

Evaluation of Groundwater Potential using Aquifer Characteristics of Parts of Boki Area, South – Eastern Nigeria.

Anthony Nuonum Ugbaja (✉ anthonyugbaja@yahoo.com)

University of Calabar <https://orcid.org/0000-0003-1790-7517>

Research Article

Keywords: Vertical Electrical Sounding (VES), pumping test, Schlumberger array, Hydraulic parameters, potential zone

Posted Date: June 14th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-382134/v1>

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Abstract

Vertical Electrical Sounding (VES) and pumping test (constant discharge and recovery test) was carried out in parts of Boki Local Government Area to evaluate the groundwater potential, using aquifer characteristics of the study area. Sixteen (16) VES point was employed for this study using the Schlumberger array, with a maximum spread of 400-600m. The stimulated result from the field data shows 3-5 layers resistivity model with the following curve types A, AK, KH, KHA, QH, QHA and QHK. The geoelectric properties include resistivity of the various layers ranging from 33.58 - $2.29 \times 10^5 \Omega m$, thickness from 0.2 - 50.2m, depth to basement varies from 2.99 - 74.60m across the study area. The litho logs show a top layer comprising of laterite, gravel/gravelly sand and siltstone intercalations and the layers underneath are made-up of clay, weathered basement containing migmatites and gneisses, fractured and unfractured basement are made up of granitic and metamorphic rocks. The weathered and fractured layers constitute the aquiferous layers in the study area. Hydraulic parameters were estimated from 16 pumped wells and results show transmissivity (T) range of 4.1×10^{-5} - $1.92 \times 10^{-1} m^2 / day$, specific capacity (SC) ranges from 2.09-21.42m² /day, hydraulic conductivity (K) varies from 2.6×10^{-5} - $3.0 \times 10^{-3} m / day$ and mean static water level (SWL) of 7.39m. Iso resistivity map of saprolite, fractured basement map, isopach map and the transmissivity map show that the studied area falls within the low-moderate groundwater potential zone.

Introduction

In the basement complex of the Obudu Plateau, ground water constitute the most reliable and major source of water for agricultural and domestic usage. It is found within the fractured / or weathered basement and are tapped by the use of hand-dug wells and boreholes. The discontinuous nature of the basement aquifers system makes detailed knowledge of the subsurface geology, its weathering depth and structural disposition through geologic and geophysical investigation inevitable (Adiat et al., 2009). This relatively low cost, high quality and quantity water source has not been properly exploited and managed, especially in developing countries. Bore-hole (water well) failures, waste of funds, abandonment of project, as well as, the loss of valuable quantitative and qualitative data on aquifer(s), characterized such areas. Therefore, there is a need for the application of geophysical and hydrological techniques such as electrical resistivity, seismic refraction, magnetic, electromagnetic, ground probing radar, pumping test, and down-hole logging in water project (Anomohanran, 2013). The electrical resistivity method (vertical electrical sounding) is used in determining the resistivity distribution of the subsurface, it is simple to apply in the assessment of groundwater occurrence (Okongbo et al. 2011), as very detailed information are obtained about the thickness and resistivity of different conducting layers of the sub-surface. It is equally important that the aquifer parameters such as transmissivity, hydraulic conductivity, storativity, etc. are determined. The analysis of these hydrogeologic parameters can be achieved through several tests such as water quality analyses, down-hole logging and pumping test. These analyses are aimed at estimating the groundwater quality and the ability of the sub-surface formations to store and transmit groundwater. A combination of Geophysical methods, hydrogeologic parameter analyses and geological surveys will further provide the needed information. Therefore, it acts as a guide on the quality and quantity of the aquiferous layer, thereby reducing the number of failed water well/projects. The use of a systematic approach in prospecting for groundwater through exploring and exploitation of groundwater potential, for a steady, qualitative and quantitative supply. The development of ground water can be viewed as a sequential process with three major phases. These are exploration phase, evaluation stage and the exploitation phase (Freeze and Cherry, 1979). The exploration phase involves the use of surface and sub-surface geological and geophysical techniques in search for suitable aquifers while the evaluation phase involves encompasses the measurement of hydro geologic parameters, the design and analyses of wells and the calculation of aquifer yield. Finally, the exploitation or management phase considers the impact between groundwater exploitation and hydro geologic system.

The aim of this work is to analyze the groundwater potential and aquifer characteristics of the study area, using electrical resistivity and pumping test to delineate groundwater aquifers for the siting of boreholes and the computation of the specific yield of the various boreholes.

LOCATION OF STUDY AREA

The study area is located between longitudes $6^{\circ} 0' 0''$ - $6^{\circ} 26' 30'' N$ and latitude $8^{\circ} 30' 20''$ - $9^{\circ} 27' 0''$. Boki is found in Cross River State, with a total landmass of about 1,070 square meters. The region is covered by the rainforest. The Boki area is an extension of the basement complex of the Obudu plateau, South - Eastern Nigeria, with the following dominant rock types Phylites, Hornblende schist, Gneisses, Migmatites, Igneous intrusive such as Granitoid, Dolerites. They rocks display Porphyroblastic, Granoblastic, Xenoblastic textures in metamorphic rocks while porphyritic, xenomorphic, and mortar features are present in igneous rocks. Ukaegbu

and Oti (2005) had observed that polydeformation has resulted in multi –directional orientation of planar and linear structure in the basement rock of southern Obudu Plateau (Fig. 1).

Material And Method

The acquisition of data was carried out in three phases, namely:

Geological or surface survey

Geophysical survey (VES)

Hydrogeology survey (pumping test)

Geologic survey or surface geology had involved research, planning, reconnaissance survey and interaction with the inhabitant of the study area. In geophysical survey, Vertical Electrical Survey (VES) was carried out. VES was carried out in 16 pre-determined communities (three VES points per sampled location) within parts of Boki Area in South-Eastern Nigeria using the Schlumberger array, with a maximum spacing of about 400- 600m between the current electrodes (Fig. 2). The process of carrying out resistivity involves the passage of current from the Geotron G41 terrameter into the ground through steel electrodes (current electrodes) which have been pinned into the ground resulting in creation of potential differences between the potential electrodes. The electrode where progressively expanded about a fixed point along the transverse line while maintaining the ratio of 1/5 of the potential electrode spacing to the current spacing. Data generated were collected along the course of traversing the survey line. The electrodes are equidistant from the center of the survey line. The field data collected was recorded from the Terrameter in each electrodes spacing along the transverse line, the field data obtained was multiplied by the geometrical factor for the Schlumberger array ($G = \pi/4[L^2 - a^2]/a$) to find the apparent resistivity. The data was analyzed and interpreted using a computer designed software called Interprex ID.

In hydrogeology survey, 16 wells (single wells were used due to the absence of Observation Wells) within the pre-selected communities within parts of Boki local area, was pumped at a constant rate until a near steady/steady state was attained using 1.0Hp (horse power) submersible Pump, dip meter and a stopwatch was used to measure the corresponding changes (drawdown) in the water level and the respective time. Prior to the pumping, the static water level (SWL) was obtained using the dip meter, coordinates and elevation was equally obtained using the Global position system (GPS) while a calibrated (20) twenty liters container was used in estimating the pumping rate. For the recovery test, the submersible pump was switched off, the aquifer allowed to recharge and the corresponding time and water level measurement was noted. The data generated was subjected to topographical and analytical analysis in estimating transmissivity of the aquifer (T), hydraulic conductivity (K), specific capacity (SC), thickness (B) and drawdown(s). Transmissivity is defined as the product of the average hydraulic conductivity (k) of the aquifer and the saturated thickness of the aquifer (B). Transmissivity may be viewed as the rate of flow under a unit hydraulic gradient through a cross section of unit-width over the saturated thickness of the aquifer. It is expressed mathematically as follows:

$$T = KB$$

Where

T = transmissivity in m²/day

K = hydraulic conductivity in m/day

B = depth in m

Similarly, transmissivity can be computed using Cooper & Jacob straight line equation, where transmissivity (T) is given by the equation:

$$T = 2.3Q/4\pi\Delta s$$

Q = Constant pumping rate

Δs = Drawdown difference per log cycle. From the time- drawdown curves plots; Δs is given by the equation:

$$\Delta s = S_2 - S_1 / \log T_2 - \log T_1$$

Where

S_2 = drawdown at point 2

S_1 = drawdown at point 1

$\log T_2$ = logarithm cycle of time 2

$\log T_1$ = logarithm cycle of time

Specific capacity (SC) is the volume of water that an aquifer would release from storage per unit surface area of the aquifer per unit decline in water table. It is equally defined as the rate per drawdown. It is expressed mathematically as follows:

$$SC = Q/s \text{ in } m^3/\text{day}$$

Where

Q = Discharge rate in m^2/day

s = Drawdown in m

Hydraulic Conductivity (k) is the quantitative measurement of permeability, Permeability is the ease in which water can pass through a unit thickness of an aquifer and is measured in meter per day(m/s). Hydraulic conductivity (K) is computed as follows:

$$T = kb$$

Results And Discussion

From the geo-electric curves simulated, the curve type varies from K, A, H, KH,HKA, QHA, QHK and HAA type, showing that the sub surface formations varies in composition (complex) and are associated within the study area. The resistivity curve shows a 3, 4, 5 geoelectric layers within the study area. FIG 3 and 4 are typical ID resistivity curves of sampled VES stations showing apparent resistivity, calculated result and computed model. Table 1 shows a summary of the geo electric properties of the sample location.

TABLE 1
Geoelectric Properties of the Study Area

Location	No of layers	Curve type	Resistivity						Thickness					Depth to basement	
			ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	h1	h2	h3	h4	h5		
Govt. PS, Okubuchi	4	KH	219.57	918.63	55.22	37016				0.327	3.313	6.228			9.87
EsekweIrruan	3	A	211.43	325.22	80126				1.922	22.748					24.67
Ntamante	4	HK	163.29	659.73	39.54	3.01E+05			4.96	3.52	8.75		α		17.23
Katchuan II	5	HKA	1169.5	565.80	3519.2	116.41	2145.9		1.9218	3.117	3.719	9.667			17.70
Wula	6	KQA	111.08	300.82	92.805	772.31	1821.3	2.29E+05	1.41	0.62	4.28	28.0	16.71		51.03
Agba II	4	HK	342.73	254.61	204.11	304.04			1.94	22.43	50.23				74.60
Biajua	6	QHK	754.12	293.9	252.16	9.710	758.01	0.1717	0.26	8.034	0.459	5.43	17.86		31.63
Biatiah	3	K	451.48	692.3	3974				1.94	10.64					12.58
UnkoBeteriko	3	H	7248	89.659	699.9				3.92	0.79					4.70
Daneri II	4	KH	2318.0	3262.0	56.70	1350			2.07	1.179	0.880	α			4.13
Okundi	5	QHA	1537.3	1002.4	159.04	13116	21.43		0.60	11.57	5.49	17.90	α		35.56
Arunkawa` Gom	6	HAA	1427.1	241.48	7039.8	60.29	2039.4	137470	0.4618	2.47	0.28	8.28	8.99		20.48
Effigbo	5	KH	286.5	109.52	2136.1	179.91	39905		5.885	3.191	11.414	18.847	α		39.34
Orimekpan	4	AAA	857.34	1197.2	310.95	11310			1.40	18.6	18.8	α			38.89
EdohIrruan	5	KHA	342.66	1560.3	228.75	890	2.21E+05		0.94	0.62	3.21	46.8	α		50.86

Geoelectric Sections

The VES results were used in the preparation of 2-D geoelectric sections, which shows the resistivity of the various subsurface layers and their respective thickness (Fig 5-8). Each section was prepared in accordance to the VES points in each transverse. The geoelectric section is made up of 3-5 subsurface geoelectric units, inferred as laterite, gravel and gravelly sand; clay weathered and fractured basement, and fresh basement. The study area is made up of two aquifer type. Type1 are aquifer found on the overburden/weathered layers and are mostly exploited using hand dug well as a result of their near –to-surface depth while Type 2 aquifers are found on the fractured rocks of the basement complex. From the correlation of the geoelectric section along transverse section A-A¹ (fig, 5) with the following sampled points (VES 13,12,6,14 respectively), the resistivity curves shows a 3-5 layer model with the following curve types KH,HAA,HK,AK along the transverse line. These layers are laterite, gravelly sand, clay, weathered basement and the unweathered basement. The aquiferous layer for this transverse area is the weathered basement with resistivity values ranging from 60Ωm to 310Ωm and thickness values ranging from 12m at VES 12 to approximately 19m at VES 6. The area will support hand-dug wells as a result of the depth of the aquifer to the surface. The resistivity of the sampled area shows that the weathered basement has high clay content therefore; the aquifer yield will be low despite the size of the thickness of the overburden.

Transverse section B-B¹(fig,6) with the following(Ves16, 8, 15 and 11 respectively).The geoelectric sections shows 3-5 layers model with a curve type of KH, k, KHA and QHA.VES 15 showing a confined aquifer. The probable aquiferous layer for this transverse section would be the weathered layered and the fractured basement. The sampled section will support both motorized and hand dug well. The thickness of the aquiferous unit ranges from 4m at VES 15 to 32m at VES 16 with the fractured basement resistivity ranging from 890Ωm to 4153Ωm.The geoelectric layers include laterite, gravelly sand clay, weathered basement, fractured basement and the fresh basement.

The transverse C-C¹(fig,7) shows three locations within the study area namely (VES 9, 5, and 7) with a resistivity range of 89.59 to 229000Ωm. The geoelectric section shows show 3-5 layers model with the following curve type H, KQA, QHK. The geoelectric layers are interpreted as laterite, clay, weathered basement, fractured and unweathered basement, with VES 7 showing a multi aquifer system at a depth of 20.5m-27.5m and 30m-33m. The possible aquiferous layer for VES 9 and 7 is the unconfined weathered basement while water can be tapped from a combination of the weathered and fractured basement in VES5.

Isopach and iso resistivity map of the aquiferous layers

The overburdens are laterite, gravel /gravelly sands, clays, weathered basement.The overburden thicknesses (depth to basement) range from 2.99m at (lowest thickness) to 74.06m at (highest thickness) with an average thickness of 27.26m within the study area. The overburden thickness at each sounding location was gridded and contoured to produce an Isopach map (Fig.9) of the overburden. An isopach map shows the spatial distribution of thicknesses within a locality. The map was broken into four zones based on ground water potentials. They zones are Zone A (high:65 and above), B (moderate:45-65), C (low:25-45), and finally D (minimal;0-25). The zones weighted as follows Zone A 6.3%, B 37.5%, C 31% and D 25%. Based on the zoning the study area could be classified into low to moderate ground water zone. According to Olurunfemi and Okhue (1992), Oyedele and Olayinka (2012), a minimum overburden thickness of 25m is required for viable ground water abstraction in the basement terrain. In the study area, the overburden thickness varies from 2.99 to 74.06m; an overburden thickness of 25 to 72m occurred in 74% of the study area, showing a very thick overburden and thus should support productive groundwater abstraction. However, according to Lenkey et.al (2005) a thick weathered layer (containing less percentage of clay) above the basement rock will constitute a water bearing layer.

An Iso- resistivity map of the weathered basement (saprolite) was produced to show the spread of resistivity at a common depth within the study area and presented as Fig.11.The resistivity values of the saprolite (weathered basement) ranges from 33.58-918.63Ωm, an indication of the present of laterites/clay, clayey/clay and sandy clay. The Iso-resistivity map show that the resistivity of the weathered basement is broken into the following zones in terms of groundwater potential: high groundwater potential (>650Ωm), moderate (400-650Ωm), low (150-450), minimal (33.58-150).

Wright (1992), Mallam(2004) and Adelusiet.al,(2004) had developed a scheme for ranking of ground water potential as a function of saprolite (weathered basement) resistivity as presented in the Table 2.

Table2. Aquifer potential as a function of saprolite resistivity

Saprolite resistivity (Ωm)	Aquifer characteristics
<20	Clayey with limited aquifer potential
20 – 100	Optimum weathered and groundwater potential
101- 150	Medium aquifer conditions and potential
151- 300	Limited weathering and poor groundwater potential
> 300	Negligible

Source: Oyedele et.al.(2012)

From the table 2, the study area has 21.43% in the optimum weathered and ground water potential zone, 7.14% in the medium aquifer conditions and groundwater potential while 50% of the area within the study area is in the negligible zone with no appeal for groundwater potential. Finally, the limited weathering and poor groundwater potential zone constitute 21.43% of the study area. In the basement terrain, the aquiferous layers are usually found in the thick, porous weathered and the fractured part of the bedrock. The fractures are mostly associated with high ground water yield when compared with the overburden as a result of its relatively high permeability. A ranking scheme for aquifer potential, as a function of the fractured bedrock which was modified by Oyedele et al.,(2012) is shown in the table 3 below.

Hydrological Analysis

From the pumping test exercise carried out, the results obtained from the various pumped location is presented as table 3.Using Cooper – Jacob straight line equation, the data was handle graphically and analytically resulting in the plotting of time- drawdown curve on a semi-log graph for the various locations and the computation and analyses of aquifer parameters, here presented as appendix 2 and Table 3 respectively.

Table 3 The computation and analyses of aquifer parameters.

S/N	Location	Transmissivity	Specific discharge	Hydraulic conductivity
1.	Govt. PS, Okubuchi	0.00541	21.424	0.00055
2.	EsekweIrruan	0.00421	4.251	0.00017
3.	Ntamante	0.059	11.398	0.0034
4.	Katchuan II	0.0125	16.67	0.00071
5.	Wula	0.00263	15.807	0.000052
6.	Agba II	0.00373	10.725	0.00005
7.	Biajua	0.192	2.9108	0.0061
8.	BiatiahUnko	0.975	3.871	0.0776
9.	Beteriko I	0.00041	2.435	0.000087
10	Daneri II	0.0258	3.184	0.0062
11	Okundi	0.0262	7.376	0.00074
12	ArunkawaGom	0.00845	16.386	0.00041
13	Effigbo	0.00373	21	0.000095
14	Orimekpan	0.002605	2.089	0.000067
15	EdohIrruan	0.00013	3.038	0.0000025
16	Ajirija	0.0013	2.8943	0.00041

Transmissivity (T)

$$T = kb$$

$$T = 2.3Q/4\pi\Delta s \dots\dots\dots (Cooper and Jacob 1946)$$

Table 3 show the computed transmissivity value for the study area, which ranges from 0.00013 to 0.975 m²/day with an average transmissivity of 0.032m²/day within the pumped locations. Fig.4 is a transmissivity map showing the spatial distribution of transmissivity within the pumped locations in the study area. Offodite(2002),suggested a transmissivity range of 5to 50m²/day to represent high groundwater potential in crystalline rock while 0.0155m²/s (10000gal/day/ft.) represent good aquifer for well exploitation(Cherry and Freeze 1979). However, the transmissivity range of the pumped wells within the study area was characterized by negligible to low ground water potential.

Hydraulic Conductivity (k)

Hydraulic conductivity is the quantitative measurement of permeability; permeability is the ease in which water can pass through a unit thickness of an aquifer. Hydraulic conductivity (K) is obtained mathematically as follows:

$$T = k b$$

Where

$$K = T/b$$

Where K, T and b are as defined in the equation above

The value of k varies from 0.0000025m/d to 0.0034m/d as shown in table 2.

The table 4 shows the saturated hydraulic conductivities (k) values found in nature.

Table 4 the saturated hydraulic conductivities (k) values found in nature.

K(cm/s)	10 ²	10 ¹	1	10 ⁻¹	10 ⁻²	10 ⁻³	10 ⁻⁴	10 ⁻⁵	10 ⁻⁶	10 ⁻⁷	10 ⁻⁸	10 ⁻⁹	10 ⁻¹⁰
K(ft./d)	10 ⁵	10 ⁴	10 ³	10 ²	10	1	0.1	0.01	0.001	0.0001	10 ⁻⁵	10 ⁻⁶	10 ⁻⁷
Relative permeability	Pervious			Semi pervious				Impervious					
Aquifer	Good			Poor				None					
Unconsolidated Sand & Gravel	Well sorted Gravel		Well sorted Sand and Gravel		Very fine Sand, Silt, Loess, Loam								
Unconsolidated Clay & Organic				Peat		Layered clay			Fat/ Unweathered clay				
Consolidated rocks	Highly Fractured Rocks			Oil Reservoir			Fresh Sandstone		Fresh Limestone, Dolomite		Fresh Granite		

From the computed hydraulic conductivity on the table 2 for the study area, the sampled location falls within the semi pervious zone with poor ground water potential.

Thickness of the Aquifer

The aquifer thickness ranges from 2.2 – 50,22m, the aquifers which is found within the weathered materials and fracture zones of the overburden has high clay content, which is very typical of the Obudu Basement Complex, as it is still undergoing weathering. Although the study area is characterized by zones of high over burden thicknesses, its high clay content places it within the low groundwater potential zones.

From the hydraulic analysis, which had involved the abstraction of water from a single well at a controlled rate and the water level response (drawdown) was measured (pumping test). The static water level, drawdown, elevation, pump water level, installed depth was obtained at each site while the following hydraulic characteristic was computed from aquifer test analysis as shown in fig2. The software, aquifer test were used in modeling the pumping test data obtained in the study area. Transmissivity (T) ranges from $0.00013\text{m}^2/\text{d}$ to $0.975\text{m}^2/\text{d}$, Specific discharge (SC) ranges from $2.09\text{m}^2/\text{d}$ to $21.42\text{m}^2/\text{d}$. Hydraulic conductivity (K) equally ranges from $0.000026\text{m}/\text{d}$ to $0.003\text{m}/\text{d}$.

Conclusion

They use of geophysical and hydrogeological methods in the evaluation of the ground water potential, and aquifer characteristic in the study area have shown the following:

- The study area falls within the low-moderate ground water potential zone as shown by the Iso resistivity map of saprolite, fractured and weathered basement results, isopach map of the overburden, lithology logs and geoelectric sections, computed transmissivity values and map, specific capacity and hydraulic conductivity result of the study area. This low – moderate ground water potential which characterized the study area is probably as a result of the high clay content in the weathered basement complex of the Obudu plateau.
- The aquiferous units are the weathered and the fractured basement, with the fractured basement being more productive than the weathered basement as shown by the computed specific yield and transmissivity.

Recommendation

As a result of the low-moderate aquifer potential of the study area, mechanized farming should be discouraged; however, two bore holes can be cited 50meters apart to improve the water supply within the farm.

The need for an observation wells in future study, this will help in the computation of storativity values.

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Appendix

Appendix was not provided with this version.

Figures

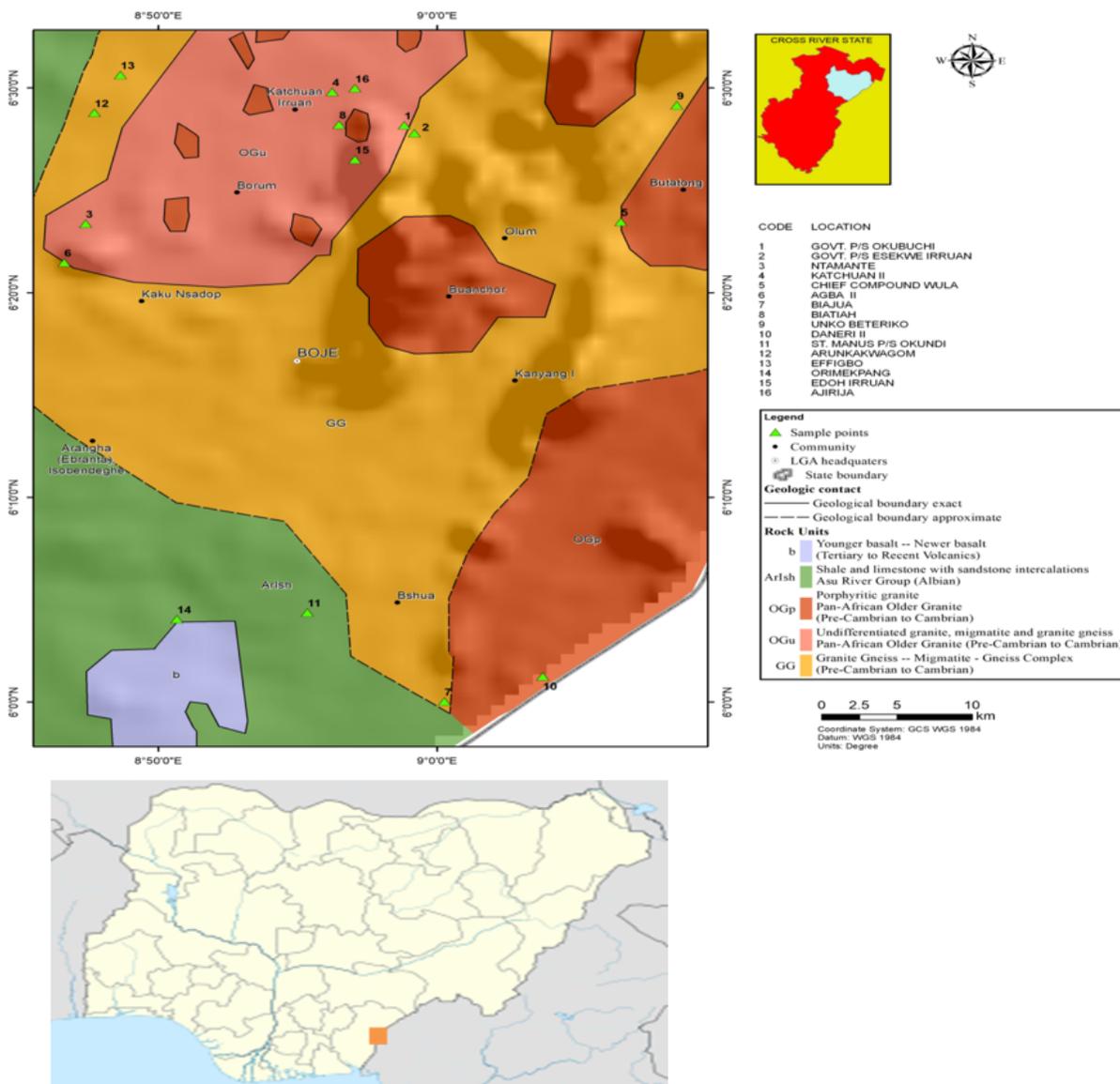


Figure 1

Geologic/Sample location map of the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

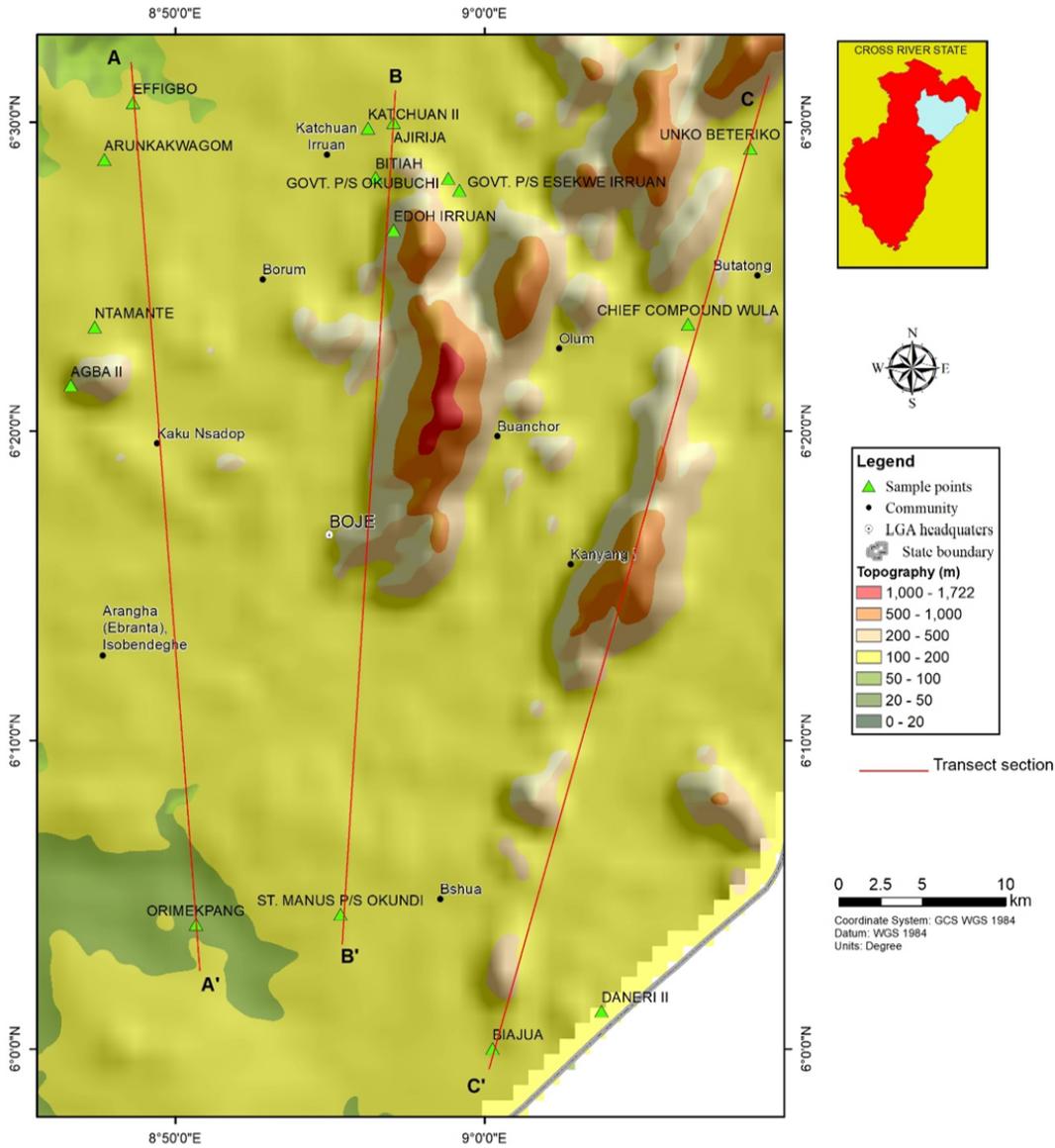
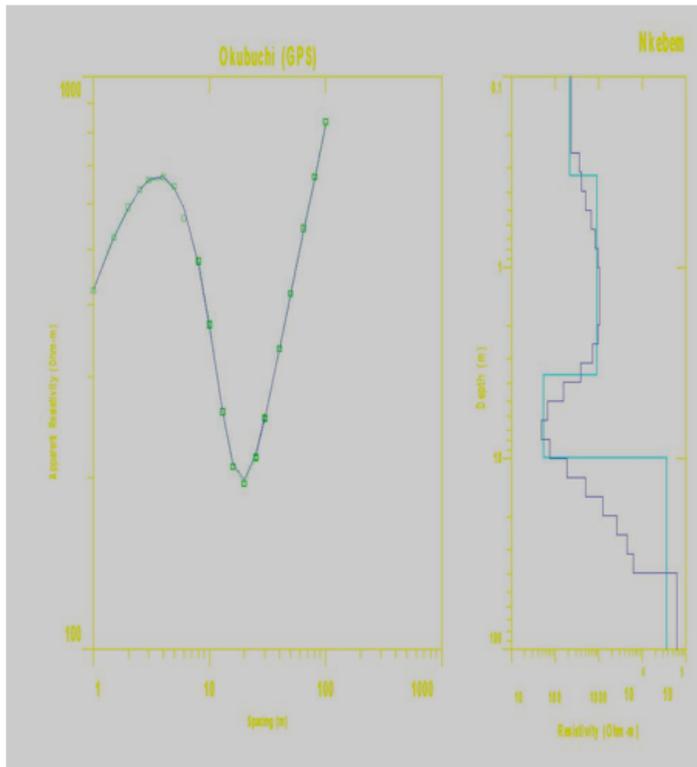


Figure 2

Topographic map, Transverse points, VES points, Borehole locations. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



No.	RES	Thickness	Depth
1	219.57	0.32	0.32
2	918.63	3.31	3.63
3	55.22	6.29	10.6
4	37016	-	

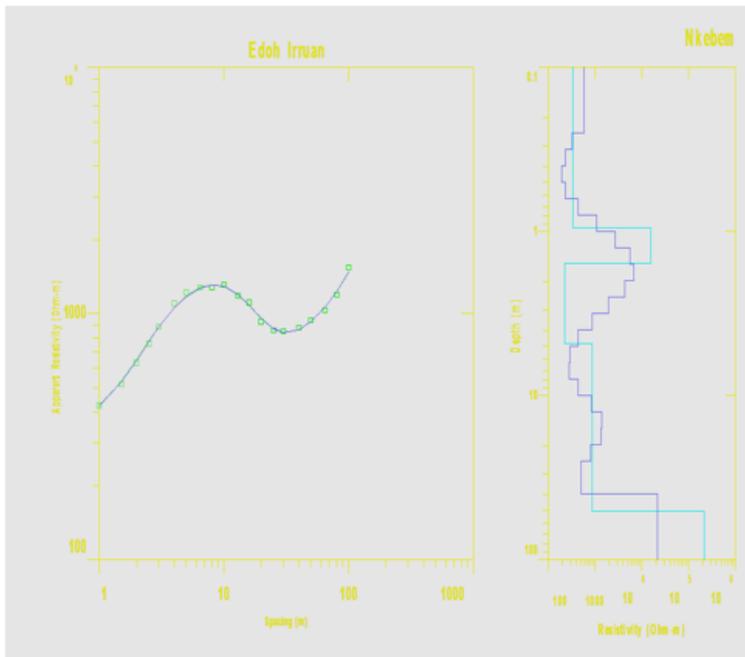
XXX = Observed apparent resistivity

_____ = Calculated apparent resistivity

┌----- = Computed apparent resistivity

Figure 3

Okubuchi Schlumberger Configuration



No.	RES	Thickness	Depth
1	211.43	1.92	1.92
2	325.22	22.7	24.6
3	80126		
4		-	

XXX = Observed apparent resistivity

_____ = Calculated apparent resistivity

┌----- = Computed apparent resistivity

Figure 4

Edoh Irruan Schlumberger Configuration

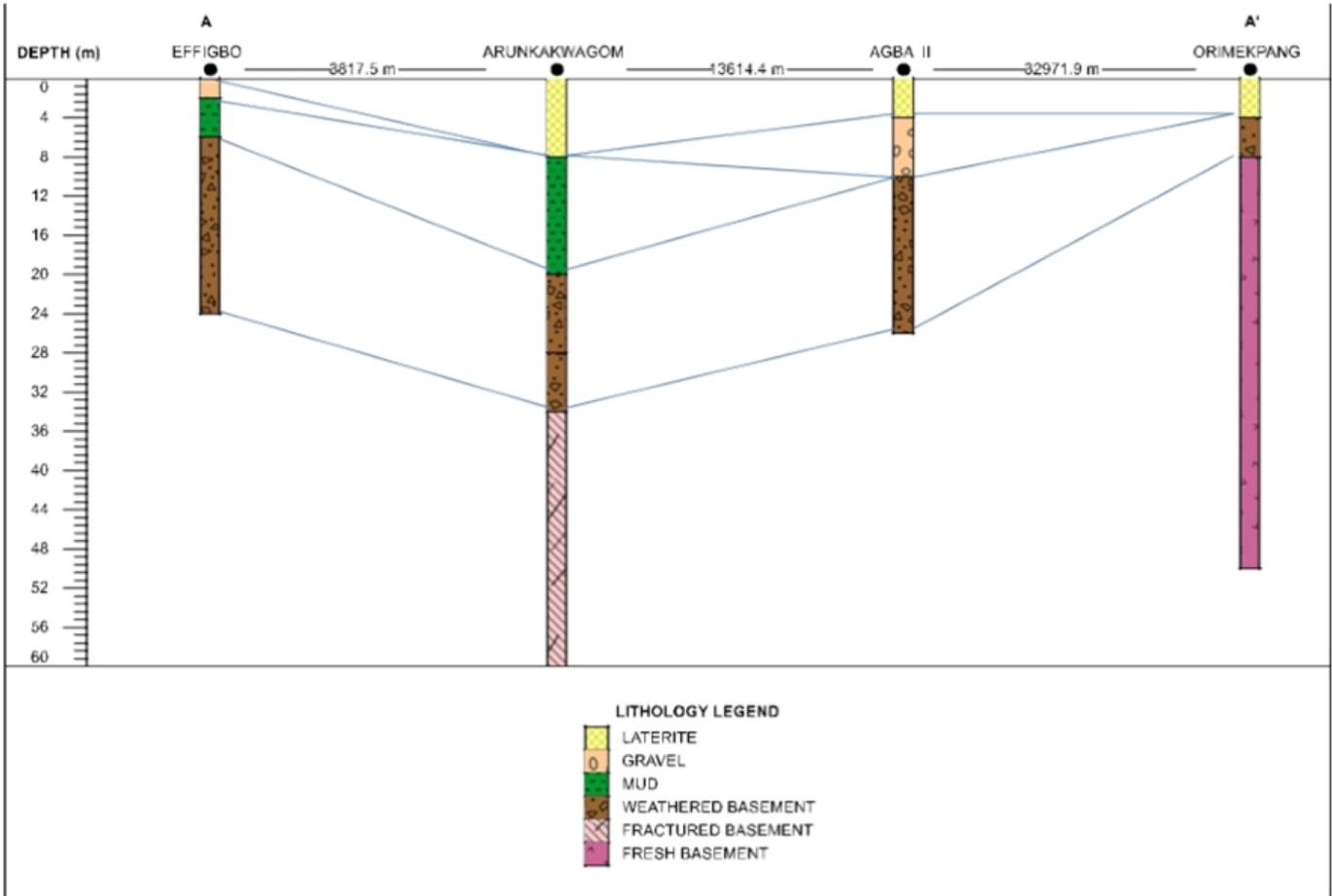


Figure 5

Geoelectric sections for traverse A-A1.

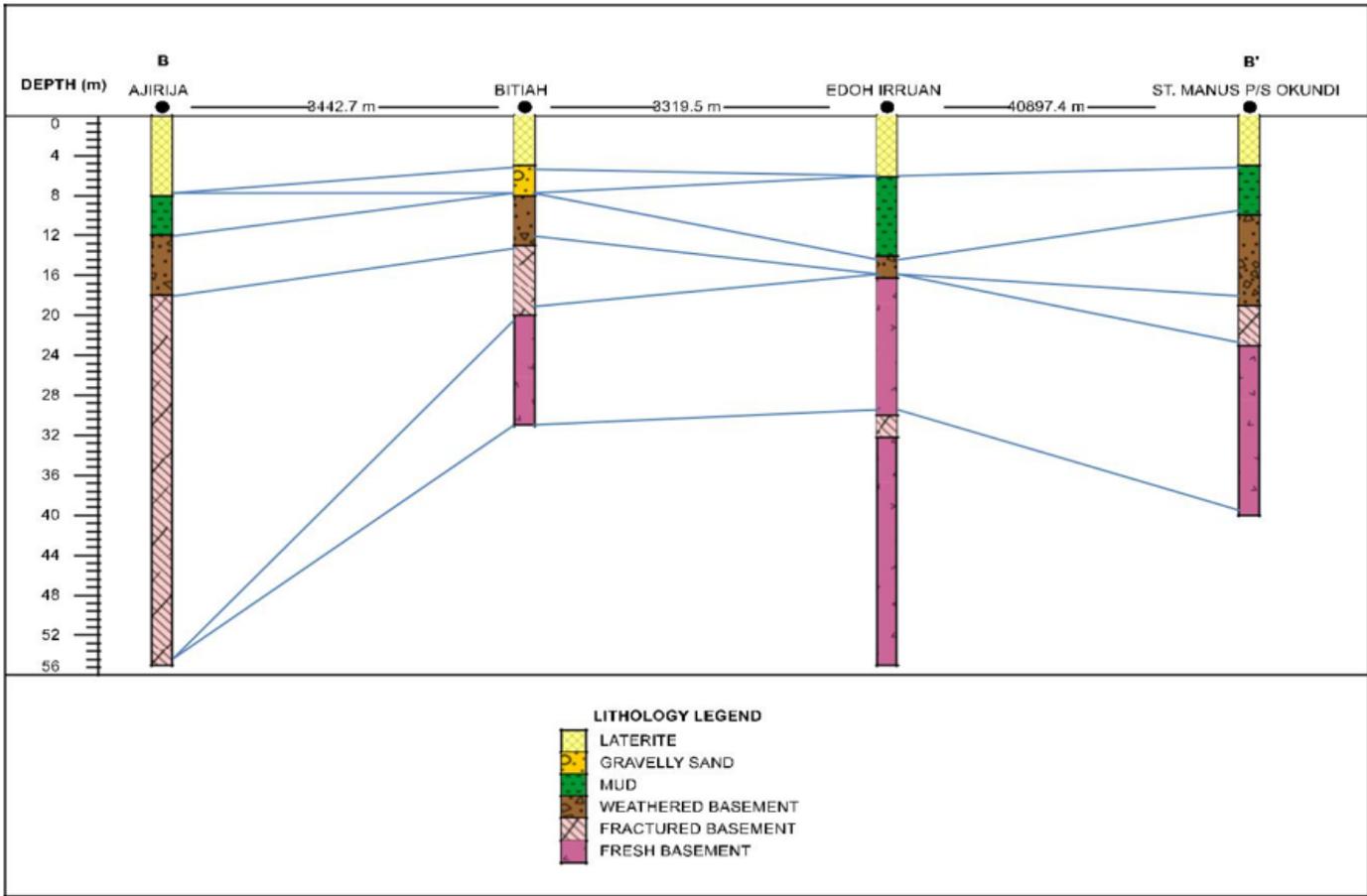


Figure 6

Geoelectric sections for traverse B – B1.

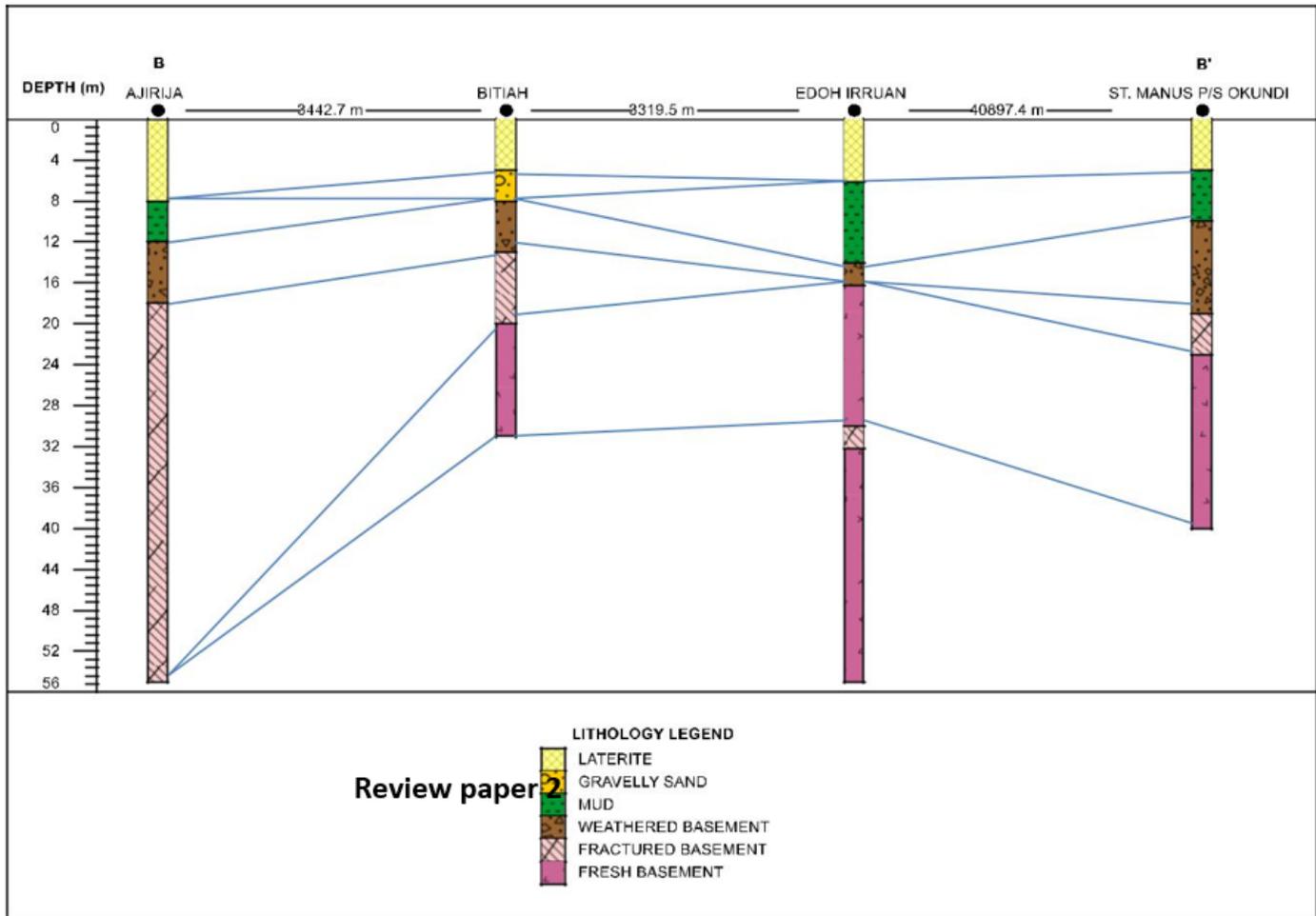


Figure 7

Geoelectric sections for transverse C-C1.

Image not available with this version

Figure 8

The VES results were used in the preparation of 2-D geoelectric sections, which shows the resistivity of the various subsurface layers and their respective thickness (Fig 5-8). Each section was prepared in accordance to the VES points in each transverse.

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Figure 9

The overburden thickness at each sounding location was gridded and contoured to produce an Isopach map (Fig.9) of the overburden. An isopach map shows the spatial distribution of thicknesses within a locality. Note: The designations employed and the presentation

of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

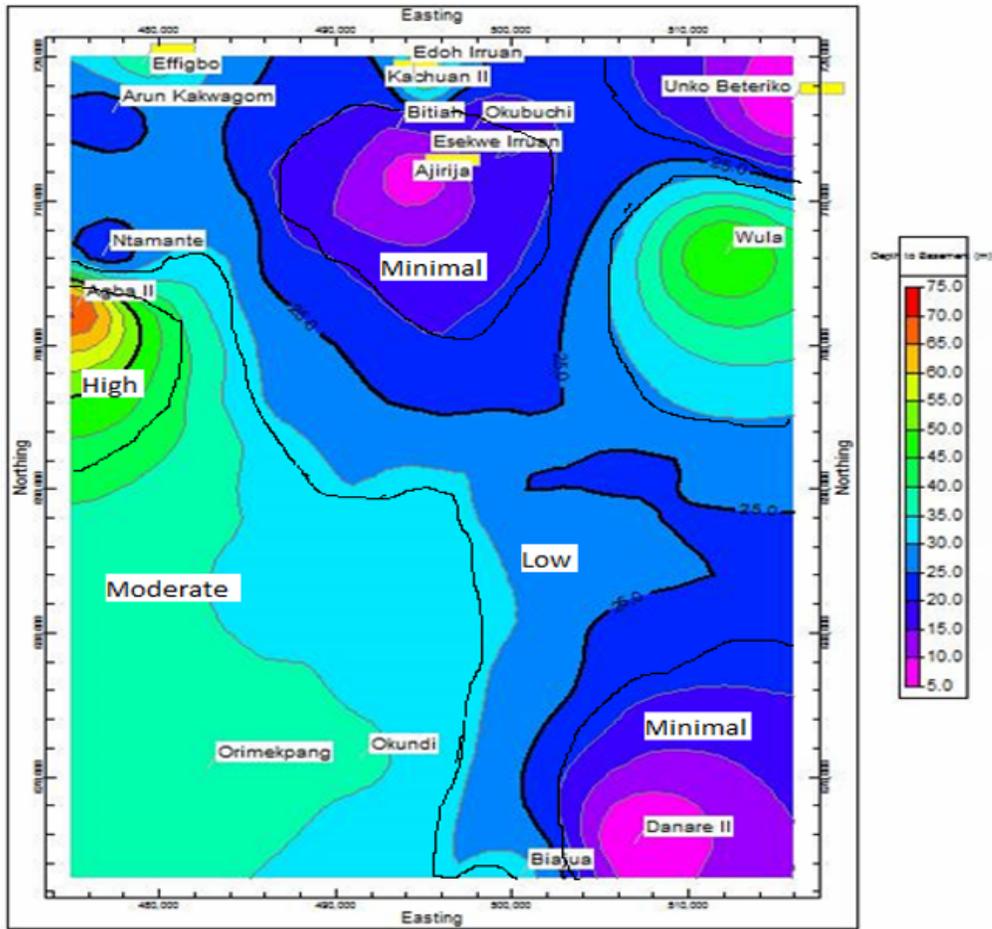


Figure 10

An Isopach Map of the Study Area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

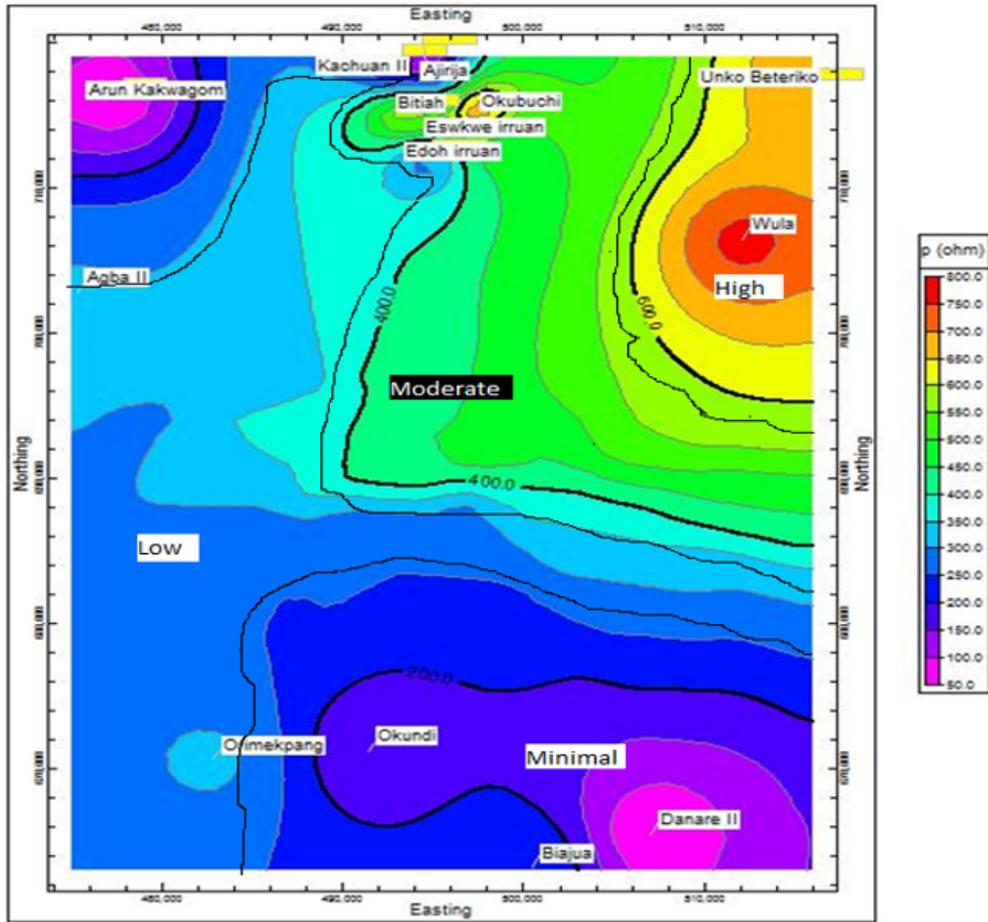


Figure 11

Iso resistivity map of weathered basement within the study area Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

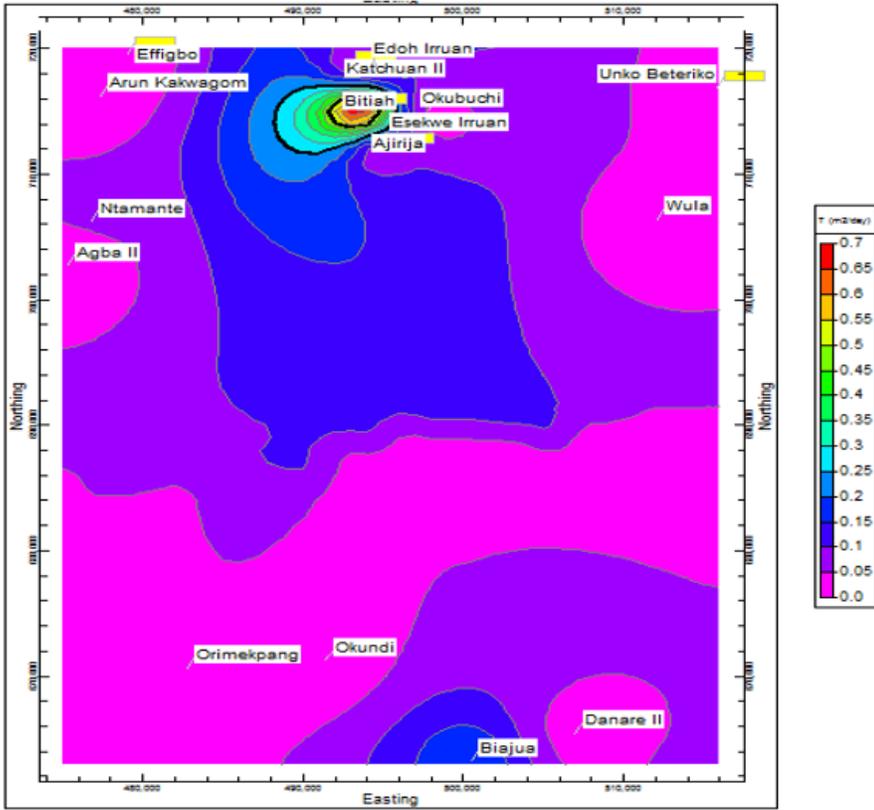


Figure 12

Transmissivity Map of the study Area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.