

## Research Article

### Observations from Square Array Resistivity Response Over Ezimo Coal Field, Southeastern Nigeria

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**Abstract:** The response of the coal seam within the Mamu Formation has been studied at Ezimo in the Anambra Basin using electrical resistivity method utilizing the square array. Apparent resistivity data obtained with the square array can be interpreted using methods for Schlumberger soundings. This is done by translating apparent resistivity data obtained from the square array to those of equivalent Schlumberger array. Sounding data was interpreted using the conventional curve matching and computer iteration method. The presence of the coal seam is characterized by high resistivity values ranging from 4900-9059  $\Omega\text{m}$  with respect to the background resistivity of the shale, sandy shale and sandstone of the Mamu Formation, which is between 74-3212  $\Omega\text{m}$ . Depths to coal from the soundings is not uniform but ranges from a depth of 20 to 201.6 m. The non uniformity in depth to coal is attributed to the surface elevation; the coal seam is deeper in regions where elevation is higher. The results were correlated with drilling records of the study area and were found to be consistent.

**Keywords:** Anisotropy, anomaly, coal seam, schlumberger array, square array

#### INTRODUCTION

Rocks and minerals have electrical resistivity which covers a wide range of magnitudes. The presence of a zone with anomalous resistivity perturbs the distribution of the electrical current/potential lines in an otherwise homogenous medium. It is thus possible to know something about the subsurface layers from the measurements of potentials at the surface. The electrical resistivity methods have been successfully applied to the study of different geologic problems in several ways. Taylor (1982), Taylor and Fleming (1988) and Ritzl and Andolsek (1992) have used the method to detect bedrock fractures. Verma and Bhui (1979) used the method to study coal seams in the Jharia coal field, India.

The square array which was originally developed as an alternative to Wenner or Schlumberger array when a dipping subsurface, bedding or foliation was present (Habberjam and Watkins, 1967) but the method had not been widely used. Schlumberger resistivity sounding is well known for determining resistivity variation with depth to the aquifer while azimuthal square array (Lane *et al.*, 1995) resistivity sounding provides method for measuring in-situ anisotropy and directional nature of vertically dipping fracture system. Recently, dc-resistivity surveys using square configuration have been conducted to detect productive fracture zones in crystalline bedrock for groundwater supply (Darboux-Afouda and Louis, 1989; Sehli, 1990).

Azimuthal square array resistivity technique has been used to identify the anisotropy caused by the fractures and the dominant strike direction as well (Lane *et al.*, 1995; Odoh *et al.*, 2012). These studies verified the work of Habberjam (1972) and showed that the square array sounding method is more sensitive to a given rock anisotropy than the more commonly used Wenner or Schlumberger arrays.

Electrical resistivity surveys employing square array have been used, for mapping the coal seam in Ezimo coalfield.

#### LOCATION AND GEOLOGY OF EZIMO AREA

The Ezimo coalfield as shown in Fig. 1 is about 60 km north of Enugu metropolis and covers an area of about 35 km<sup>2</sup> within latitudes 6° 53 N and 6° 57 N and longitudes 7° 31 E and 7° 35 E.

The area is underlain by the Maastrichtian formations which include the paralic sequence of the Mamu Formation, the continental fluvial sequence of the Ajali Sandstone and the Enugu Shales. In the study area, the Lower Maastrichtian Mamu Formation and Upper Maastrichtian Ajali Sandstone were exposed along streams that drained the area. The Mamu Formation which was deposited as the sea became shallower consists of alternating sequence of sandstone, mudstone and sandy shale/shale beds; the thickness of this formation is 440 m (Reyment, 1965). Commercial quantity coal seam occurs in this formation also known

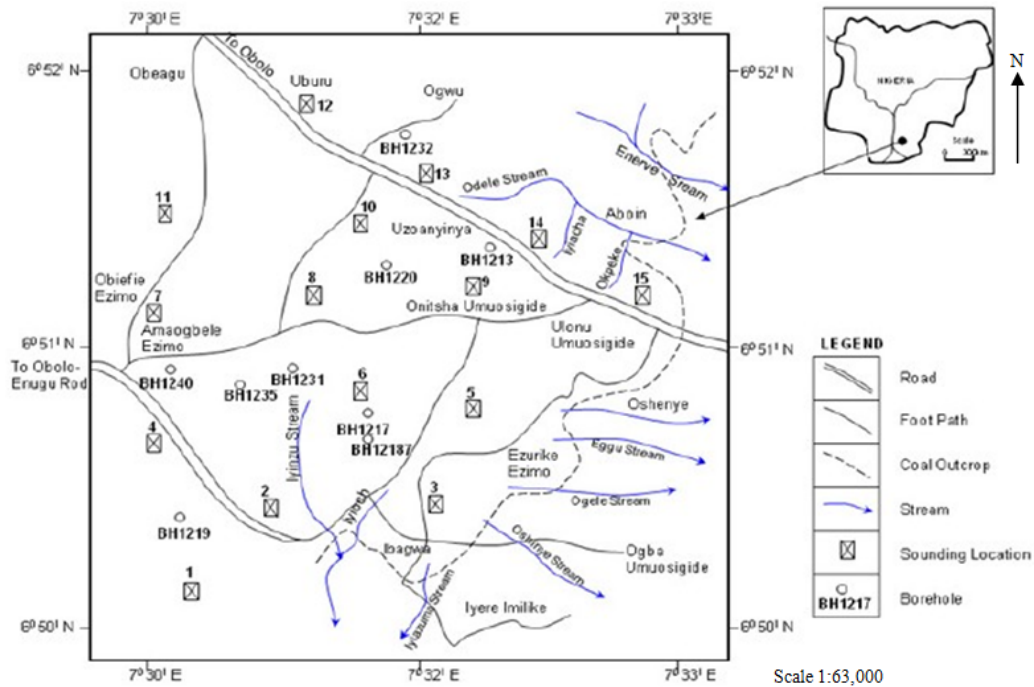


Fig. 1: Map of study area

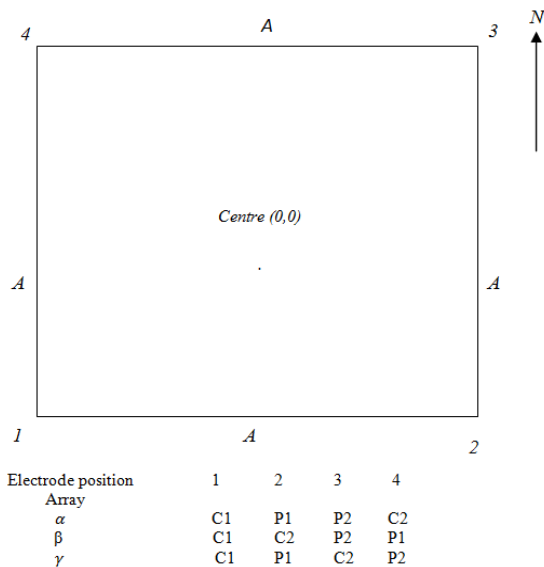


Fig. 2: The square array of electrodes and the possible modes of connection for resistivity measurement (Habberjam and Watkins, 1967)

as lower coal measure (De Swardt and Cassey, 1961). The coal strike azimuth NE and have an average dip of  $4^\circ$ . The regression of the sea during the later part of Maastrichtian led to the deposition of the Ajali Sandstone which overlies the Mamu Formation and has been described as white false-bedded sandstone (Tattam, 1944). Around Iyazu stream, the Ajali Sandstone exhibits a characteristic white friable, moderate to poorly sorted, medium to coarse grained,

pebbly and cross-bedded sandstones. The Enugu Shales, were poorly exposed in the study area. The only fresh exposures of the formation occur in the Eggu stream, near the southeastern margin of the area and in Okpeke stream in the northeast. This formation consists of dark-grey shales and mudstones with occasional nodules of clay-ironstone (Simpson, 1954).

**The square array method:** A dc-resistivity survey using the square array method is similar to that of the traditional collinear arrays. The location of a measurement is assigned to the centre point of the square with four people at the ends of the square expanding the electrodes symmetrically about the central point, in increments of  $A(2)^{1/2}$  (Habberjam and Watkins, 1967) so that sounding can be interpreted as a function of depth. For each square, three measurements are made: two perpendiculars (alpha- $\alpha$  and beta- $\beta$ ) and one diagonal measurement (gamma- $\gamma$ ) as shown in Fig. 2.

In an isotropic medium

$$\rho_{\alpha\alpha} = \rho_{\beta\beta}, \text{ therefore, } \rho_a = 0$$

and in a homogenous anisotropic medium:

$$\rho_a = \rho_{\alpha\alpha} - \rho_{\beta\beta}$$

where,

$\rho_a$  = Apparent resistivity, in ohm-meters

Apparent resistivity is determined using the equation:

$$\rho_a = \frac{K\Delta V}{I}$$

where,

- K = Geometric factor for the array
- $\Delta V$  = Potential difference, in volts
- I = Current in amperes

For the square array:

$$K = \frac{2\pi A}{2-(2)^{1/2}} \text{ (Habberjam and Watkins, 1967)}$$

### MATERIALS AND METHODS

All the field observations were taken using ABEM Terrameter SAS 4000. Fifteen vertical electrical soundings were taken, using square array at different locations with an electrode spacing ranging from 2 m to 500 m as shown in Fig. 1. Habberjam and Watkins (1967) demonstrated that apparent resistivity data obtained with the square array can be interpreted using methods for Schlumberger soundings. This is done by translating apparent resistivity data obtained from the square array to those of equivalent Schlumberger array. The square array resistivity measurements are converted to a single measurement ( $\rho_m$ ) by the equation:

$$\rho_m = [(\rho_{\alpha\alpha})(\rho_{\beta\beta})]^{1/2} \text{ Habberjam and Watkins (1967)}$$

where,

$\rho_m$  = mean geometric resistivity

It should be noted that  $\rho_{\alpha\alpha}$  and  $\rho_{\beta\beta}$  provides information on the directional variation of the subsurface apparent resistivity ( $\rho_a$ ) while the  $\rho_{\alpha\gamma}$  measurement serves as a check on the accuracy of the  $\rho_{\alpha\alpha}$  and  $\rho_{\beta\beta}$  measurements.

Depth sounding curves were prepared for each location by plotting the mean geometric resistivity values against its equivalent Schlumberger configuration spacing. The electrode spacing, A of the

square array can be converted to its equivalent Schlumberger spacing, r using the expression below:

$$A = r \left[ \frac{2(r+s)}{(2r+s)} \right]$$

where,

- A = Square array side length
- r = AB = Current electrode separation
- s = MN = Potential electrode separation

The curves were interpreted by partial curve matching technique, with two-layer master curves with their auxiliary point diagrams (Zhandov and Kelly, 1994). These provided approximate layer resistivities and thicknesses which were optimized using computer interactive technique for quantitative interpretation.

### RESULTS AND DISCUSSION

The results of the electrical resistivity data are presented as sounding curves (Fig. 2), tables (Table 1) and maps (Fig. 3 and 4). The sounding curves were evaluated for signatures that are diagnostic of coal occurrence i.e., high resistivities since coal is a poor conductor. The interpretation of the sounding curves shows that the geologic sequence at Ezimo consists of laterite, sandstone, sandy shale and shale. The end part of the sounding curves as interpreted, gives high resistivity values which indicate the presence of the coal seam at Ezimo. The relatively high resistivity values ranging between 707-3212  $\Omega m$  are due to the presence of sandstones of the intervening Mamu Formation while the lower resistivity values ranging between 74-176  $\Omega m$  and 227-311  $\Omega m$  corresponds to the presence of shale and sandy shale, respectively.

Observations from the sounding curves show that the coal seam was well reflected on 73.3% of the sounding curves which indicates anomaly traceable to occurrence of coal. The depth to the coal seam ranges from 20 m (VES 15) in the eastern part to 201.6 m (VES 13) in the northern part. It is felt that as soon as

Table 1: Summary of geoelectric data interpretation results of Ezimo coal field

VES Station	Resistivity ( $\Omega m$ )	Thickness (m)	Remarks	Depth to coal (m)
	$\rho_1 / \rho_2 / \rho_3 / \dots / \rho_n$	$h_1 / h_2 / h_3 / \dots / h_n$		
1	749/1590/1451/7484/182	0.5/25.6/49.6/1.4	1 coal anomaly	75.7
2	1721/835/1191/5062/116	1.8/39.3/29.9/1.6	1 coal anomaly	71
3	1345/2522/1535/8749/108	2.6/24.5/33.7/1.1	1 coal anomaly	60.8
4	877/1337/195/1922/7371/1783	1.7/27.9/3.3/49.1/2.1	1 coal anomaly	82
5	781/904/1301/4900/1108	1.3/50.9/21.8/1.2	1 coal anomaly	74
6	1322/1745/1007/5986/965	2.6/43.4/30.6/1.9	1 coal anomaly	76.6
7	1157/806/74/912/1251/8707	1.6/23/6.2/31/46.8	1 coal anomaly	108.6
8	745/1508/63/993/1021	2.2/14.6/3.8/51.7	No anomaly traceable to coal	-
9	872/1106/1812/106/756/9059	1.4/28/22.6/5.1/71.9	1 coal anomaly	129
10	979/1115/176/1625/966/236	2.0/31.2/8.1/26.1/12.1	No anomaly traceable to coal	-
11	1880/1011/227/1702/193/96	1.8/13.6/14.2/44.7/7.6	No anomaly traceable to coal	-
12	704/1360/82/865/1039/242	2.1/10.2/6.0/56.2/27.5	No anomaly traceable to coal	-
13	1952/3212/311/156/707/1236/5972	1.8/39.5/25/5.3/51.6/78.4	1 coal anomaly	201.6
14	1244/2251/171/885/5196	1.6/18.1/2.8/9.5	1 coal anomaly	32
15	772/1127/1606/8749/1206	1.9/10.5/7.6/1.8	1 coal anomaly	20

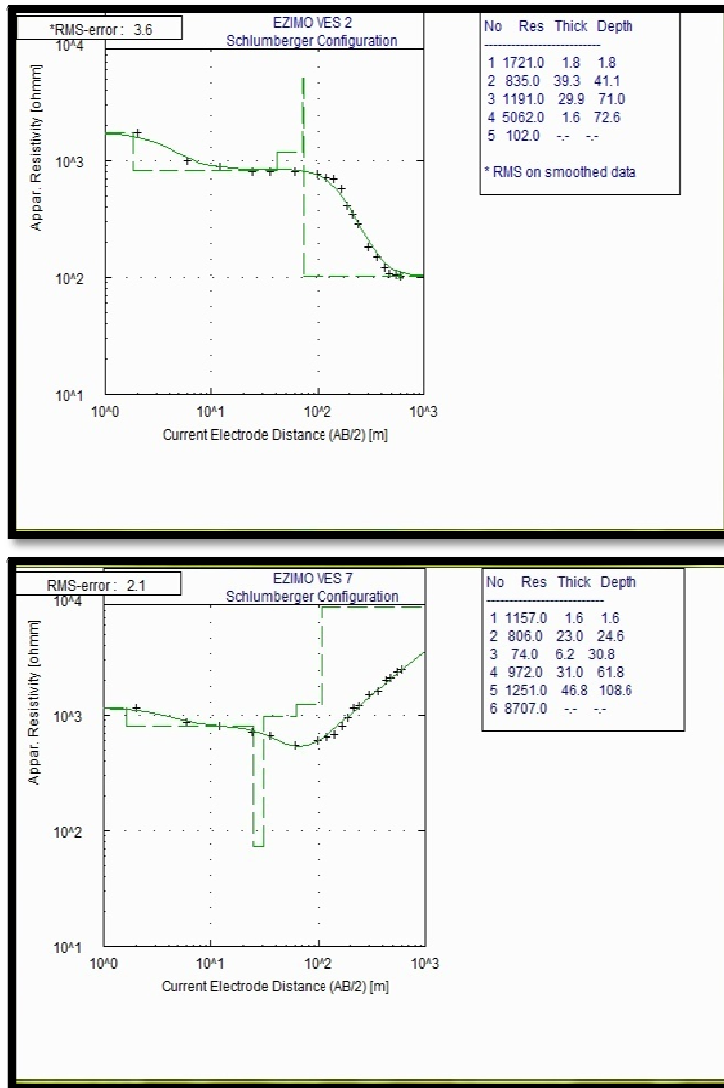


Fig. 3: Typical sounding curve for Ezimo

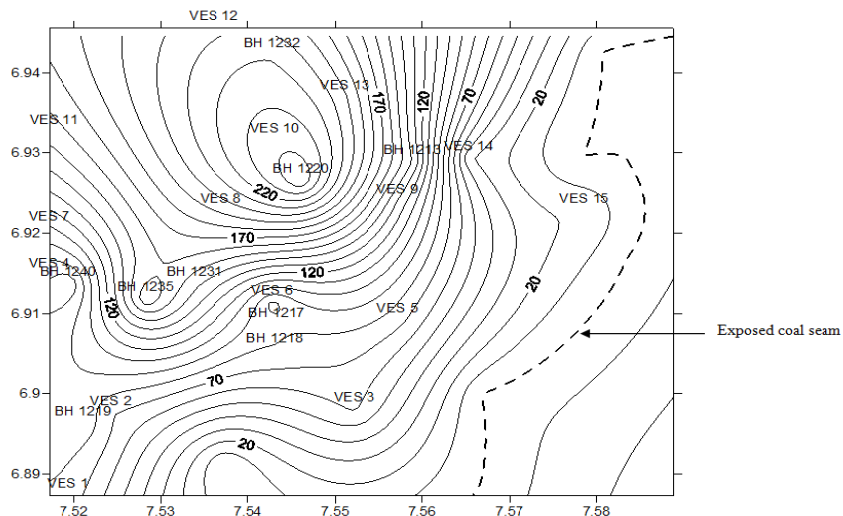


Fig. 4: Isopach map of depth to coal seam

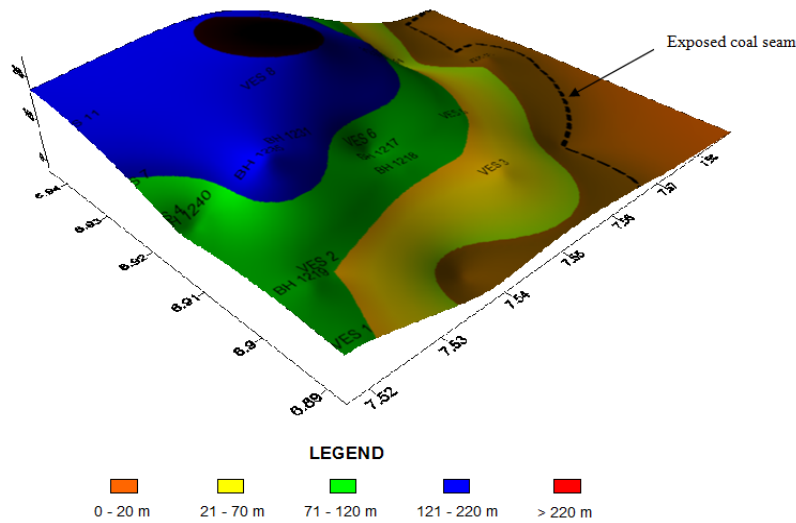


Fig. 5: 3-D structure of Ezimo coal field showing variation in depth to coal with elevation

Table 2: Drilling records at Ezimo

BH NO	Elevation (m)	Depths to coal (m)	Coal seam from m <sub>1</sub> to m <sub>2</sub>		Thickness (m)
1213	360	14.0 <sup>a</sup>	125.7	125.8	0.1 <sup>a</sup>
			132.1	134.1	2.0
1217	358	82.5 <sup>b</sup>	-	-	-
1218	319	79.0 <sup>b</sup>	-	-	-
1219	354	88.4	80.6	81.9	1.3
1220	464	248.0 <sup>c</sup>	240.9	242.6	1.7 <sup>c</sup>
1231	390	142.7 <sup>a</sup>	139.0	139.4	0.29 <sup>a</sup>
1232	423	218.7 <sup>b</sup>	-	-	-
1235	390	163 <sup>a</sup>	140.9	140.9	0.29 <sup>a</sup>
			159.1	160.7	1.57
1240	352	79.6 <sup>b</sup>	-	-	-

a - shaly coal, b - abandoned hole, c - recovery incomplete; (Geological Survey of Nigeria, 1961)

the current lines penetrate the Mamu Formation and touch the coal seam, the nature of the sounding curves changes resulting in high resistivity values that ranges from 4900-9509 Ωm while the thickness of the coal seam range from 1.1-2.4 m. The high resistivity value of 3212 Ωm in the second layer of VES 13 is not due to the presence of the coal seam as there is no record of coal at Ezimo occurring at depth as shallow as 1.8 m, this layer is sandstone. Several literatures have linked sandstone to resistivity higher than 3000 Ωm (Paranis, 1986; Loke, 1999; Kearey *et al.*, 2002). Drilling records at Ezimo (Table 2) however show depth to coal exceeding 218 m. The coal seam was not reflected on VESes 8, 10, 11 and 12; this is due to the greater depth to coal seam at these locations and limitation of depth of penetration of the current.

Depth to the coal seam as shown in Fig. 3 and 4 increases towards the north and northwestern parts, this was due to increasing elevation (elevations at these locations is >400 m) and reduces towards the eastern and southern part of Ezimo. The coal seam is well exposed near streams in the eastern part of the study area along a belt trending northeast-south (orange colour) as shown in Fig. 5.

## CONCLUSION

An attempt has been made to study the response of the coal seam at Ezimo to electrical resistivity soundings using the square array. The coal seam can be well picked up using this method and it was observed that the coal seam is characterized by high resistivity values ranging from 4900-9509 Ωm with thickness ranging from 1.1-2.4 m. The depth to the coal seam from the interpretation of the sounding curves is not uniform but ranges from a depth of about 20-201.6 m and this can be attributed to the elevation at the surface. Hence, the coal seam is deeper in regions where elevation is higher because of the greater overburden thickness.

The coal seams do appear to be extensive within the study area since >70% of the points sounded indicated anomaly traceable to occurrence of coal. The results of this study strongly agreed with the drilling record at Ezimo. Therefore it can be concluded that electrical resistivity soundings can be successfully applied for mapping coal seams having a reasonable overburden thickness.

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