image beneath Traverse 1

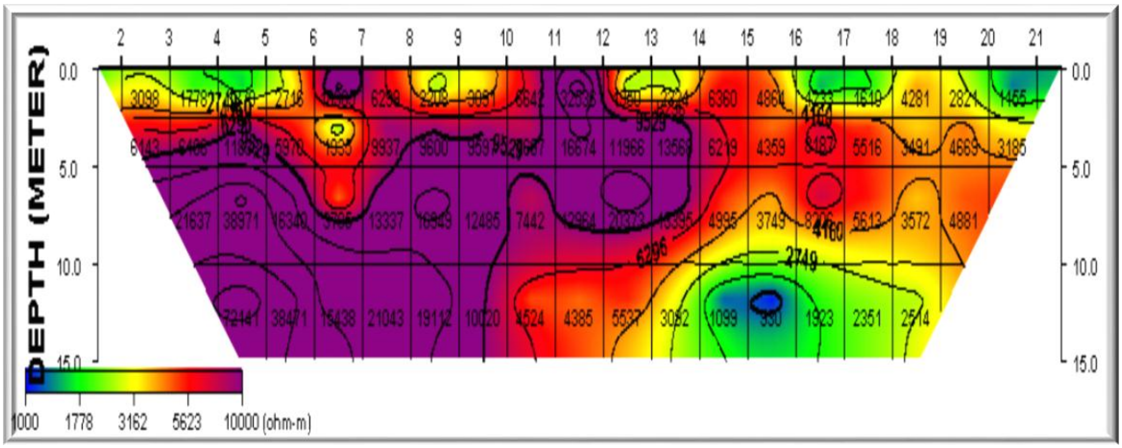


Figure 11: 2-D-Electrical Resistivity Image beneath Traverse 2

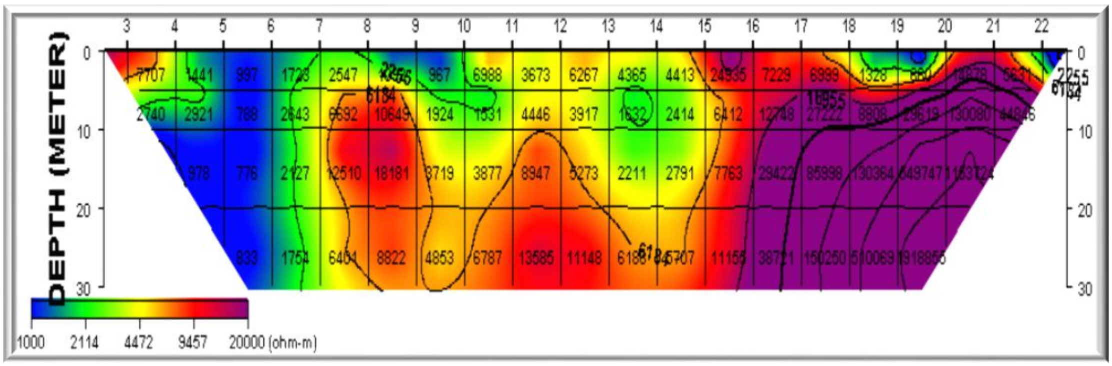


Figure 12: 2-D-Electrical Resistivity Image beneath Traverse 3

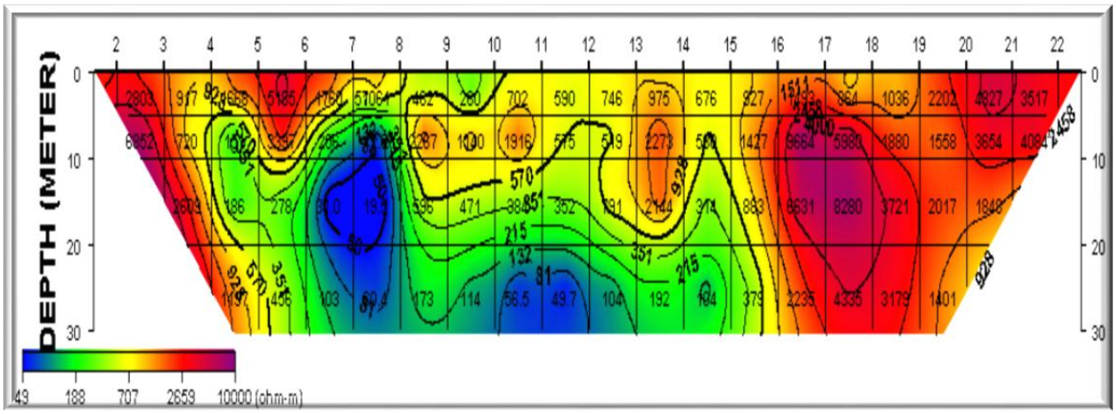


Figure 13: 2-D-Electrical Resistivity Image beneath Traverse 4

Table 2: Harmonized Interpretation Legend of the 2-D Electrical Resistivity Images

Resistivity Range (ohm-m)	Colour(s)	Inferred Lithology	General Depth of Occurrence (m)
900 – 2500		Topsoil/ Lateritic hardpan	< 2.5
< 1500		Clayey Bauxite	> 10
1500 – 3000		Mottled Bauxite	> 5
3000 – 7000		Granular Bauxite	> 2.5
> 7000		Pisolitic Bauxite	0 – 20
> 7000		Bedrock	> 20

Demarcated 2-D Resistivity Images

The 2-D resistivity images obtained from the four traverses were demarcated with a view to isolating the geoelectric characteristics earlier attributed to the bauxite ore in Table 2. The demarcated images on Figure 14 show that the bauxite ore has a Northeast – Southwest spatial orientation in the study area. The central parts indicate the presence of larger deposits of the bauxite ore, judging from the over 65% ore coverage observed on the images on Traverse 2 and Traverse 3.

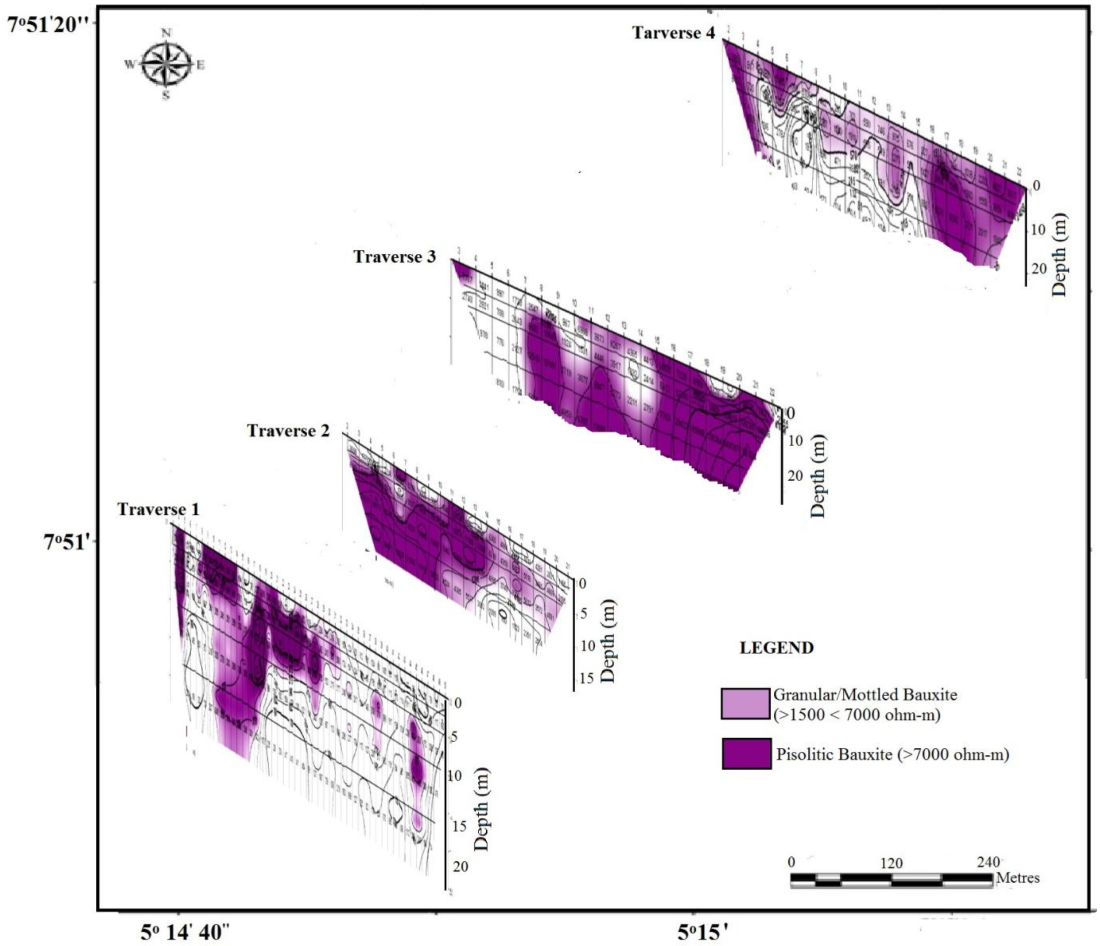


Figure 14: Demarcated 2-D Resistivity images beneath Traverses 1,2, 3 and 4 showing the Spatial orientation of the Bauxite in the study area.

CONCLUSIONS

A portion of Orin-Ekiti, Ekiti State earlier reported to posses bauxite ore has been investigated using 1-D Vertical Electrical Sounding (VES) and 2-D Electrical Resistivity Tomograpy (ERT) techniques of the Electrical Resistivity Method with the aim of delineating the bauxite ore and estimating its lateral and depth extents.

The results of the VES showed that there are a total of five (5) distinguishable lithologic units within the study area. The Topsoil/lateritic hardpan is the first lithologic unit,it forms the bauxite ore's overburden and it has an average thickness less than 3 m. Other litholigic units include the bauxite ore; the weathered layer/bauxitic clay/mottled bauxite; the partly weathered/fractured bedrock and the charnockitic bedrock. The 2-D ERT images also showed the presence of the above mentioned lithologic units, but with greater degree of accuracy due to the continuous nature of resistivity measurements. The bauxite ore zones on the 2-D images were classified with respect to the texture of the ore samples obtained from the test holes. Resistivity values generally less than 1500 ohm-m with depth of occurrence below 10 m were classified as the clayey bauxite; resistivity values greater than 1500 ohm-m but less than 3000 ohm-m were attributed to the mottled bauxite; while the granular bauxite inferred to be associated with resistivity values between 3000 ohm-m and 7000 ohm-m. On the other hand, resistivity values greater than 7000 ohm-m within the upper 20 m of the subsurface were classified as the pisolitic bauxite. The trend of the ore in the study area is Northeast – Southwest and the central parts are found to be associated with larger deposits.

Conclusively therefore, considering the average ore thickness which is greater than 5 m and its extensive areal coverage, the bauxite ore deposit at Orin-Ekiti can be said to be economically viable. The thinness of the overburden covering the ore is also a major advantage because of the ease that would attend the mining whenever the exploitation commences.

Acknowledgement

The authors are thankful to Tertiary Education Trust Fund, Nigeria for funding the research.

REFERENCES

[1] Bayowa, O. (2013). *Hydrogeophysical Investigation of the Basement Complex Terrain of Ekiti State, Southwestern Nigeria.* Unpublished Ph.D. Thesis, Department of Geology, Obafemi Awolowo University, Ile-Ife.

[2] Bing-Kun, B. (2009). The Application of the Electric Method to Bauxite Exploration. *Journal of Geophysical and Geochemical Exploration , 33* (2).

[3] Bobachev, A. (1990). *Patent No. IPI2WIN Resistivity Sounding Software.* Moscow.

[4] Dipanwita, G. (2016). *Top Five Countries with Highest Bauxite Reserves in the World*. Retrieved from http://www.Alcircle.com/Bauxite-News

[5] Neishtadt, N., Eppelbaum, L., & Levitski, A. (2006). Application of Piezoelectric and Seismoelectrokinetic Phenomena in Exploration Geophysics. *Geophysics , 71* (2), B41-B53.

[6] Qadrouh, A., Alanezi, A., Hafiz, I., Munir, K., & Alyousif, M. (2013). Performing High Resolution Seismic Reflection for Mapping Bauxite Layers. *Open Journal of Geology , 3*, 13-16.

[7] Rahaman, M. (1988). Recent Advances in the Study of the Basement Complex of Nigeria. *Precambrian Geology of Nigeria* , 11-41.

[8] Talabi, A., Ademilua, O., Ajayi, O., & Ogunniyi, S. (2013). Preliminary Geophysical Evaluation of Orin Bauxite Deposit, Southwestern Nigeria. *Journal of Emerging Trend in Engineering and Applied Sciences , 4* (3), 423-437.

[9] Tsourlos, P., Tsokas, G., & Yiamas, A. (2005). Detecting Bauxitic Lenses in Galleries Using Geophysical Techniques. *Proceedings of the 2nd Conference of the Committee of Economic Geology, Mineralogy and Geochemistry of the Greek Geological Society*, (pp. 367-376). Thessaloniki, Greece.