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GEOPHYSICAL INVESTIGATION AS AN AID TO UNDERSTANDING COMPLEX GEOLOGICAL TERRAIN: A CASE OF YIKPATA TRANSITION ZONE IN SHARE, NORTH-CENTRAL NIGERIA

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ABSTRACT

A geophysical method of investigation has been deployed in order to give a quick overview of the nature and the rapidly changing subsurface lithologies that characterized Yikpata, Share, Kwara State, Nigeria. A total of nine (9) vertical electrical soundings (VES), using Schlumberger Array uniformly divided into three groups: basement, basement/sedimentary boundary and sedimentary terrain, and horizontal profiling (HP) using Wenner Array were deployed for this study. The study revealed variation in the subsurface resistivity, thus depicting changes in lithology/rock types along this basement-sedimentary contact zone. The interpretation revealed that the Basement Complex terrain consists of 3-4 geoelectric layers: the topsoil, the weathered, weathered/fractured basement and the fractured basement. Depths beyond ≥ 12 m where the fractured basement occurs can be target for groundwater exploration and structurally controlled mineralization. The resistivity values around the Basement/Sedimentary unconformity zone shows about 3 – 4 geoelectric layers. The resistivity values show remarkable characteristics of the basement and the sedimentary terrains and also reflect the rapidly changing subsurface geology in the area. In the sedimentary terrain, 4 geoelectric layers were delineated: Topsoil, clayey sand, sandy clay and clay. Geoelectric sections reveal the variation in the subsurface lithology laterally and vertically. The study has shown that the resistivity method can be an aid to understand complex geologic environments with rapidly changing subsurface geology. Also, the knowledge of the geology of an area is very important in order to make sensible geophysical interpretation.

Keywords: Basement complex; Electrical resistivity, Geoelectric; Vertical electrical sounding.

1 INTRODUCTION

Over the years, the geophysical method of investigation has proved to be an irreplaceable tool in understanding the geological distribution and the subsurface geology of an area, most especially in areas of rapidly changing geology. The geophysical method of investigation helped immensely in economic geology and other aspects of geophysical exploration. The use of the electrical resistivity method proved to be versatile in understanding the geology of an area. Various researchers have applied electrical resistivity method of survey in unraveling the geology of an area [1], [2], [3], [4], [5], etc.

Eighty-five (85) stations of vertical electrical sounding (VES) survey were used by [5] to delineate prolific groundwater aquifer in basement complex terrain of Ilorin. They evaluated the subsurface in terms of their thickness, depth and resistivities and identified suitable sites for bore hole drilling. [2] studied the electrical resistivity anisotropy in rocks of Odo Ara, near Egbe, West central Nigeria, using sixty radial vertical electrical sounding (RVES). Analysis of the data obtained showed a significant presence of electrical resistivity anisotropy within the study area and the VES curves obtained were predominantly of H-type ($\ell 1 > \ell 2 < \ell 3$). Authors in [1] carried out 25 VES in Edu and Pategi Local Government Area of Kwara State to investigate the geologic and geoelectric characteristics of the aquifers within the study area. The study aimed at serving as an aid in determining the changes in the production of aquifer around the study area. From the analysis of the 25VES data, areas around Lafiagi district were identified to show high prospect for sustainable groundwater development. Electrical resistivity Tomography (ERT) survey was carried out in the Taprang Landslide, Kaski district, West Central Nepal by [6] to determine the subsurface lithological condition, depth and geometry of the slip surface using Wenner and dipole-dipole arrays. The study revealed that there are three main geoelectric layers from the surface to the bottom. Judging from the wide range of resistivity values which connote different kinds of layers at the subsurface and the dip slip surface was discovered to occur at a depth of 25 m. The geophysical study (Electrical resistivity survey) conducted by [7] to delineate the boundary between the basement complex and the sedimentary rocks in Kakara Village, Kano State is also of high relevance to this research. In the research, a total of twenty-four vertical electrical soundings (VES) were obtained within the study area. Analysis of the data obtained revealed that the sedimentary rock was lying unconformably on the basement rock at a depth of 5 m and this agrees with the borehole data within the study area.

There is a need to deploy the geophysical method as an aid in understanding the subsurface lithological layers, depth to basement and the characteristic nature of the lithologies around the contacts between the sedimentary and the basement complex rocks in a basement/sedimentary area like Yikpata, Share as the knowledge of this is hitherto very minimal. Therefore, this study is designed to use Electrical geophysical method to map the subsurface geology by determining the number of geoelectric layers, the depths to basement and resistivity values traversing through the Basement Complex terrain, to the Sedimentary terrain. This study will provide useful information that will aid in geologic mapping of the study area which is invaluable for future geologic/geophysical exploratory studies around complex terrains as this is often associated with difficulties in drilling programs given their peculiar characteristics with rapidly changing subsurface geology.

1.1 General Geological Setting and Local Geology of the Study Area

The Geology of Nigeria is broadly classified into three units, which are the Precambrian Basement Complex, the Jurassic Younger Granites, and the Cretaceous to Recent sedimentary basins, [8] and [9].

The Basement Complex terrain occupies the central, southwestern and southeastern part of Nigeria, and is roughly grouped into four main lithological units, from the ancient Migmatite-Gneiss Complex, Liberian (ca 2800Ma) to Pan African (600 Ma) in age [10]. The Schist belt, which are usually of low grade (Green Schist facies), is mainly composed of metamorphosed semi-pelitic assemblage [11]. The Syntectonic to Late tectonic granitoids, which are generally called Older Granites, intruded both the Migmatite-Gneiss Complex and Schist belts. Pegmatites which are of rare metal and non-rare metal bearing, believed to be Late Pan African intrusive of the Older Granite suite, its prominent occurrence have been found in Obalinku and Obudu in south-eastern part [11].

The Mesozoic Younger Granite ring complexes of Nigeria, which occupies the North Central part of Nigeria, forms a part of a wider province of alkaline anorogenic magmatism. They occur in a zone 200 km wide and 1,600 km long extending from northern Niger to south central Nigeria. Rb/Sr whole rock dating indicates that the oldest complex of Adrar Bous in the north of Niger is Ordovician in age, with progressively younger ages southwards, while the most southerly ring complex of Afu is Late Jurassic in age [8].

The Nigeria sedimentary basins comprise of the Benue Trough (the Lower Benue Trough, the Anambra Basin, the Middle Benue Trough, the Upper Benue Trough, the Gongola basin and the Yola basin), the Chad basin, the Mid-Niger / Bida basin, the Sokoto basin, the Dahomey basin and the Niger Delta basin. About seven sedimentary basins (the Middle and Upper Benue Trough, the southeastern sector of the Chad basin, the Mid-Niger (Bida) basin and the Sokoto basin) make the Northern Nigeria Sedimentary basins, while the rest make up the southern sedimentary basins [8]. Different basins are characterized by differing lithological units, depending on the depositional environment and other geologic condition at the period of deposition.

The rocks of the Precambrian Basement Complex and that of the sedimentary basins are in sharp contact in some places, while in other places, the contact is gradational. Generally, where these contacts are observed, the sediments are found to lie unconformably on the basement rocks. This is what characterizes the study area which is situated at the contact between the conglomeratic sandstone of the Mid-Niger/Bida basin and the Southwestern amphibolite schist and granodiorite basement rocks as shown in Figure 1.

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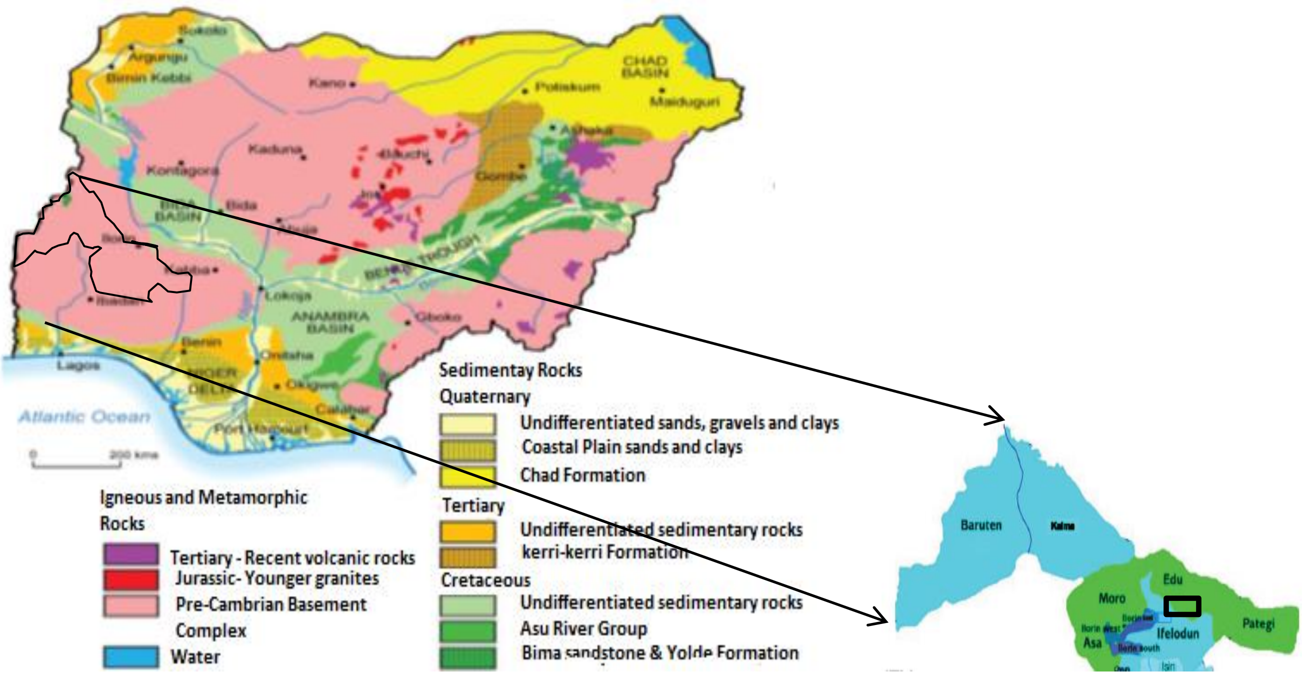
As the geology changes from the basement rocks to the sedimentary rocks, the geophysical characteristic of the lithology is also expected to change gradually from the basement complex terrain to the sedimentary rocks. The depth to basement has also been observed to be shallower in Basement Complex terrain and deeper in the sedimentary basins [12].

Share town where this research was carried out is the capital of Ifelodun local government and is situated at about 65 km, North-East of Ilorin, the capital of Kwara State, Nigeria. The area is bounded by latitude 08˚48’00” N to 08°51’00” N and longitude 05°03’00” E to 05˚07’00” E. Share has a unique but complex geology; part of the area is located at the margin of the Southwestern Basement Complex of Nigeria and part at the flank of Bida/Nupe basin. Sandstone, siltstone, sandy clay, clayey sand and lens of pebble are predominantly the sediments that make up the Nupe basin. The sediments thin southward and are of Campanian to Maastrichtian age [13], while the area of lower relief to southwest and southeast of Share are mainly underlain by Precambrian Basement Complex rocks such as granites, granodiorite and amphibolite schist. The Basement Complex underlies the entire Nupe basin [8].

The Basement Complex in this zone is predominantly made of porphyritic granite to granodiorite and amphibolite schist. The amphibolite schist is highly conspicuous at the northern and southern end of the town and extends westward to about 500 m before it is eventually overlaid by the sandstone of the Bida Basin around Yikpata, this sandstone continues westward to Share town (Fig. 1).



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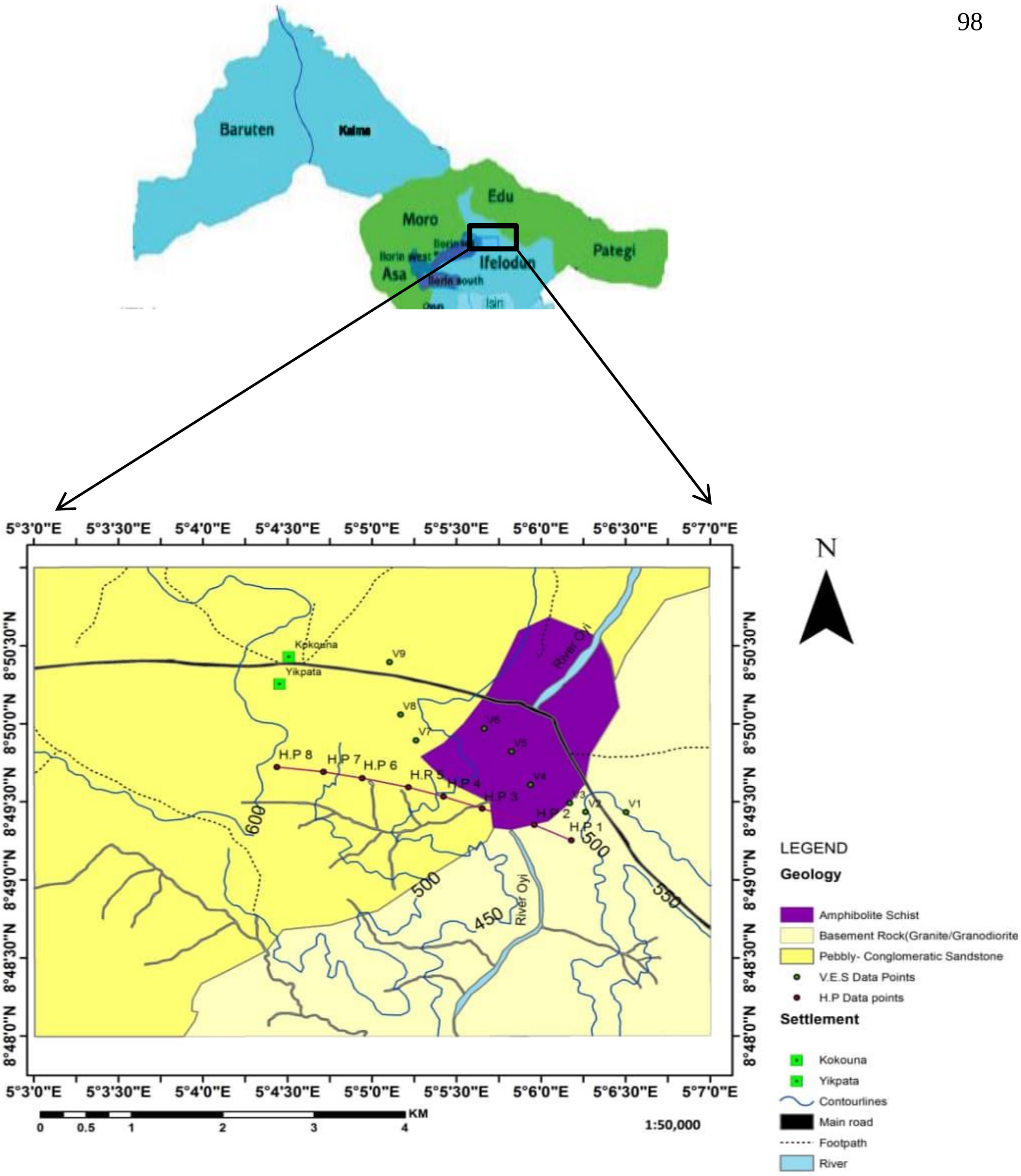

Figure 1. *Modified generalized geological map of Nigeria (modified from [8]); inset: Map of Kwara state (modified from [14]); inset: Geological map of the study area (Share)*

2 METHODOLOGY

2.1 Basic Concept of Electrical Resistivity Survey

Electrical resistivity survey is a method of survey that involves the use of resistivity of earth's materials to investigate the subsurface. Here, the potential difference is measured at the surface by artificially generated electrical current introduced into the ground. Deviation from the general pattern of potential differences expected from homogeneous ground provides information on the form and the electrical properties of the subsurface inhomogeneities.

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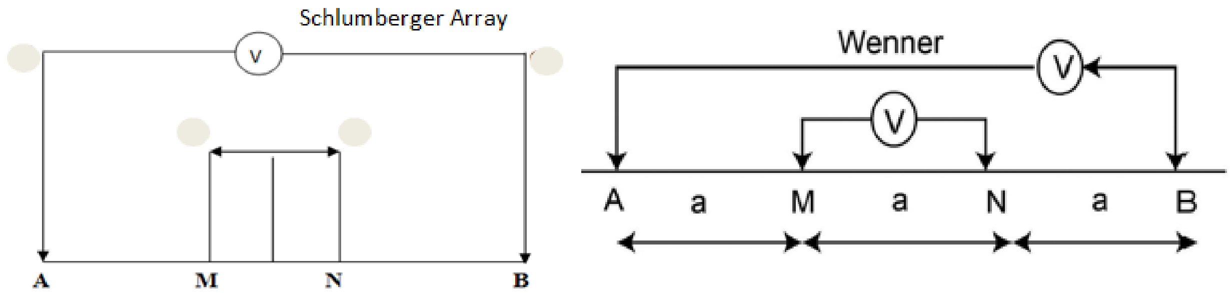

(a) *(b)*

Figure 2. *(a) Schlumberger Configuration and (b) Wenner Configuration [15]*

AB = Current Electrode Distance, where A is the first current electrode and B is the second current electrode, MN = Potential Electrode Distance, where M is the first potential electrode and N is the second potential electrode. For Wenner configuration, we have equal distance "a" between the electrodes.

Geometric factor $K = \frac{\pi\left[\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2\right]}{2*\left(\frac{MN}{2}\right)}$ for Schlumberger array.

Geometric factor $K = 2\pi a$ for Wenner array.

The Geometric factor (K) is multiplied by the Resistance to obtain the apparent Resistivity 'ℓ' in Ohms. m. In vertical electrical sounding using Schlumberger array (Fig. 2a), the potential electrodes remain fixed, while the current electrodes spacing is expanded symmetrically about the center of the spread. For large value of AB, it is necessary to increase MN also in order to maintain a measurable potential, so that AB ≥ 5MN. The assumption is that the wider the current electrode spacing, the deeper the earth is being probed. At each measurement, the resistivity meter displayed ground resistance values. The recorded resistance values were then used to compute apparent resistivity values by multiplying the values with the geometric factors. The Wenner array shown in Figure 2b, is used for the horizontal data acquisition with constant "a" of 10 m, this is done to understand the resistivity variation at a depth 10 m across the zone. The results obtained from horizontal profiling using Wenner array and VES using Schlumberger array are summarized in Tables 1 and 2 respectively.

2.2 Data Acquisition and Processing

2.2.1 Data Acquisition

The VES data were acquired using the ABEM Terrameter SAS 4000 Campus Ohmega, with current electrodes spacing (AB) of 2 to 60 m. The Terrameter displayed the resistance of various earth materials to the injected current. The resistance values were then converted to true resistivity value by partial curve matching and computer iterations using WinResist Software. A total of nine (9) VES were acquired along three transverses. The first three (3) VES (1, 2 and 3) were acquired on the basement complex terrain; three (3) VES (5, 4 and 7) were acquired around the basement-sedimentary contact zone, while the last three (3) VES, which are VES 6, 8 and 9 at the sedimentary zone moving westward (Figure 1) using the Schlumberger configuration.

2.2.2 Data Processing

The data obtained from the field were subjected to manual partial curve matching and computer iteration. WINRESIST Software was used for the final interpretation of the data. Figures 3 (a and b) are examples of depth

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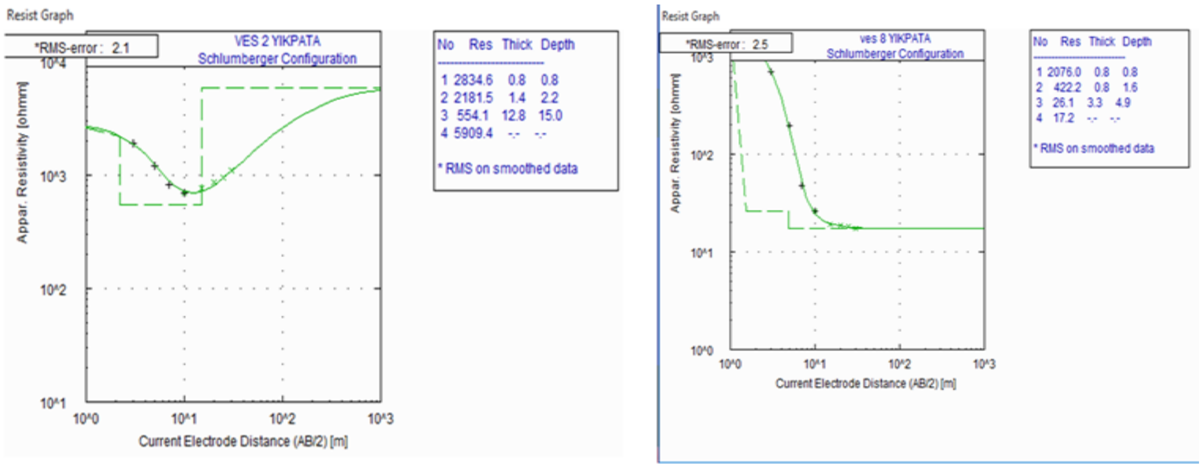
sounding curves generated from WINRESIST software, from which the thickness and the inverted resistivity values were obtained and used to generate geoelectric section (Figures 4–6), using SURFER software. Generally, deductions were made according to some specific standard given for resistivity of common earth material according to [16] and the general geologic knowledge obtained by detailed geologic mapping of the study area.

3 RESULTS AND DISCUSSION

The results obtained from the interpretation of the VES acquired are summarized in Table 2, while Figures 3 (a and b) show samples of curves obtained after minimal iterations and minimal RMS error (< 5 %). This is done for all other VES curves used for this study.



(a) **(b)**

Figure 4. *Depth Sounding curve for VES 2 (a) and 8 (b)*

From the resistivity values obtained, the profile in the basement terrain (Fig. 5) shows 3–4 geoelectric layers: the topsoil with depth range of 0–1.0 m, resistivity range of 2835–6609 Ohms.m. These high resistivity values reflect the lateritic nature of the topsoil. The second layer has a depth range of 2.2–2.7 m and resistivity range of 841–2181.5 Ohms.m. This is characteristic of a weathered/partly weathered bedrock. The third layer is the weathered/fractured bedrock with resistivity values ranging from 77–554 Ohms.m, with depths range of ≥ 12 m, which agrees with the result obtained by [2]. Beyond the depth of 12–15 m, the fresh basement rock occurs with resistivity range of 1981–5909 Ohms.m.

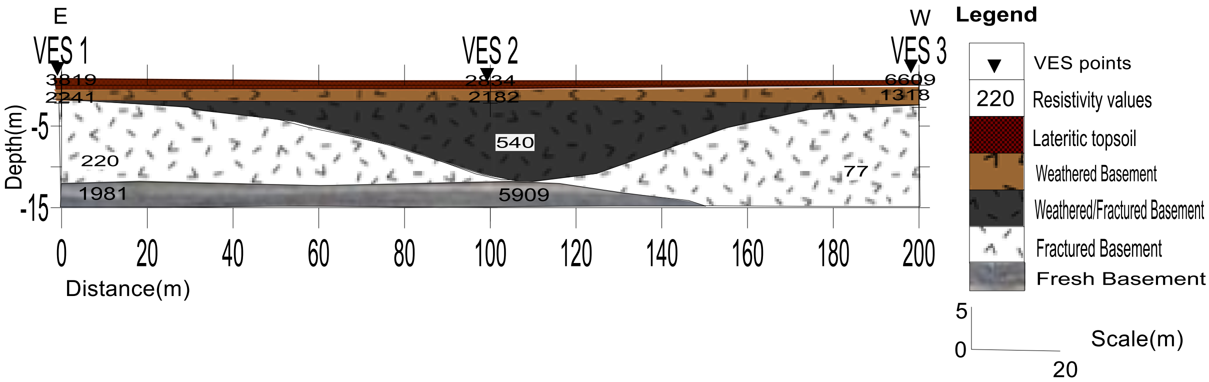


Figure 5. *Geoelectric section along the profile in the Basement Complex terrain*

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Figure 6 shows the geoelectric section of the profile acquired along the Basement/Sedimentary contact zone. The geoelectric layers interpreted from the resistivity values show remarkable characteristics of the basement and the sedimentary terrains. This is expected as contact zones often combine the features of the two distinct geologic terrain and also mark the boundary for same. At least 3–4 geoelectric layers are recognizable. First, the topsoil with resistivity values ranging from 1108–2979 Ohms.m and a depth range of 0–0.8 m. This resistivity values also show the lateritic nature of the topsoil similar to that of the basement terrain. The second layer has resistivity values ranging from 296–859 Ohms.m. This is interpreted as a sandy unit as it is in the range of the resistivity of sand reported by [17]. The sand occurs at depths range of 2–7.9 m. Although sand is a good aquiferous unit for groundwater, the depths of occurrence and the thicknesses of the sand unit is low. The thickness of the sand and the thickness/nature of the overlying unit are important factors to be considered in groundwater abstraction [18]. While the thickness of the sand unit is directly proportional to the amount or quantity of water in the aquifer, the thickness and nature of the overlying lithology is a measure of the protective capacity for the aquifer. The sand unit at this depth range is therefore not favourable as target for groundwater abstraction due to predicted poor quantity and poor quality from proximity to surface contamination. The third geoelectric layer is characterized as by resistivity in the range of 160–361 Ohms.m and interpreted as sandy clay/clayey sand. These values are also within the range of resistivity reported for similar lithologic unit by Oloruntola et al. [17]. The depth ranges from 4.3–7.1 m. These values of resistivity are lower than the resistivity values of the weathered layer which is the second layer of the basement terrain and higher than the resistivity values of the clay layer, which is the fourth layer of the adjoining sedimentary terrain. This therefore shows that the basement/sedimentary contact area combines or averages the resistivity values of the basement and sedimentary terrains and also reflects the nature of the subsurface geology in both terrains. The fourth layer is interpreted as a clayey layer occurring beneath the sandy-clay layer/clayey sand. This is typified by a remarkably low resistivity that is less than 18 Ohms.m. While there is no geoelectric layer interpreted as clay in the basement terrain, the contact zone shows a pocket of clayey layer in a single VES location (VES 7, which is closest to the sedimentary terrain), meanwhile, the sedimentary terrain has clay in all the VES locations. This once again shows how subsurface lithologic layers can rapidly change in areas around contact of basement-sedimentary rocks and therefore require adequate and careful geophysical/geological studies before any drilling program be embarked upon.

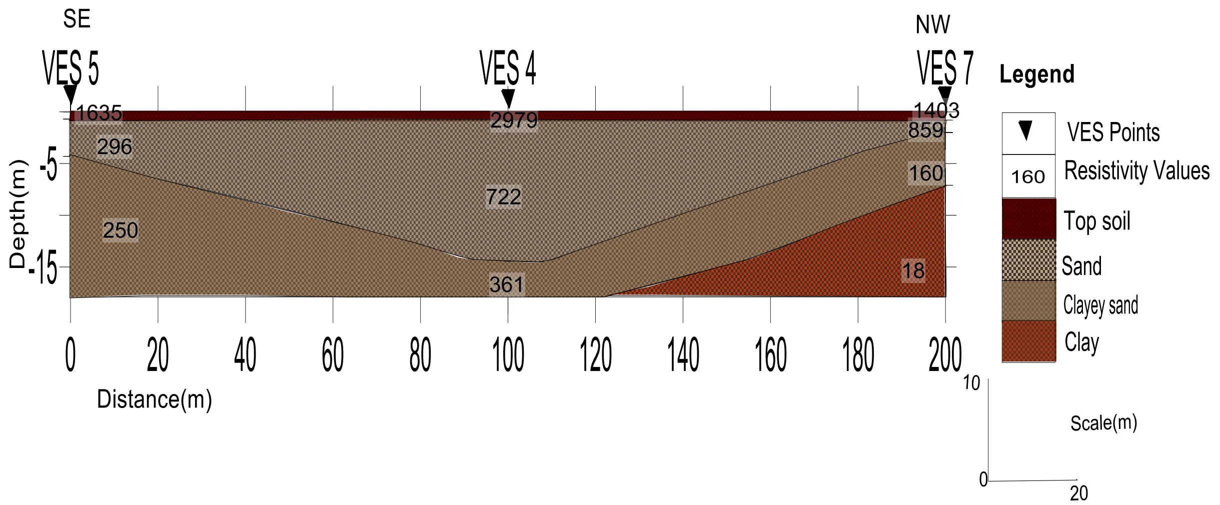

Figure 6. *Geoelectric section along basement-sedimentary contact*

VES 6, 8 and 9 are stations on the profile obtained from the adjoining sedimentary terrain (Fig. 7). The first layer is topsoil with resistivity values ranging from 782.5–1108 Ohms.m and depths range from 0–0.8 m. This layer is underlain by a clayey sand layer with resistivity values in the range of 371–537 Ohms.m and depths of 1.6–3.4 m. The sandy clay is the third layer, and it has a resistivity value of 40.3–157.4 Ohms.m and depths range of 12.0–22.1 m. The layer beneath the sandy clay is the clay which occurs in the three VES stations on sedimentary terrain and characterized by resistivity values in the range of 17.2–113 Ohms.m. This resistivity range also falls within the range of resistivity interpreted as fractured basement by [2] and sandy clay in the basement and basement-sedimentary contact zone. This therefore implies that the knowledge of geology of the area is very important in order to make meaningful geophysical interpretation of the subsurface geoelectrical properties.

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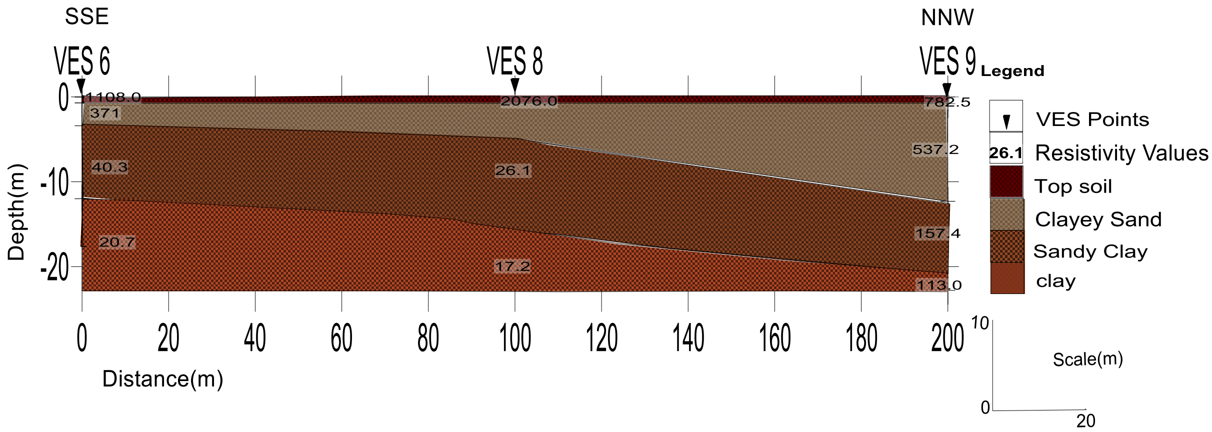

Figure 7: *Geoelectric section along the profile in the Sedimentary Terrain*

The result of the horizontal profiling at a depth of 10 m shows a lateral variation in the resistivity of the lithological units across the study area. The resistivity is generally observed to decrease from the basement complex rocks to the sedimentary terrain. This result agrees with study carried out by [12]. Among the seven resistivity values obtained here, the first three at the Basement complex terrain are 1561, 606 and 726 Ohms.m respectively, while the other four at the sedimentary terrain are 48, 33, 39 and 59 Ohms.m respectively (see Figure 8).

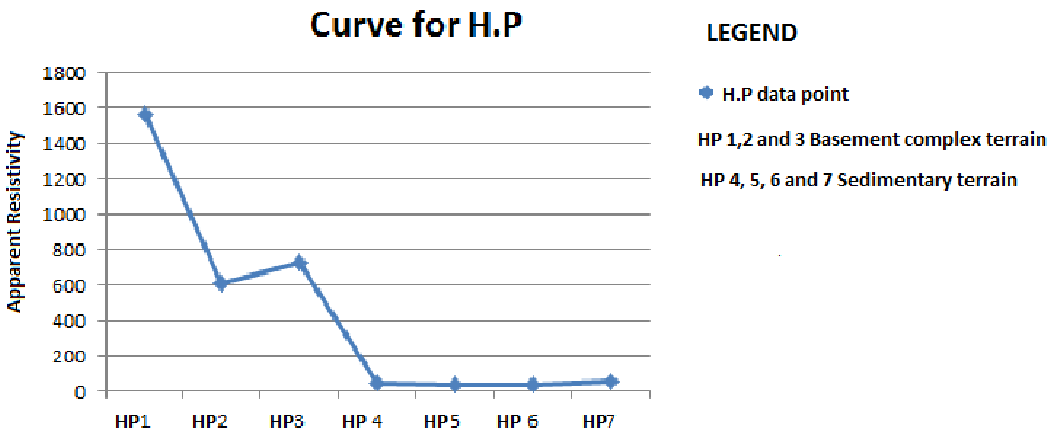

Figure 8. *HP data curve showing resistivity variation at depth of 10m across the study area.*

The 3D overburden sediment thickness map (Fig. 9) shows a steady increase in the sediment thickness from the basement through the basement-sedimentary contact to the sedimentary terrain in that order. The range of thickness of sediments in the basement is less than 3 m; while it is 4–12 m in the basement-sedimentary contact zone and > 12 m in the sedimentary terrain. This therefore implies that the depth to basement increases from the Basement Complex through the basement-sedimentary contact zone to the sedimentary terrain, in agreement with [2] and [12].

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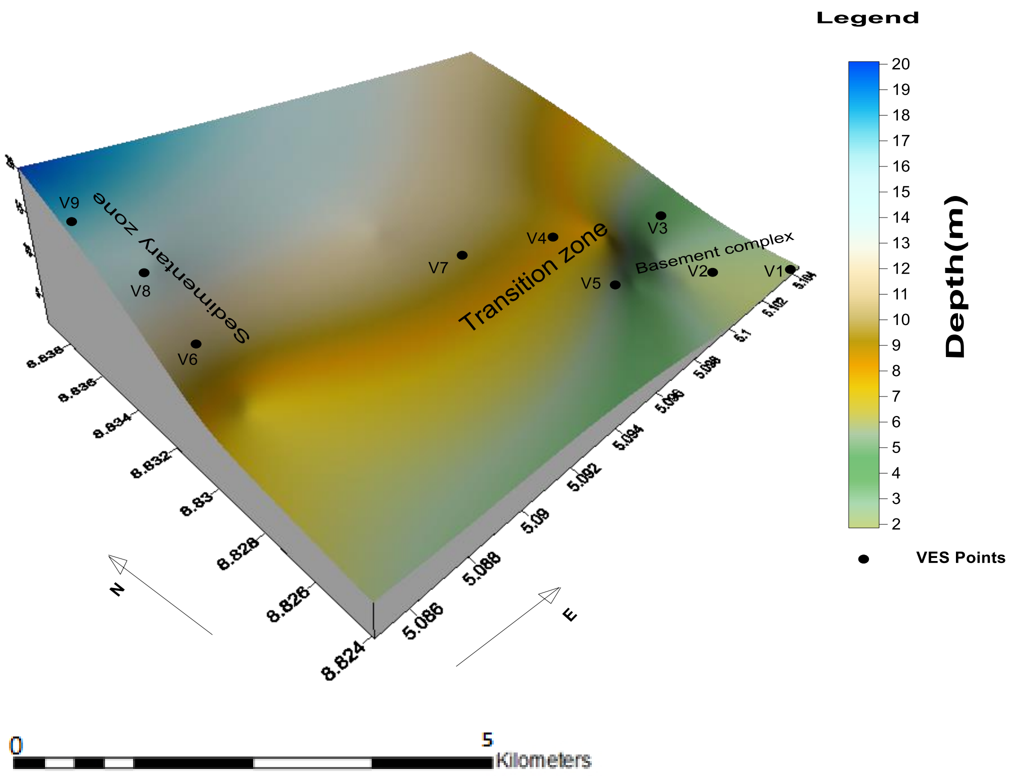

Figure 9. *3D- map showing overburden sediment thickness and the VES points across the study area (sing WGS-84 Coordinate system)*

3.1 Curve types

The resistivity curves of across the study area also vary and depict the varying geologic terrains. The basement terrain is characterized by 2 QH curve and one Q curve. QH curve is a four-layer type curve with the general formula $\ell 1 > \ell 2 > \ell 3 < \ell 4$, implying that the resistivity of the first layer is greater than the second layer, which is higher than the third layer but less than the fourth layer. While the Q curve typifies a 3-layer curve type with resistivity of the first layer is greater than that of the second layer which is greater than the third layer ($\ell 1 > \ell 2 > \ell 3$), depicting a continuous reduction in resistivity [19].

The basement-sedimentary contact zone is made up of Q, Q and QQ curves. The Q curve type has been explained above. The QQ curve type is a four-layer curve type depicted by $\ell 1 > \ell 2 > \ell 3 > \ell 4$. The curve types for the sedimentary terrains are all QQ. Thus, the basement-sedimentary contact zone combines both the resistivity curve type from the basement and that of the sedimentary terrain, reflecting the nature of the subsurface geology in both terrains.

***Table 1**. Summary of the HP Survey*

HP	Depth (a) m	K ($2\pi a$) m	Resistivity (Ohms.m)	Distance (m)
1	10	68	1561	0
2	10	68	606	80
3	10	68	726	160
4	10	68	48	240
5	10	68	33	320
6	10	68	39	400
7	10	68	59	480

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***Table 2**. Summary of the Result of VES Result*

S/N	TERRAIN	VES	LONGITUDE	LATITUDE	RESISTIVITY (Ωm)	DEPTH (m)	LITHOLOGY DEDUCTION
1	Basement complex	VES1	5°6’16.0” E	8°49’06” N	3819.5	1.0	Topsoil
		Curve type: QH			841.0	2.2	Weathered Basement
					220.0	12.0	Fractured Basement
					1981	-----	Fresh Basement
		VES2	5°6’3.3” E	8°49’33.9” N	2834.6	0.5	Topsoil
		Curve type: QH			2181.5	2.5	Weathered Basement
					554.0	15.0	Fractured/Weathered Basement
					5909.4	------	Fresh Basement
		VES3	5°6’4.3” E	8°49’38.8” N	6609.0	0.6	Topsoil
		Curve type: Q			1313.0	2.7	Weathered Basement
					77.0	------	Fractured Basement
2	Basement-sedimentary contact	VES4	5°5’56.7” E	8°49’41.3” N	2979.0	0.8	Topsoil
		Curve type: Q			722.0	7.9	Sand
					361.0	------	Clayey sand
		VES5	5°5’56.1” E	8°49’36.8” N	1635	0.7	Topsoil
		Curve type: Q			296.0	4.3	Sand
					250.0	------	Clayey Sand
		VES7	5°5’33.4” E	8°49’55.9” N	1108	0.8	Topsoil
		Curve type: QQ			859.0	2.0	Sand
					160.0	7.1	Sandy Clay
					18.0	-------	Clay
3	Sedimentary Terrain	VES6	5°5’10.2” E	8°49’49.1” N	1108.0	0.7	Topsoil
		Curve type: QQ			371.0	3.4	Clayey sand
					40.3	12.0	Sandy clay
					20.7	-------	Clay
		VES8	5°5’10.8” E	8°50’4.7” N	2076.0	0.8	Topsoil
		Curve type: QQ			422.2	1.6	Clayey sand
					26.1	14.9	Sandy clay
					17.2	-------	Clay
		VES9	5°5’5.9” E	8°50’22.2” N	782.5	0.8	Topsoil
		Curve type: QQ			537.2	2.3	Clayey sand
					157.4	22.1	Sandy clay
					113.0	-------	Clay

4 CONCLUSION

The overall assessment shows variability in the resistivity values through the three selected zones typifying changes in lithological/rock types. There is a general increase in thickness of sediments fill traversing from the basement through the basement-sedimentary contact zone to the sedimentary terrain and an increase in depth to basement. The geoelectric curve types in the area do not only show the sequence of subsurface lithology it also reflects the changes in the geological environments. The study has shown that the resistivity method of survey is effective and reliable in delineating subsurface lithological units being very sensitive to degree of weathering, fluid content and nature of subsurface lithology. It can help to a large extent in understanding complex geologic terrains with rapidly changing subsurface geology. In the same vein, the knowledge of geology of an area is paramount in order to make sensible geophysical interpretation.

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