



2-Dimensional Resistivity Imaging of Inyi Coal-Field, Anambra Basin, Nigeria

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Abstract

2-Dimensional resistivity imaging of Inyi coalfield has been carried out with a view of imaging the coal field for possible location and future exploitation of the coal seam in the area and to carry out detailed geological mapping aimed at producing the geologic map of the area and to provide recommendations for managing the exploitation and exploration of solid minerals in the area. ABEM Terrameter SAS 1000 was used for resistivity data collection and Wenner-Schlumberger array electrode configuration was used because of its sensitivity to both horizontal and vertical structures. 2-D imaging was targeted at determining the lateral extent of the coal seam, the depth to the coal seam and the thickness of the coal seam. 50 VES points was conducted to help in delineating lithology and to be used in correlating 2-D results. Result reveals a resistivity values ranging from 600Ωm to 45000Ωm around the surveyed area. It also show that the coal in the area occurred at varying depth between 4m to about 14.3m which could be extensive below this depth and the thickness ranging from 1m to 3m. Twenty one (21) points of coal seams was identified using VES at various depths ranging from about 0.9m to 23m. The thickness of the coal seams found in the area ranges from about 0.2m to 4m. The coal in the study area is disseminated and occurred at shallow depth hence it's not in economic quantity but the coal can be mined locally.

Introduction

The area (fig. 1) is bounded by latitude 06⁰ 04¹ N and 06⁰ 10¹ and longitudes 07⁰ 14¹ E and 07⁰ 20¹ E and it was mapped on a scale of 1: 100,000. It covers an area extent of about 123.2sqkm. This study was prompted because of lack of interest and poor information on Inyi coal (Dateer, 2017). A detailed geologic study aimed at exposing the outcrops and the local geology of the area so as to delineate lithologies in the study area was done.

Hazell, 1956 said that the interest in the Inyi coal was revived when the Electricity Corporation of Nigeria decided to build a power station at Oji-River on the Enugu-Onitsha road. The Geological Survey carried out a reconnaissance to determine the location of the best outcrops and selected an area for further study. Four boreholes were drilled to prove the extension of the seam in depth, three of the four boreholes intersected the coal.

A 2D resistivity survey was targeted at determining the lateral extents of the coal seam, resistivity values associated with the coal seam and depth to the coal seam (Ojonugwa, *et al* 2018). Geo-electrical resistivity surveying has improved and has become a vital and

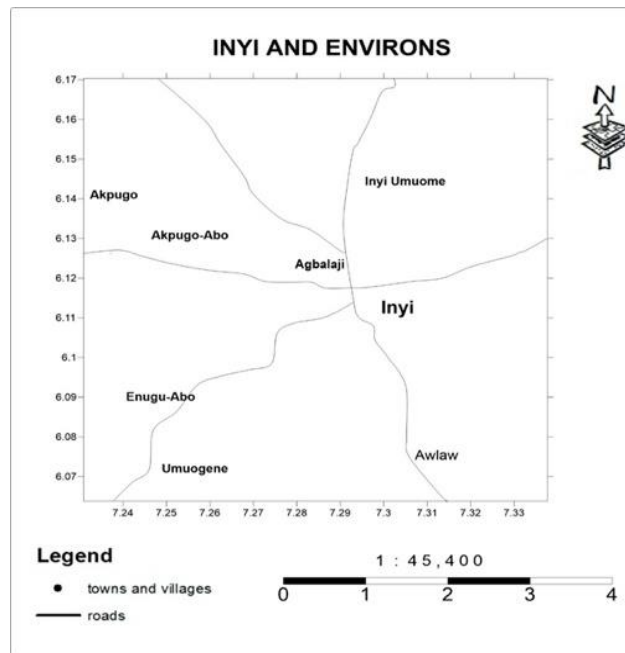


Figure 2. Map showing accessibility of the study area

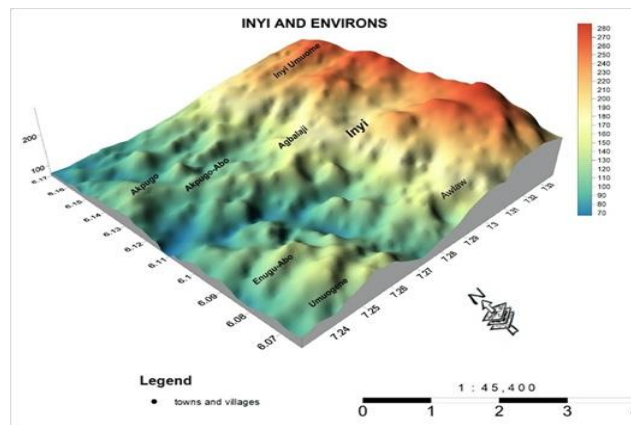


Figure 3. 3d surface map of the study area.

Geology of the Area

The Inyi area is underlain by sediments of the Uppermost Cretaceous and lower Paleocene. The succession is as follows (De Swart & Casey, 1961).

Nsukka Formation: shales with sandstone bands, medium-grained to gritty sandstone, with a few shale bands and fine-grained sandstone, with coal seams.

Ajali Sandstone: Medium to coarse-grained, false bedded sandstone. Only the upper part of the False-bedded Sandstones is exposed near Inyi. It comprises partially consolidated grey-white sandstones, of medium to coarse grain. They are usually iron stained, but contain carbonaceous streaks and bands at various horizons. The basal sandstones and shale horizon of the Upper Coal Measures is about 50ft thick, it is carbonaceous throughout and contains many nodules and bands of siderite and marcasite. The main coal seam lies at or near the top of this horizon and other seams, usually impersistent and less than 1ft thick, may occur lower down (Hazell 1956, Murat, 1970 and Okoro, 1995). The medium to coarse grained sandstones which are from 30 to 70ft thick, contain gritty and pebbly bands and are cross-bedded in places (Wilson & Bain 1928; Wilson, 1925). The upper shales are mainly carbonaceous and contain thick beds of white to grey sandstones. They are at least 150ft. in thickness. The higher horizons of the Upper Coal Measures, which outcrop to the west, have not been investigated.

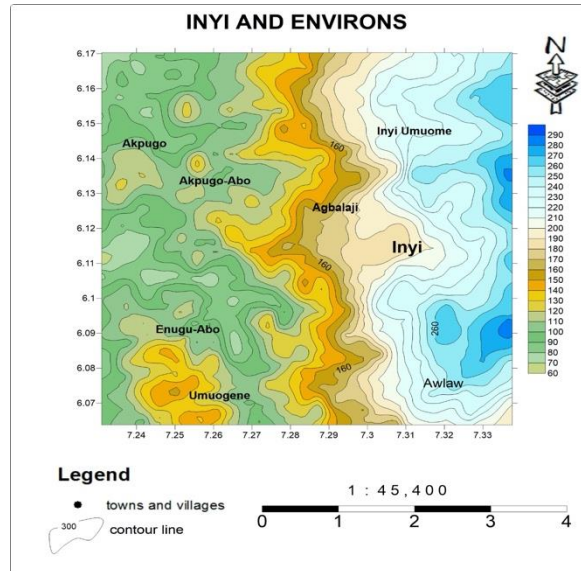


Figure 4. Geologic map of the study area.

Methods

The methods used in this present study include; desk study, preliminary (reconnaissance) study, geological field work, laboratory analyses and Geophysical survey.

Geological Field Mapping

Geological field mapping involves a field visual examination of rocks in their natural locality, inputting the information in field base map and recording details in a field notebook, collecting relevant samples, fossils etc., from the outcrop, and transferring the data onto a base map. Gradually, the database builds up and a map is developed in which the distribution of rocks and the superficial deposits are shown (fig. 5).

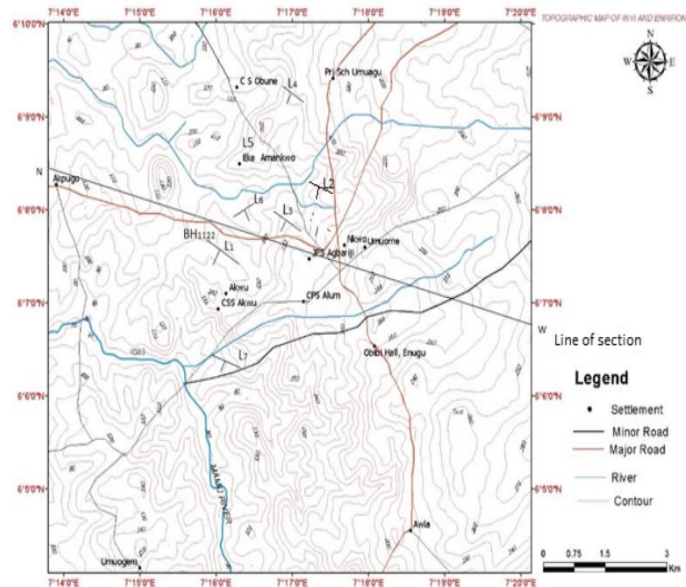


Figure 5. Geologic map of the study area.

Geo-electric survey

Data was acquired along two major traverses (Traverse 1 and 2) where the outcrops of inyi coal are distinctively exposed (Figure 6a and b). The high resolution SAS 1000 meter was used. Eight Profiles were taken for the electrical resistivity survey (6 representing the Schlumberger spread and 2 Wenner spread). They are thus represented as VES I to VES 6 and PROFILE I

and 2. VES was also conducted along PROFILE I and 2 although the starting points differed. The apparent resistivity (in ohm.m) of the areas penetrated were later obtained from the raw field data (resistance in ohms) by multiplying it (resistance, ohms) with their respective geometric factors (k) this was also done in works of Steve, (2002), Sigh et al, (2004) Adewumitaiwo (2016).

The apparent resistivity were against distance (spacing $(\frac{AB}{2})$ in meters) for profiles VES-I to VES-6 while the apparent resistivity were against the depth (m) for Profile I and 2. Where “a” is the electrode separation and “R” is the Resistance. Computed apparent resistivities were processed using the Res2Div software. Of the possible electrode configuration used (Fig 6 and 7) in obtaining the resistivity and 2D resistivity data, the Schlumberger array setup and Wenner configuration was employed in the present study respectively. Data was acquired at different depth probe (electrode separation) of 3meters, 6meters, 9meters, 12 meters and 15 meters to station distance of 250meters for Wenner array configuration and 300m for Schlumberger setup.

Theories of Electrical Resistivity Techniques

Vertical Electrical sounding (VES) (fig.4) and Schlumberger electrode configuration was used in the investigation. The electrode was kept at the center of the field station while current electrode is spaced (increase in depth probed). Our instrument records the apparent resistivity (ρ_a) at a given depth and current (I).

$$\rho_a = G \frac{\Delta v}{I} (\text{ohm} - \text{m}) \quad (1)$$

Where, ρ_a = Apparent resistivity of the aquiferous layer; G = the geometric factor of the electrode arrangement; Δv = potential difference; I = current

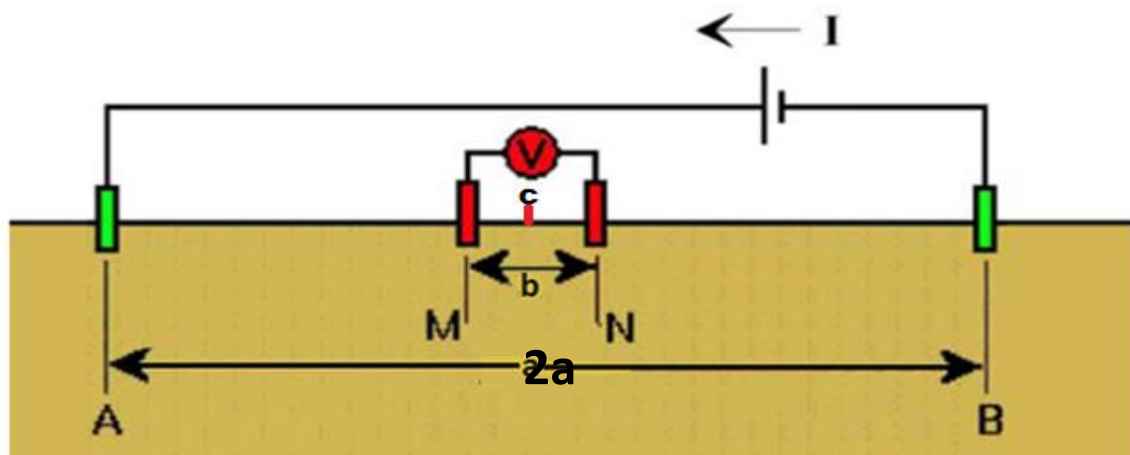


Figure 6. Diagrammatic representation of Schlumberger array (from Omali et al, 2018)

The data obtained in the geophysical survey is recoded and a plot of the recorded field apparent resistivity (ρ_a) against current electrodes spacing was plotted on a bilogarithmic graph. This plot contains vital information such as the depth the caustic bodies, thickness of each layer, resistivity of each layer etc. this clue may in qualitative and quantitative interpretations.

Mathematical Background

From Darcy, the fluid discharge (Q) has the relationship;

$$Q = KIA \quad 2$$

And in a conducting medium current flow is guided by Ohm's law;

$$\mathbf{J = \sigma E} \quad \mathbf{3}$$

Consideration a prism of materials with thickness, h and cross-sectional area. Niwas and Singhal 1981 combined equations (2) and (3) to establish the relationship given as,

$$\mathbf{T = K\delta R = KS/\delta = Kh} \quad \mathbf{4}$$

Where K = hydraulic conductivity; J= current density; σ = electrical conductivity; T = aquifer transmissivity, h = Aquifer thickness, R= Transverse resistance and S = longitudinal conductance.

S and R are often referred to as the Dar- Zarrouk parameters and are designated by

$$\mathbf{S = h/\rho_a} \quad \mathbf{5}$$

And

$$\mathbf{R = h\rho_a} \quad \mathbf{6}$$

Where, h and ρ_a are thickness and apparent resistivities of various geo-electric layers respectively.

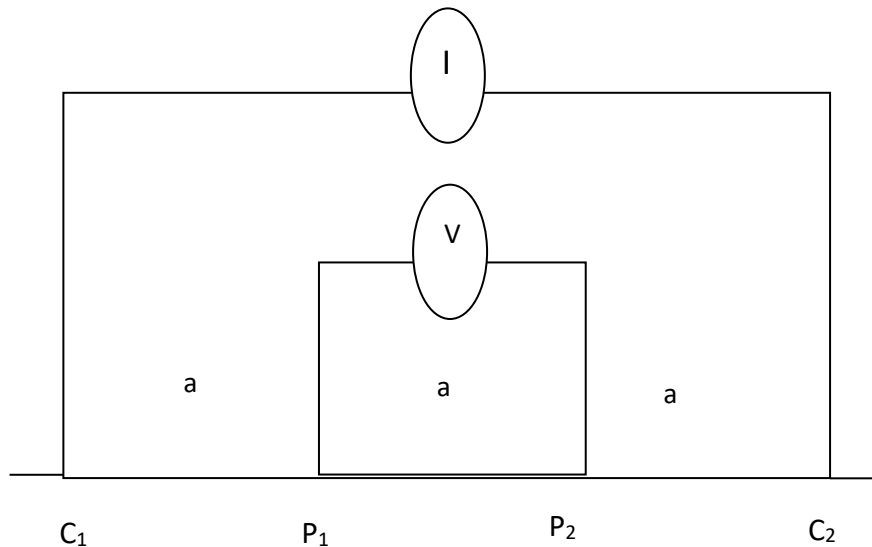


Figure 7. A Wenner array configuration

Results and Discussion

Qualitative Interpretation of Ves Results

Fifty (50) VES were conducted, the data was interpreted in terms of resistivity, depth and curve types. Numerous curve types were obtained which varied from A, K, Q and H curve typed to the complex curve types. The computer iterated sounding interpretation revealed six to seven subsurface sequences composing of lateric sand, coal, sandy-shale, sandstone, wet sandstone, clay/ shale/fractured shale and shaly coal. Coal seams were found in 13 points out of 50 points where VES was conducted.

In this area delineating coal seam using VES was done under the following considerations;

Geology of the area and Resistivity values; A general resistivity value range for coal seam ranges from few hundred Ωm to about to few thousand Ωm , also usually coal has high resistivity with respect to other surrounding formation (Singh *et al*, 2004). For the purpose of this work, coal seam in the study area is considered to have resistivity value of about 2000 Ωm

to 8800Ωm. Coal seam in this area associated with shale is found to have low resistivity values as seen in VES 2 (2468.7Ωm and 2713.2Ωm), VES 7 (2000Ωm), VES 25 (2406.1Ωm), and VES 50 (2164.2) while in some of these VES points with low resistivity values but large thickness is suspected to be the zone of aquifer as evidenced from borehole data and geology of the area as seen in VES 2 (2713.2Ωm) with a thickness of about 87.170m, VES 3 (2762Ωm) with a thickness of about 49.085m, VES 7 (4956.8Ωm) with a thickness of about 31.472m, VES 11 (2688.2Ωm) with a thickness of about 77.11m, VES 19 (3545.3Ωm) with a thickness of about 121.28m, VES 21 (2276.1Ωm) with a thickness of about 85.409m and VES 25 (2793.8Ωm) with a thickness of about 46.852m. Coal seam in this area that is associated with sandstone is found to have high resistivity values as seen in VES 1 (3661.8Ωm and 8736.6Ωm), VES 3 (3214.5Ωm), VES 6 (4506.1Ωm and 5993.8Ωm), VES 9 (4811.9Ωm), VES 10 (5494.2Ωm), VES 11 (7965.2Ωm), VES 19 (5648.7Ωm and 7594.6Ωm), VES 34 (5516.2Ωm and 3292.1Ωm), VES 36 (4407.6Ωm) and VES 50 (3605.4Ωm and 5905.6Ωm).

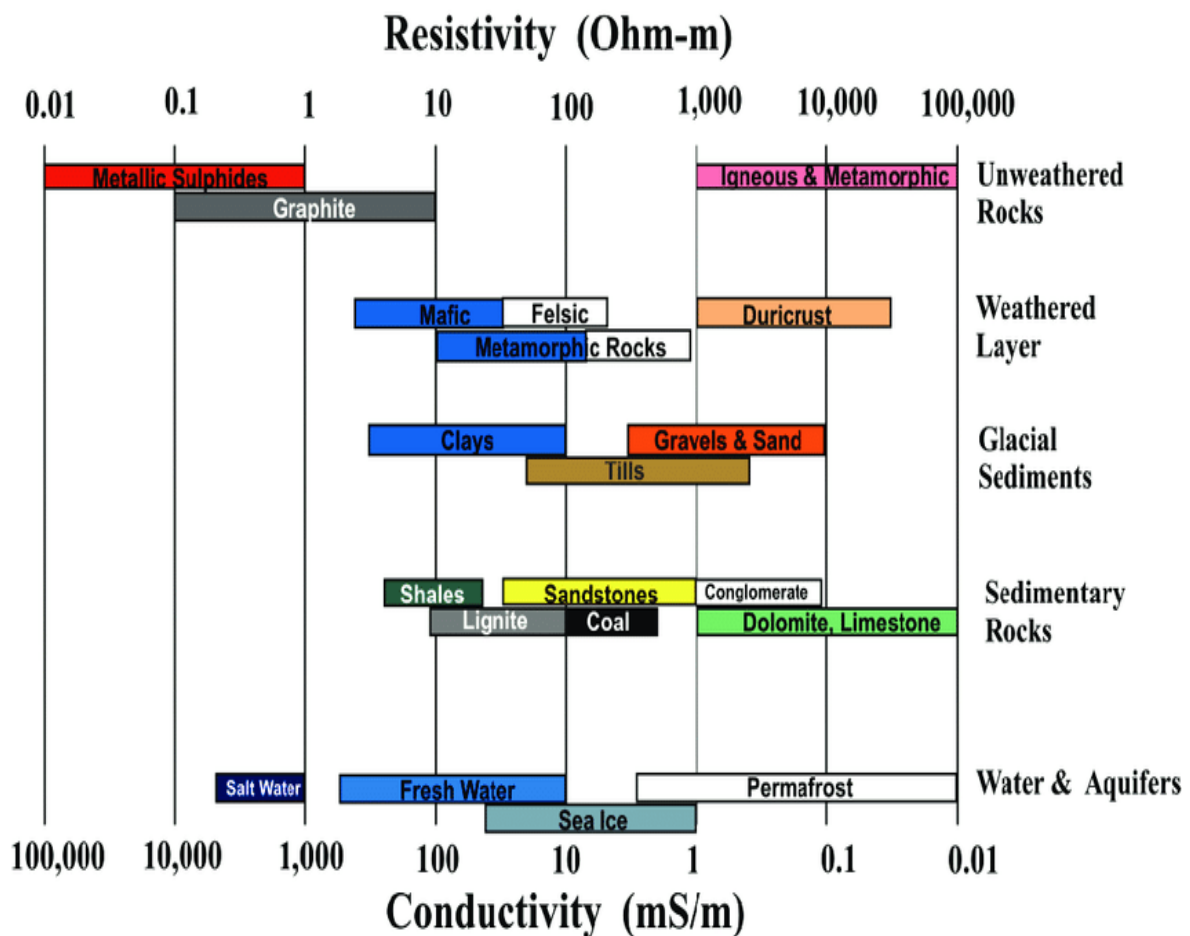


Figure 8. Typical ranges of electrical resistivity and conductivity of earth materials (Ladipo, 1988)

**VERTICAL ELECTRICAL SOUNDING(SHLUMBERGER ARRAY)
NWACHIINYI ALUM IN OJI RIVER L. G. A OF ENUGU STATE.**

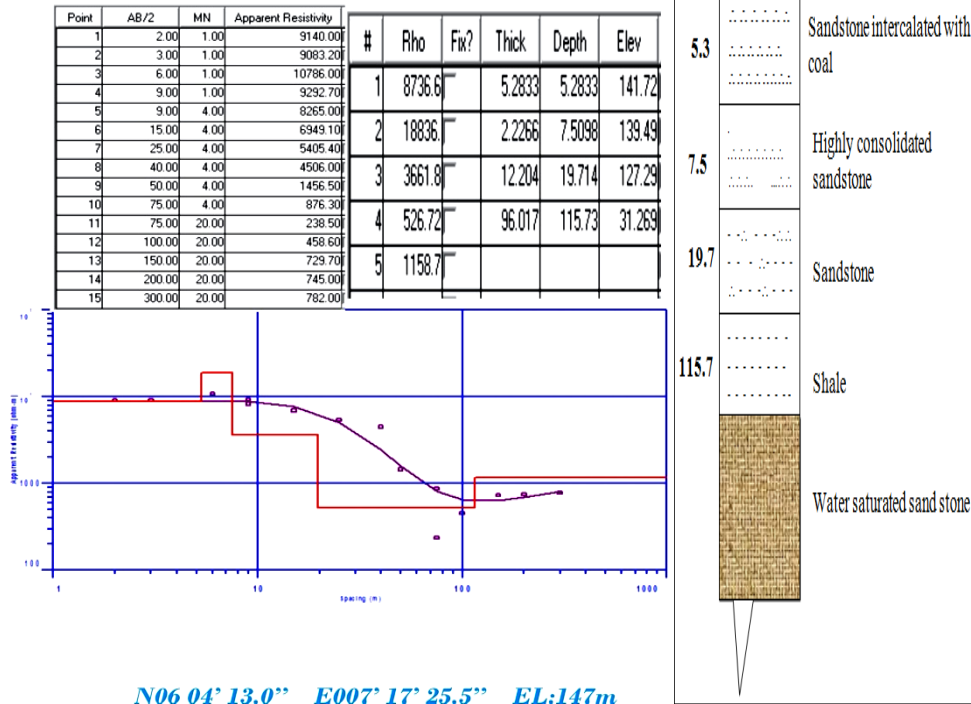


Figure 9. VES 1 Traverse 1- Apparent resistivity plot (Ωm) and Goelectric section.

**VERTICAL ELECTRICAL SOUNDING(SHLUMBERGER ARRAY)
URUKU SPRING, UMUAGU IN OJI RIVER L. G. A OF ENUGU STATE.**

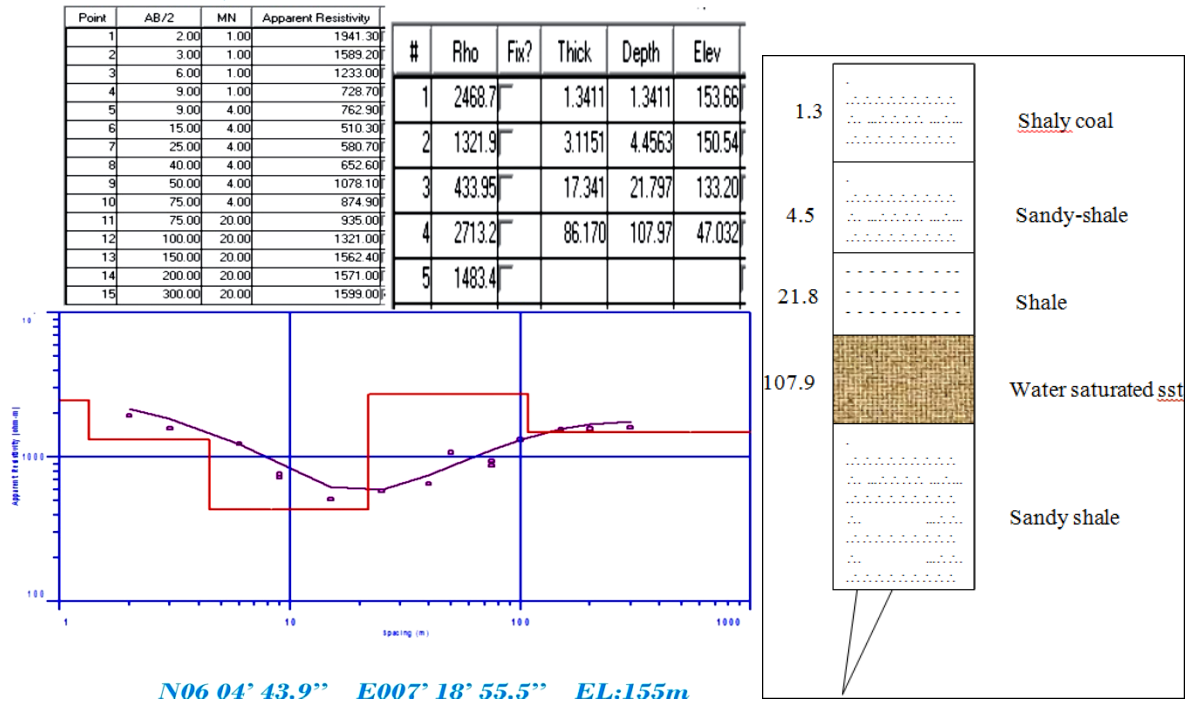
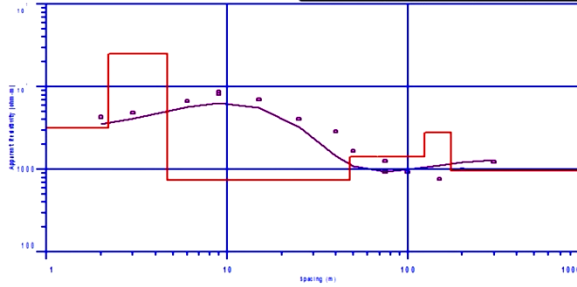


Figure 10. VES 2 Traverse 1- Apparent resistivity plot (Ωm) and Goelectric section.

VERTICAL ELECTRICAL SOUNDING(SHUMBERGER ARRAY)
 IYAYA STREAM UMUAGUIN OJI RIVER L. G. A OF ENUGU STATE.

Point	AB/2	MN	Apparent Resistivity	#	Rho	Fk?	Thick	Depth	Elev
1	2.00	1.00	4311.00	1	3214.5		2.1979	2.1979	131.80
2	3.00	1.00	4858.00	2	25280		2.4720	4.6698	129.33
3	6.00	1.00	6750.00	3	749.71		43.231	47.901	86.099
4	9.00	1.00	8135.00	4	1425.0		76.308	124.21	9.7911
5	9.00	4.00	8778.00	5	2752.0		49.085	173.29	-39.294
6	15.00	4.00	7020.00	6	963.39				
7	25.00	4.00	4095.00						
8	40.00	4.00	2895.00						
9	50.00	4.00	1667.00						
10	75.00	4.00	1259.00						
11	75.00	20.00	942.00						
12	100.00	20.00	933.00						
13	150.00	20.00	765.00						
14	200.00	20.00	1001.00						
15	300.00	20.00	1232.00						



N06 05' 23.0" E007' 16' 47.0" EL:134m

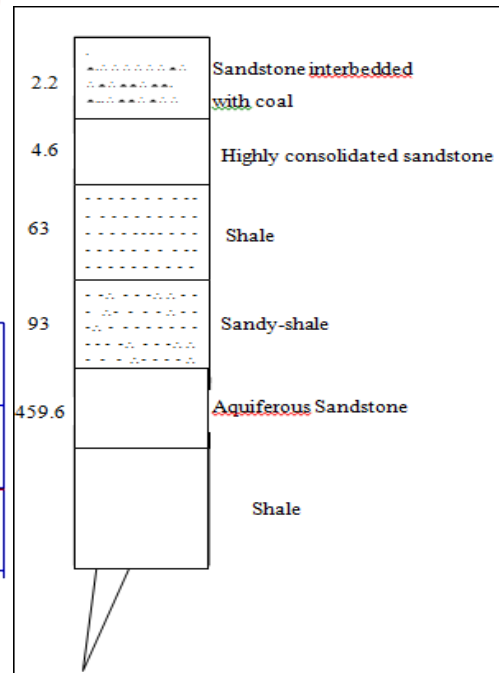
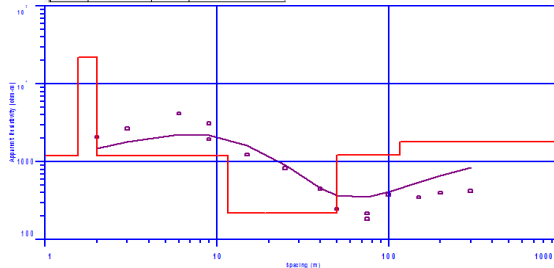


Figure 11. VES 3 Traverse 1- Apparent resistivity plot (Ωm) and Geoelectric section.

VERTICAL ELECTRICAL SOUNDING(SHUMBERGER ARRAY)
 NODU STREAM ANANKOIN OJI RIVER L. G. A OF ENUGU STATE.

Point	AB/2	MN	Apparent Resistivity	#	Rho	Fk?	Thick	Depth	Elev
1	2.00	1.00	2085.00	1	1200.2		1.5466	1.5466	102.45
2	3.00	1.00	2672.00	2	22039		0.45187	1.9985	102.00
3	6.00	1.00	4204.00	3	1200.2		9.6203	11.619	92.381
4	9.00	1.00	3108.40	4	217.67		38.542	50.160	53.840
5	9.00	4.00	1959.00	5	1230.2		66.095	116.26	-12.255
6	15.00	4.00	1240.90	6	1808.8				
7	25.00	4.00	827.30						
8	40.00	4.00	450.60						
9	50.00	4.00	247.00						
10	75.00	4.00	185.00						
11	75.00	20.00	217.70						
12	100.00	20.00	379.20						
13	150.00	20.00	350.40						
14	200.00	20.00	398.00						
15	300.00	20.00	421.00						



N06 04' 52.1" E007' 18' 25.0" EL:104m

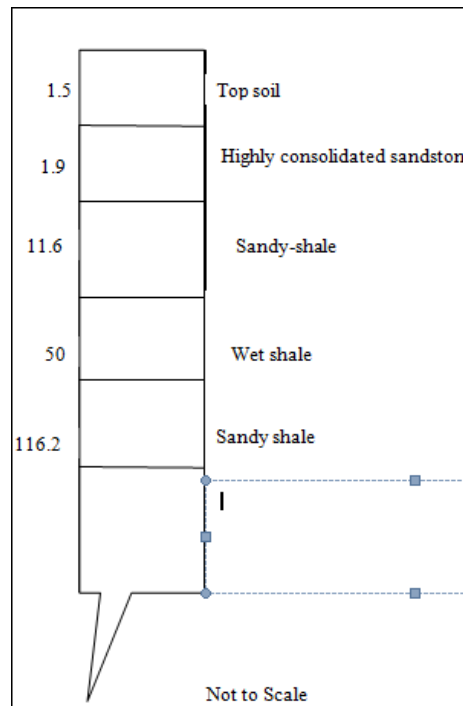


Figure 12. VES 4 Traverse 1- Apparent resistivity plot (Ωm) and Geoelectric section.

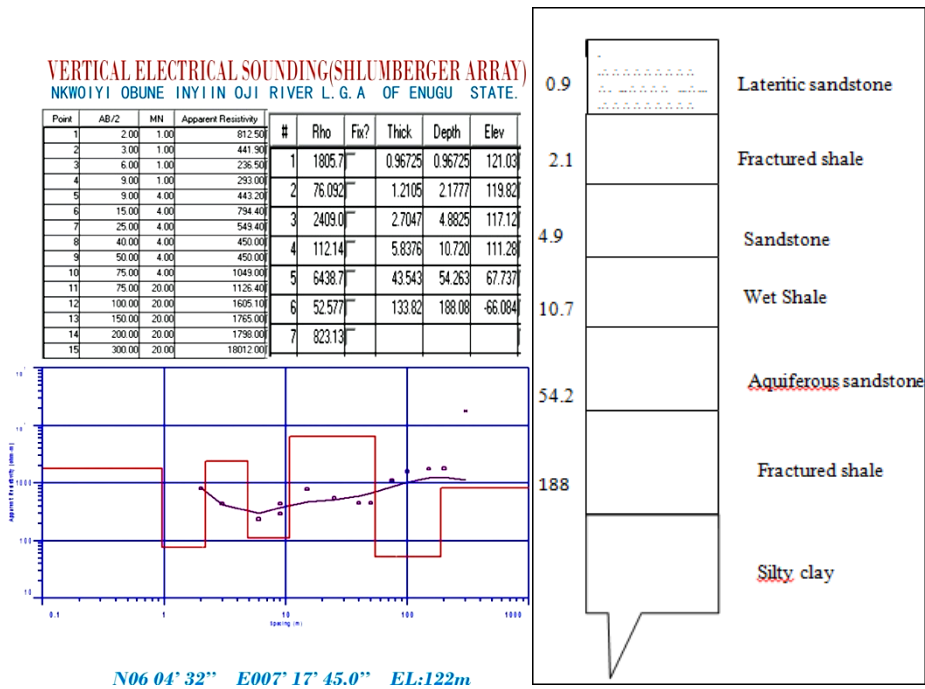


Figure 13. VES 5 Traverse 1- Apparent resistivity plot (Ωm) and Geoelectric section.

Two-dimensional (2-D) geo-electric resistivity imagery was achieved by integrating the interpreted vertical electrical sounding data and electrical profiling pseudo-section. The interpreted apparent resistivity value can be presented in pictorial form using pseudo-section contouring which gives an approximate picture of the subsurface resistivity distribution. The plotted pseudo-section serves as an important guide for detail quantitative interpretation (Onwuemesi and Egboka, 2006). The pseud-section plot can identify a poor resistivity measurement. The pseudo-depth value or are based on the sensitivity value the Frechet derivate for a homogenous half-space. Electrical sounding shows resistivity in relation to depth i.e. it measures the vertical variation.

The 2D resistivity pseudo sections for Profile 1 and 2 are shown in Figures 14 and 15 respectively.

Qualitative Interpretation of 2d Resistivity Imaging

Two profiles were acquired for this work and emphasis was made on them as both profiles reveal the possible occurrence of coal. The inversion result for each profile is also shown depicting the images of the geoelectric sections obtained from the processed data. The resistivity model reveals changes in the geologic components of the subsurface, with respect to the recorded resistivity with scales shown at the lower end of the plot, ranging from $0.33\Omega m$ to $45008\Omega m$; the side bar shows the depth below the subsurface with a mean depth of about 13.1m and the profile distance is shown above the section.

Profile one

Profile one (Fig. 14) was carried out in Nwachiya Alum. The maximum depth penetrated in this area is about 14.3m and a profile distance of about 250m. This is around VES 1 location. Fig 14 shows recorded apparent resistivity pseudo-section, calculated apparent resistivity pseudo-section and the resistivity model section. The resistivity model discloses a thin low resistivity layer which ranges from $600\Omega m$ to $1800\Omega m$ which may be composed of shale and sandy-shale. Underlying this layer is a high resistive body of about $2600\Omega m$ to $8000\Omega m$ which believed to compose of sandstone interbedded with coal at a profile distance of about 20m and 30m, this high resistive layer was also observed at a profile distance of about 41m to a depth of about 5m. At a profile distance of about 65m and 81m a distinctive layer which interpreted

as coal is seen occurring at a depth of about 6m to 8m. There is a manifestation of small section of low resistivity between a distance on the profile of about 100m to 120m from a depth of 4m to 7m. it is believed that the low resistivity fragment might be groundwater trapped in the aquifer. Although no borehole data was used to correlate the results because there was no borehole around the study area, reference was made to typical resistivity values of geological materials and the spring water which was found in the area. An anomalous body of very high resistivity of about 10000Ωm to 12000Ωm is seen at a profile distance of about 200m to 240m and occurring at a depth of 7m to 14.3m, this could be an indicative of a highly consolidated sandstone boulders as seen on the surface.

Profile two

Profile 2 (fig. 15) was conducted at Oji Alum where VES-6 was also carried out with different starting points. The maximum depth penetrated in this location is about 11.9m with profile distance of about 150m. This profile is marked with high apparent resistivity ranging from 20,000Ωm to 25,000Ωm at 3m to 15m profile distance to a depth of about 1m, this could be dry or highly consolidated sandstone boulder, from the profile distance of 6m to 15m and depth of 2m to about 6m a low resistivity value ranging from 1,800Ωm to 3,000Ωm, this could be aquiferous sandstone, it is also seen at a distance of 90m to 110m and depth of 7m to 11.9m. A high apparent resistivity value is seen at a profile distance of 49m to 71m, this could be an indicative of coal seam interbedded with sandstone hence the high resistivity value. A large anomalous body occurring at a profile distance of about 72m to 93m and from the depth of 4m to 11m is seen, this could be a highly consolidated sandstone boulder, references was made to evidence from the surface and local geology of the area.

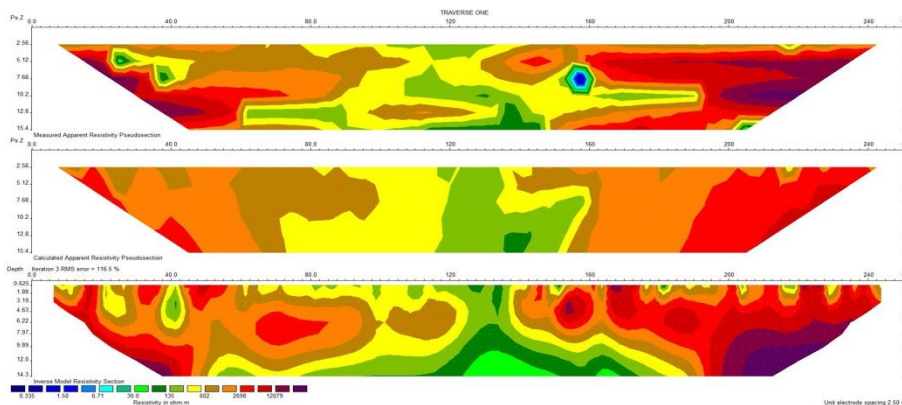


Figure 14. Apparent resistivity pseudo-section for Profile 1

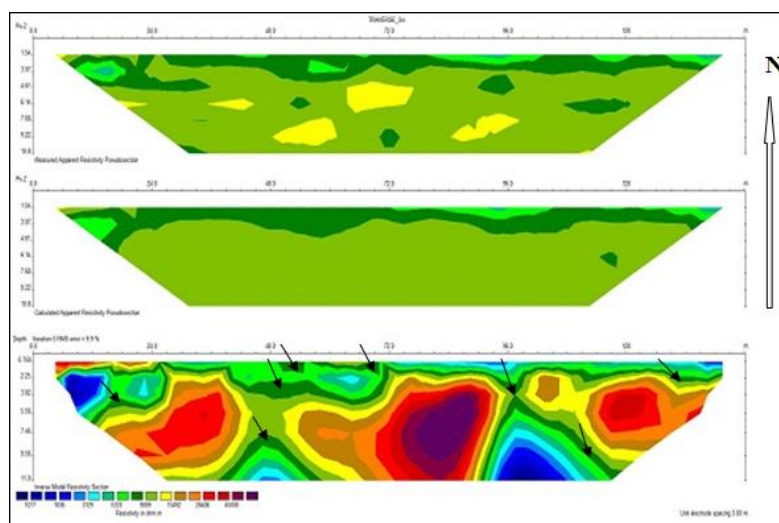


Figure 15. Apparent resistivity pseudo section for Profile 2

Correlation of VES 1 and VES 6

In fig. 16, an anomalous body of high apparent resistivity value of about 18836 Ω m and 30851 Ω m respectively occurring at a depth of about 7.5m and 7.4m respectively is observed in both VES 1 and VES 6, this also coincides with profile 1 resistivity pseudo-section in fig 16 where an anomalous body of high apparent resistivity value is seen occurring at a depth of about 6m to 14m

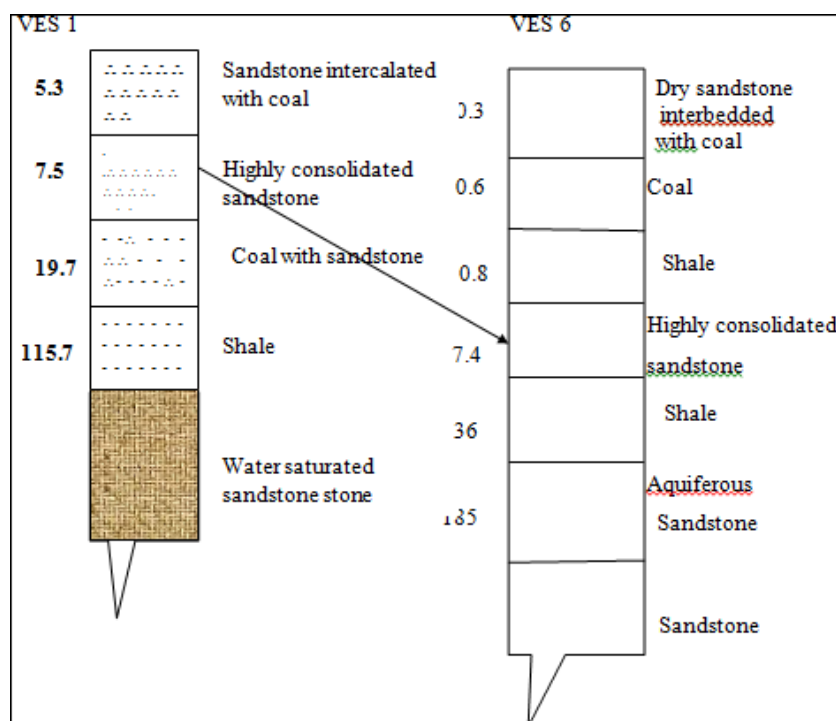


Figure 16. Correlation VES 1 AND VES 6 Geoelectric section

The result of electrical resistivity imaging shows that the near surface material may be composed of lateritic sand/weathered shale forming the top soil with resistivity ranging from 700 Ω m to 3000 Ω m and to a depth of about 0.5m to 3.5m, below this surface material is a layer likely to be coal seam at a depth of about 1.3m to 4m, when the coal seam is interbedded with shale it tends to give a low resistivity value ranging from about 2000 Ω m to 3100 Ω m as seen in VES 2, this is also seen in PROFILE 1 (at a depth of about 1m to 3m and also seen at 6m to 7m in some station distance) where the coal seam is found to be underlying shale formation and occurring very close to the surface but when the coal seam is intercalated with sandstone it tends to have a high resistivity values of about 3200 Ω m to 8000 Ω m as seen in VES 1 (3661.8 Ω m and 8736.6 Ω m), VES 3 (3214.5 Ω m), VES 6 (4506.1 Ω m and 5993.8 Ω m), this is also the case with PROFILE 2 (at a depth of about 1m to 2m and also seen at 6m and 7m in some distances) as the coal seam is found to have a very high resistivity value range of about 5000 Ω m to 9000 Ω m and sandwiched in between sandstone. Underlying this coal seam is an anomalous body of a very high resistivity value ranging from about 10000 Ω m to 31000 Ω m, this is seen in VES 1, VES 3, VES 4, VES 6, occurring at a depth of about 4m to 7m on average. This anomalous body which is considered to be a highly consolidated sandstone evidence from the surface. This was also observed in both PROFILE 1 and PROFILE 2 and occurring at a depth of about 4m to 14m. Underlying the anomalous body is shale (some of the shales in this area are fractured as suggested by VES results and evidence from the surface, these fractures were also seen in the field during the geologic mapping) the fracture could be as a result of the overlying highly consolidated sandstone exerting pressure on the underlying shale, following this shale is sandy shale, wet sandstone which could be filled with water because of its low resistivity value serves as aquifer in this area (this could be from the underlying Ajali Sandstone

according to the geology of the area) (Plate 1). In some VES points like VES 1, 2, 3, 4 and 5, aquiferous sandstone is sandwiched in between shales, thereby putting the water under pressure and resulting in artesian well, unconfined aquifer also exists as seen in VES 6. This information might serve as a useful initial guide for any future hydrogeological/hydrological and geotechnical project in the area.



Figure 17. An outcrop of a well exposed coaliferous layer of Unit B.

Conclusion

2D resistivity imaging conducted on Inyi coalfield has revealed that the area surveyed is covered by lateritic sandstone/top soil, followed by coal which is disseminated and occurred at shallow depth and hence not in economic quantity but the coal can be mined locally, a massive highly consolidated sandstone was also discovered in the study area and found to be directly overlying shales hence the reason for fractured shales in some locations, this should serve as a geotechnical guide as heavy or complex buildings should not be sited in the boundary of this massive consolidated rock and adjacent formation rather it can be secured directly on the massive highly consolidated rock. VES conducted in the study area shows that the coal is interbedded with shales as well as sandstone, an aquiferous zone that is confined is revealed by the VES hence the reason for artesian well in the area. A sandy-shale, dry sandstone and wet shale are also part of the lithologies exposed in the study area, this supports the geology predicted in the area by early workers to be Ajali Sandstone which is aquiferous and Nsukka Formation which is coaliferous. The 2D resistivity pseudosection revealed the coal seam boundaries, depth sections and coal distribution in the area. However, there is a likelihood from the study that the coal seam might extend beyond the depth of 15m. Therefore, it is recommended that 3D survey

should be carried out on the profiles since most of the geologic features in the occurs in 3D form.

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