

INTEGRATED GEOSCIENTIFIC INVESTIGATION OF COAL DEPOSIT FOR SUSTAINABLE RESOURCE DEVELOPMENT, IN PART OF NORTHERN ANAMBRA BASIN, NIGERIA

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Abstract

This study presents an integrated geophysical investigation aimed at delineating coal seam occurrence within Ofugo, Ankpa Local Government Area of Kogi State, Nigeria. Electrical Resistivity Tomography (ERT), Vertical Electrical Sounding (VES), and Natural Electromagnetic Field (NEF EM) methods were employed to characterise subsurface lithology and identify coal bearing formations within the Anambra Basin. The results reveal a multi layered subsurface consisting of laterite, sandstone, shale, clay, and coal seams. Coal horizons are characterised by resistivity values ranging from 154 to 366 Ohm m, while NEF EM responses indicate conductive anomalies between 0.06 and 0.2. The coal seams occur at depths between 13 m and 40 m, with thickness ranging from 2 m to 6 m. Integrated interpretation reveals lateral continuity and structural dipping of shallow coal seam within the Mamu Formation which occur towards the southeastern portion of the study area. These findings further confirm the presence of economically viable coal deposits at shallow depth and highlight the effectiveness of integrated geophysical methods in mineral exploration which provides a framework in most resource evaluation.

Keywords: Coal exploration; Electrical resistivity tomography; Vertical electrical sounding; NEF EM; Anambra Basin; Nigeria

1. Introduction

Coal remains an important energy resource globally due to its affordability and widespread availability, particularly in developing economies. In Nigeria, coal deposits are primarily located within the Anambra Basin and have been identified as a viable alternative energy source for power generation and industrial use (World Energy Council, 2016). The estimated coal reserves in Nigeria exceed 2.7 billion tonnes, highlighting the need for renewed exploration efforts (Sada, 2012). Despite this considerable resource base, exploration activities in many parts of the basin remain inadequate, and modern geophysical techniques have not been systematically deployed to evaluate subsurface coal occurrences in several localities within the northern Anambra Basin.

Geophysical methods provide a means of investigating subsurface conditions without physical disturbance and are widely used in mineral exploration. Electrical resistivity techniques, including Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT), are effective for mapping lithological variations due to contrasts in electrical properties (Dahlin and Zhou, 2003; Loke et al., 2013). Electromagnetic (EM) methods complement resistivity surveys by detecting conductive anomalies associated with mineralisation and groundwater (Sharma, 2017). Outcropping coal resources on land are becoming increasingly scarce, and geophysical prospecting in coalfields must now focus on deep or concealed exploration targets, which requires the use of deep penetrating geophysical tools such as EM methods (Guo et al., 2020).

Theoretically, coal exploration using EM methods is based on the measurable differences in electrical resistivity between coal seams, associated geological structures (such as goafs, faults, and collapsed columns), and their surrounding rock formations. Resistivity can vary notably across these materials: water filled goafs and fracture zones exhibit low resistivity, while dry goafs and intact coal seams may show relatively higher resistivity (Xue et al., 2019). Consequently, electromagnetic methods play an important role in coal exploration and are widely used for hydrogeological investigations, deep explorations in mined out areas, and the detection of hazardous geological structures that threaten safe and efficient coal production (Guo et al., 2020; Xue et al., 2019). The integration of multiple geophysical methods enhances interpretation accuracy and reduces ambiguity (Olorunfemi and Fasuyi, 2019). This study applies an integrated approach to delineate coal seams within Ofugo, Ankpa, and evaluate their depth, thickness, and economic potential.

1.1 Location of the Study Area

The study area is situated along Ikah Road, Ofugo, in Ankpa Local Government Area, Kogi State, Nigeria. It is geographically bounded by latitudes 7 degrees 34 minutes 32.0 seconds N to 7 degrees 34 minutes 44.0 seconds N and longitudes 7 degrees 40 minutes 11.6 seconds E to 7 degrees 40 minutes 23.4 seconds E as shown in Figure 1. Access to the area is primarily via untarred roads and footpaths. Table 1 presents the spatial relationship of the measurement points.

2. Geological Setting

The study area lies within the Anambra Basin, a sedimentary basin formed following the Santonian tectonic event that affected the Benue Trough (Reijers and Nwajide, 1998; Nwajide, 2013). Sedimentation in the basin commenced with the deposition of the Nkporo Shale, followed by the coal bearing Mamu Formation and the overlying Ajali Sandstone. The Mamu Formation (Lower Coal Measures) consists of alternating sequences of sandstones, shales, mudstones, and coal seams deposited in a paralic environment (Simpson, 1954; De Swardt and Casey, 1963). The formation reflects cyclic depositional processes influenced by marine transgression and regression.

Underlying formations include the Asu River Group, composed of shales, limestones, and sandstones (Petters, 1982), while tectonic activities described by Ojo (1992) contributed to basin development. The presence of coal within both the Mamu and Nsukka formations has been documented (Agunleti and Peter, 2014). The geology of the study area is therefore controlled by sedimentary processes and structural deformation, which influence coal seam distribution and thickness.

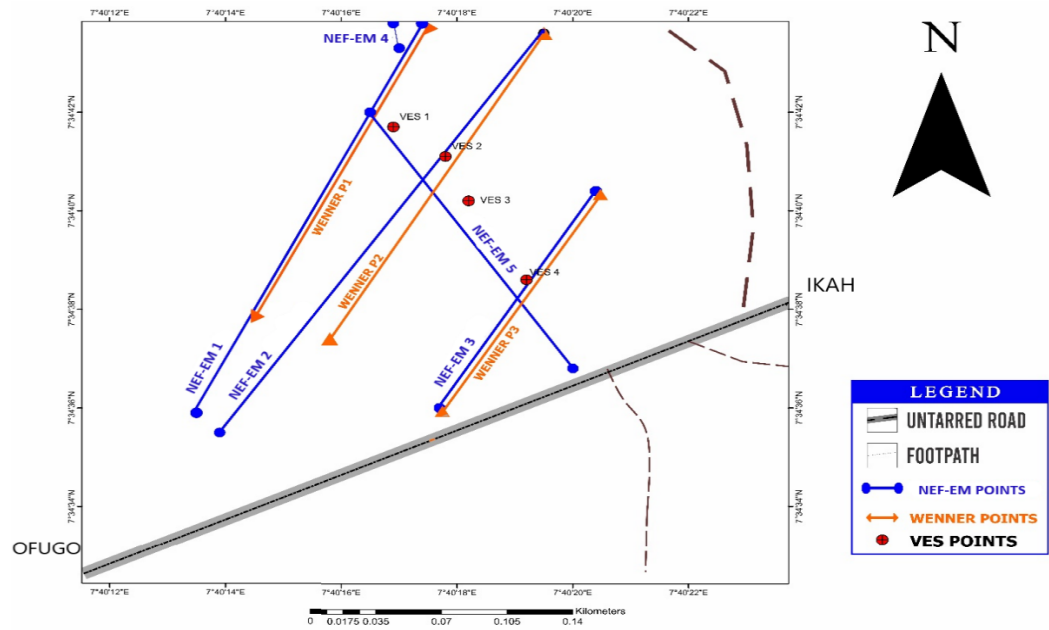


Figure 1: Location map of the study area showing survey profiles and VES stations within Ofugo, Ankpa LGA, Kogi State

Table 1. Measurement Locations (VES, Wenner, NEF EM) Referenced to the Study Area

Method	ID	Coordinates	Relation to 2D Profiles
VES	VES 1	7°34'41.75"N, 7°40'17"E	Between Wenner 1 and 2
VES	VES 2	7°34'41"N, 7°40'17.75"E	Near Wenner 2 start
VES	VES 3	7°34'40.25"N, 7°40'18.25"E	Near Wenner 3
VES	VES 4	7°34'35.50"N, 7°40'19.25"E	Near Wenner 2 end
Wenner	Wenner 1–3	Study area extent	Three parallel profiles
NEF EM	NEF EM 1–3	Coincident with Wenner lines	Coincident surveys

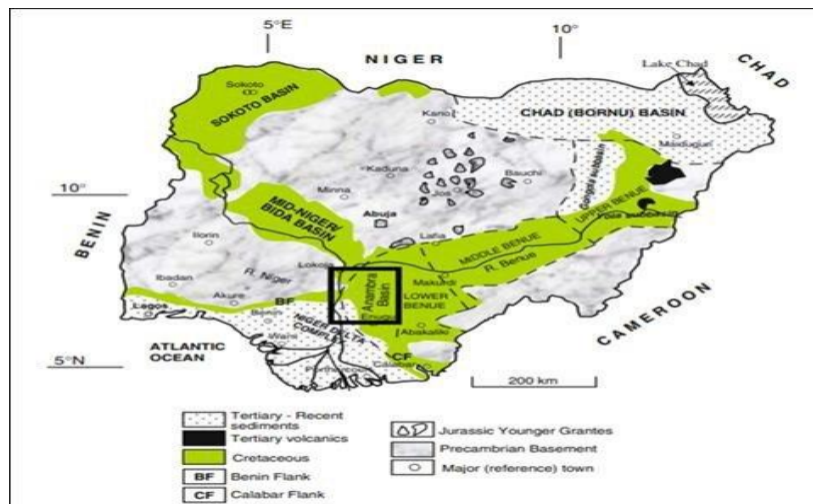


Figure 2: Geological map of Nigeria showing the Anambra Basin in the thick rectangular box (Obaje, 2009)

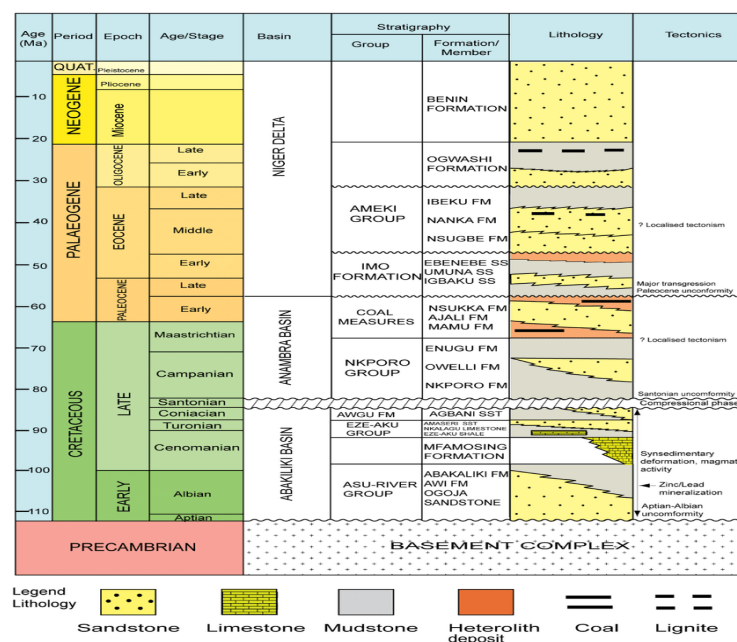


Figure 3: Stratigraphic Succession in the Anambra Basin and Outcropping Niger Delta (Ekwenye and Nichols, 2016)

3. Materials and Methods

3.1 Electrical Resistivity Method

The electrical resistivity survey was conducted using a DDR3 Terrameter. Two techniques were employed: Vertical Electrical Sounding (VES) using the Schlumberger configuration and Electrical Resistivity Tomography (ERT) using the Wenner configuration. The Schlumberger array allows deeper penetration by increasing current electrode spacing while maintaining smaller potential electrode spacing. The apparent resistivity is calculated using:

$$\rho_a = K \times R \dots\dots\dots (1)$$

Where K is the geometric factor and R is the measured resistance. The Wenner array, known for its high signal strength and noise resistance, uses equal electrode spacing and is effective for mapping horizontal layers (Okpoli, 2013; Auduson, 2018). Three profiles were established with lengths between 200 m and 240 m. Electrode spacing was progressively increased to enhance depth penetration and improve resolution of subsurface features.

3.2 Electromagnetic Method (NEF EM)

The ADMT 300sx is a contemporary instrument for subsurface water and mineral detection. This device functions as a frequency selection system powered by the Earth's natural electric field (Hunan, 2018). The ADMT series detects resistivity contrasts among different geological materials using three specific frequencies: 25 Hz, 67 Hz, and 170 Hz. Although its operational principle resembles that of traditional resistivity equipment, it operates more than ten times faster, allowing the identification of subsurface features including water bodies or mineral deposits, as well as their position, depth, geometry, and extent (Ali et al., 2024).

During field surveys with the ADMT 300sx, non polarisable electrodes are employed to passively record the electric (E) and magnetic (B) fields in orthogonal directions at the ground surface. This technique assumes that the geomagnetic field behaves as a plane wave travelling vertically downward from a remote source (Alabi et al., 2020). Subsurface resistivity is determined by computing the ratio between the horizontal electric field component and the magnetic field magnitude, either in the time or frequency domain (Ali et al., 2024). To compute apparent resistivity, the measured electric and magnetic components are inserted into Cagniard's scalar resistivity equation:

$$\rho_m = (1 / 5f) \times (E_x / H_y)^2 \dots\dots\dots (2)$$

In this equation, ρ_m represents the resistivity of the subsurface medium (Ohm m), f is the operating frequency (Hz), H_y denotes the magnetic field component (A/m), and E_x refers to the electric field component (V/m). Although the magnetic component is assumed to remain constant, the electric field component interacts perpendicularly with the ground, permitting a qualitative relationship between the electric field and subsurface resistivity to reveal geological characteristics (Waff, 2000). The penetration depth of plane electromagnetic waves travelling through the subsurface is expressed as:

$$\delta = 503.3 \times \sqrt{\rho / f} \dots\dots\dots (3)$$

Where δ represents the depth of penetration in metres, ρ is the resistivity of the medium (Ohm m), and f is the frequency (Hz). This relationship demonstrates that, at a fixed frequency, the penetration depth varies directly with the square root of the subsurface resistivity. Natural electromagnetic fields utilised by this method derive from two principal geophysical mechanisms. First, the geodynamo process within the Earth's liquid outer core generates the planet's magnetic field. As conductive fluids move across a magnetic field, they induce an electric current, which subsequently produces a secondary magnetic field with an identical frequency but a phase shift (Heilig et al., 2018). Second, natural EM fields also originate from the radioactive disintegration of elements present in rocks, ore deposits, or groundwater (Ali et al., 2024). Measurements were taken at intervals of 1 m and 5 m with electrode separation maintained at 10 m.

3.3 Data Processing and Interpretation

VES data were interpreted using Interpex 1D software, while ERT data were processed using RES2DINV software to generate two dimensional subsurface images. NEF EM data were processed into three dimensional models. Interpretation involved correlating resistivity values with known lithological units. Coal seams were identified based on their characteristic resistivity range and their position within the stratigraphic sequence.

4. Results and Discussion

4.1 Electrical Resistivity Results

The electrical resistivity data obtained from both 2D ERT and VES reveal a complex, multi layered subsurface consistent with sedimentary sequences typical of the Anambra Basin. The interpreted geoelectric sections across the study area indicate the presence of five principal lithological units: lateritic overburden, sandstone, shale, clay, and coal seams. The lateritic topsoil is characterised by relatively high resistivity values due to its compact nature and low moisture content. Beneath this layer, sandstone units exhibit very high resistivity values, in some cases exceeding 16,000 Ohm m, which is consistent with dry, coarse grained formations typical of the Ajali Sandstone (Petters, 1982). The shale and clay layers are marked by low resistivity values, reflecting their fine grained nature and higher water retention capacity.

Coal seams within the study area are consistently identified by moderate resistivity values ranging from 154 Ohm m to 366 Ohm m, which aligns with previously reported values for coal bearing formations in sedimentary basins (Ehinola et al., 2022). These resistivity signatures distinguish coal from surrounding shale (lower resistivity) and sandstone (higher resistivity), making them reliable indicators for interpretation. The comparative resistivity ranges of identified lithological units are presented in Figure 15.

4.1.1 Profile 1 Analysis

The 2D resistivity section along Profile 1 (Figure 4) reveals multiple coal seam occurrences at varying lateral positions. Coal seams are observed between 0 to 30 m, 60 to 100 m, and 200 to 230 m along the profile. The depth to the top of the coal seam varies between 13 m and 25 m, with thickness generally less than 5 m. The resistivity value of approximately 195 Ohm m supports its

identification as coal. The VES interpretation at 70 m along this profile provides further confirmation, indicating a coal layer at a depth of approximately 21 m, with a thickness of about 7.72 m and resistivity of 245.42 Ohm m (Figure 5, Table 2). This relatively higher thickness suggests localised accumulation of organic material, possibly influenced by paleo depositional conditions such as swamp stability and sediment supply.

The variation in depth and thickness along this profile suggests lateral heterogeneity in sediment deposition, which is typical of paralic environments where coal forms under fluctuating marine and continental conditions (Simpson, 1954; De Swardt and Casey, 1963). The resistivity contrast between the coal seam (245.42 Ohm m) and the overlying shale (121.67 Ohm m) and underlying clay (7.69 Ohm m) provides a clear geophysical signature that facilitates reliable identification. Such contrasts are characteristic of the Mamu Formation lithological assemblage and have been widely documented in geophysical investigations across the Anambra Basin (Ehinola et al., 2022; Olorunfemi and Fasuyi, 2019).

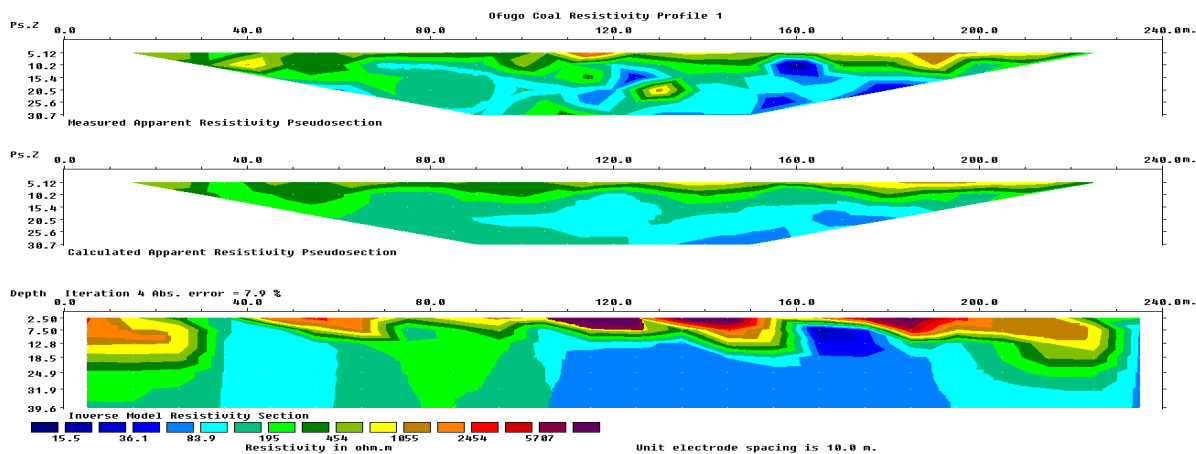


Figure 4: 2D Resistivity Profile 1 Along Ikah Road, Ofugo Coal Exploration Site

Table 2. Geoelectric Section and Inferred Lithology for VES 1

Layer	Resistivity (Ohm m)	Thickness (m)	Depth (m)	Inferred Lithology
1	283.30	0.40	0.40	Laterite overburden
2	26,044.00	0.13	0.53	Sandstone
3	121.67	18.25	18.78	Shale
4	245.42	7.72	26.50	Coal
5	7.69	—	—	Clay

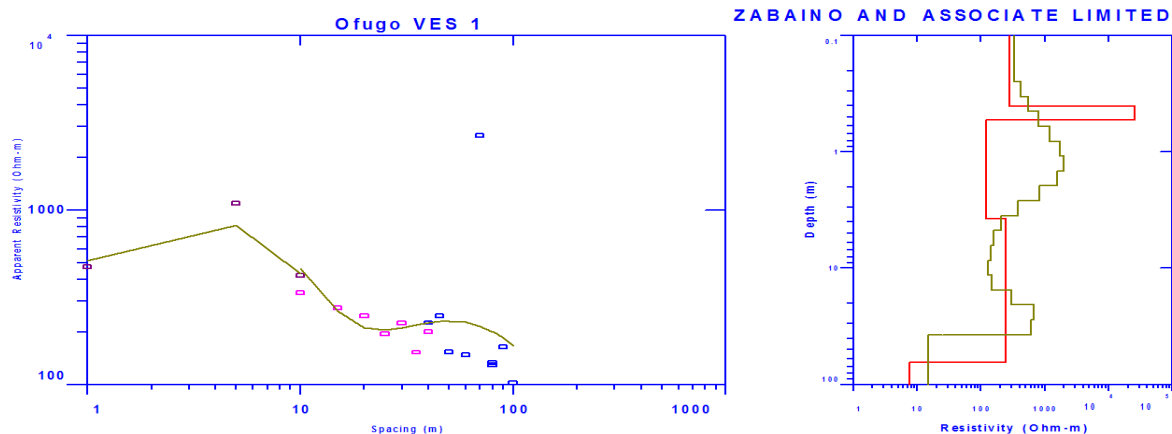


Figure 5: A plot of VES 1 Along Ikah Road, Ofugo Coal Exploration Site

4.1.2 Profile 2 Analysis

Profile 2 shows a more extensive and laterally continuous coal seam compared to Profile 1 (Figure 6). The coal seam extends across a substantial portion of the profile, with resistivity values around 158 Ohm m. Depth variations are observed as follows: 23 m depth (0 to 30 m segment), 25 m depth (40 to 80 m segment), and 28 m depth (150 to 170 m segment). The progressive deepening of the coal seam along this profile is consistent with the regional southeastward dip of sedimentary beds within the Anambra Basin (Reijers and Nwajide, 1998).

Interestingly, the coal seam appears absent between 90 m and 130 m in the 2D resistivity image. However, VES 3 conducted at 110 m reveals the presence of coal at a greater depth of approximately 40 m (Figure 8, Table 4), indicating that the seam continues but lies beyond the depth of penetration of the ERT survey. This discrepancy highlights the importance of integrating VES and ERT methods, as VES provides deeper penetration while ERT offers better lateral resolution (Loke et al., 2013). The coal thickness along this profile ranges from 2 m to 4 m, suggesting a relatively thinner but more laterally extensive seam.

VES 2 further supports the structural interpretation by indicating a coal seam at 37 m depth, confirming a progressive deepening (dip) of the coal layer toward Profile 2 (Figure 7, Table 3). This structural trend is consistent with regional basin geometry (Reijers and Nwajide, 1998). The three layer geoelectric model derived from VES 2 (sandstone overlying clay/shale overlying coal) represents a simplified but diagnostic representation of the Mamu Formation stratigraphy in this locality.

4.1.3 Profile 3 Analysis

Profile 3 (Figure 9) reveals a relatively continuous coal seam extending from the beginning of the profile to approximately 90 m. The seam is located at a depth of about 24 m and exhibits a resistivity value of approximately 225 Ohm m. VES 4 conducted at 70 m along this profile indicates a deeper coal occurrence at about 37 m, suggesting vertical variability in seam position. This may be attributed to structural deformation or differential sediment loading during deposition.

Unlike Profiles 1 and 2, Profile 3 shows a more uniform distribution of coal, which may indicate a more stable depositional environment during the time of formation. The resistivity contrast between coal and surrounding lithologies remains consistent, reinforcing the reliability of the interpretation. The three layer model from VES 4, showing laterite (259.52 Ohm m) overlying sandstone (16,474 Ohm m) overlying coal (366.42 Ohm m), indicates that in this location the coal seam lies at relatively shallow depth directly beneath the sandstone unit, with the intervening shale layer absent or too thin to resolve. This lateral variation in stratigraphy further illustrates the heterogeneous depositional architecture of the Mamu Formation across the study area.

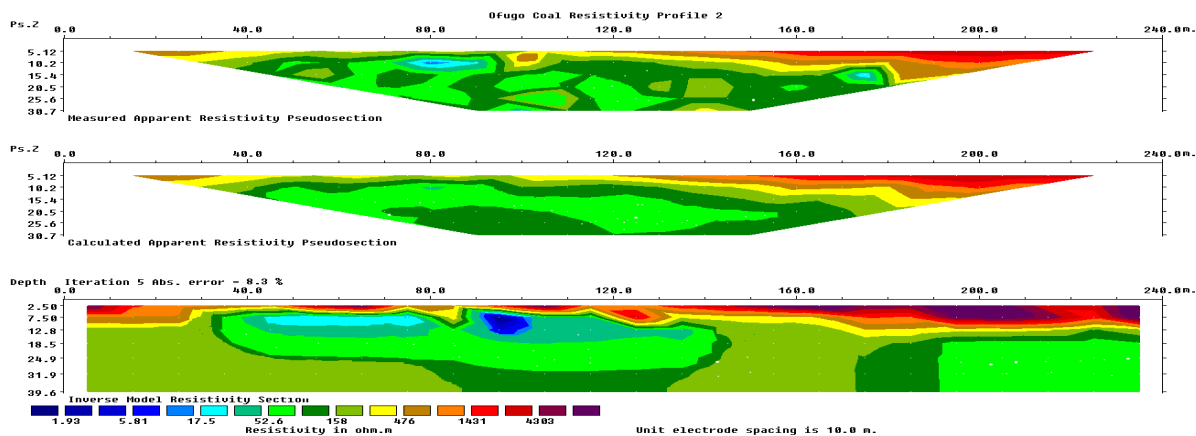


Figure 6: 2D Resistivity Profile 2 Along Ikah Road, Ofugo Coal Exploration Site

Table 3. Geoelectric Section and Inferred Lithology for VES 2

Layer	Resistivity (Ohm m)	Thickness (m)	Depth (m)	Inferred Lithology
1	1047.00	8.82	8.82	Sandstone
2	30.53	29.87	38.69	Clay/Shale
3	153.53	—	—	Coal

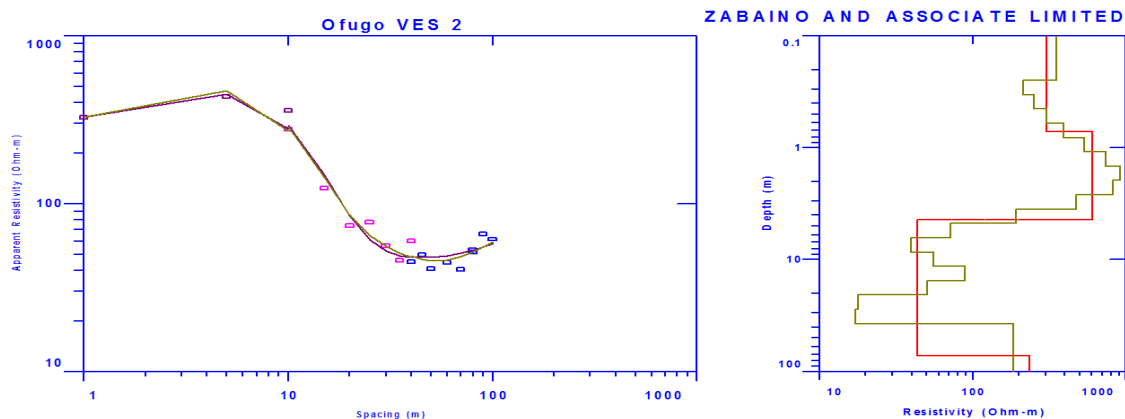


Figure 7: A plot of VES 2 Along Ikah Road, Ofugo Coal Exploration Site

Table 4. Geoelectric Section and Inferred Lithology for VES 3

Layer	Resistivity (Ohm m)	Thickness (m)	Depth (m)	Inferred Lithology
1	301.92	0.72	0.72	Laterite overburden
2	602.19	3.71	4.43	Sandstone
3	43.76	67.95	72.37	Clay/Shale
4	235.22	—	—	Coal

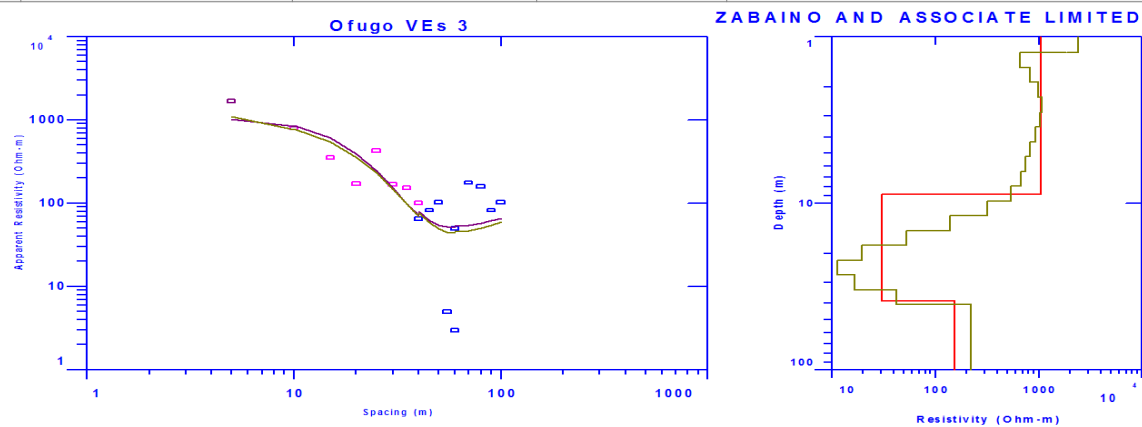


Figure 8: A plot of VES 3 Along Ikah Road, Ofugo Coal Exploration Site

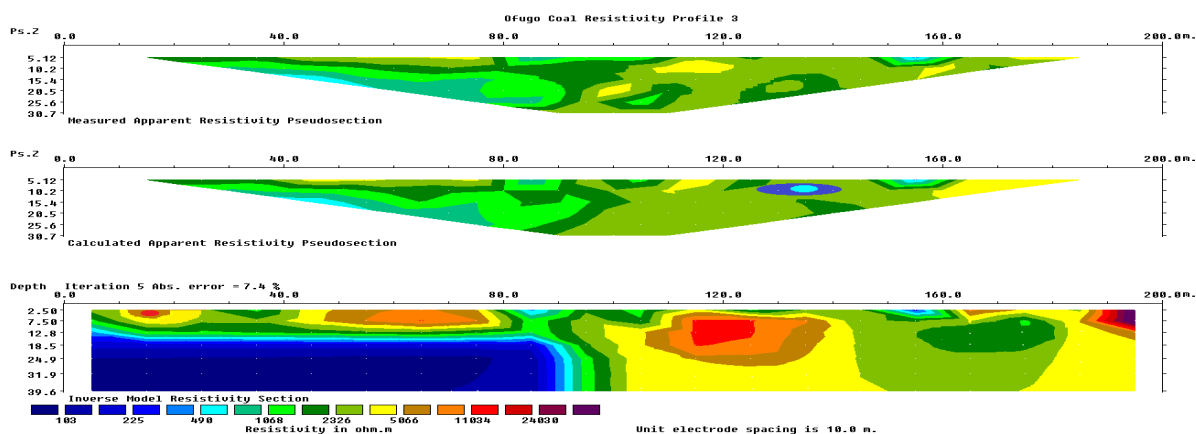


Figure 9: 2D Resistivity Profile 3 Along Ikah Road, Ofugo Coal Exploration Site

Table 5. Geoelectric Section and Inferred Lithology for VES 4

Layer	Resistivity (Ohm m)	Thickness (m)	Depth (m)	Inferred Lithology
1	259.52	0.63	0.63	Laterite overburden
2	16,474.00	2.91	3.55	Sandstone
3	366.42	—	—	Coal

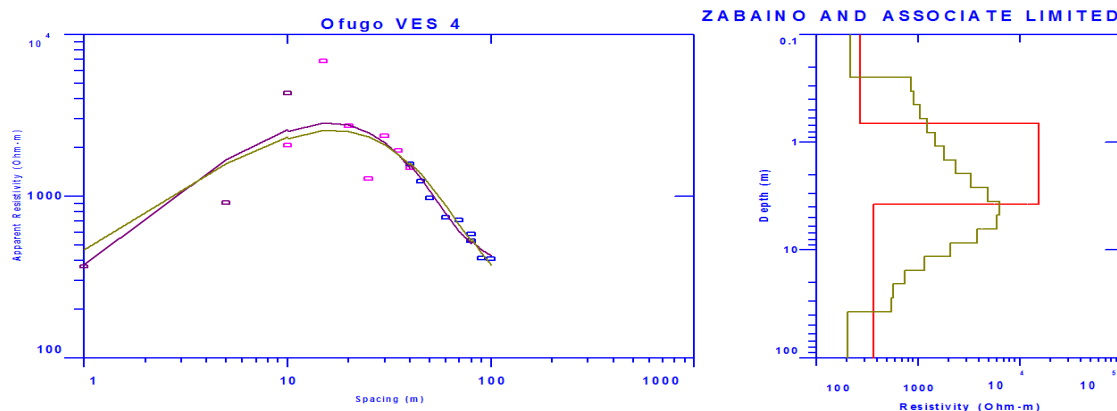


Figure 10: A plot of VES 4 Along Ikah Road, Ofugo Coal Exploration Site

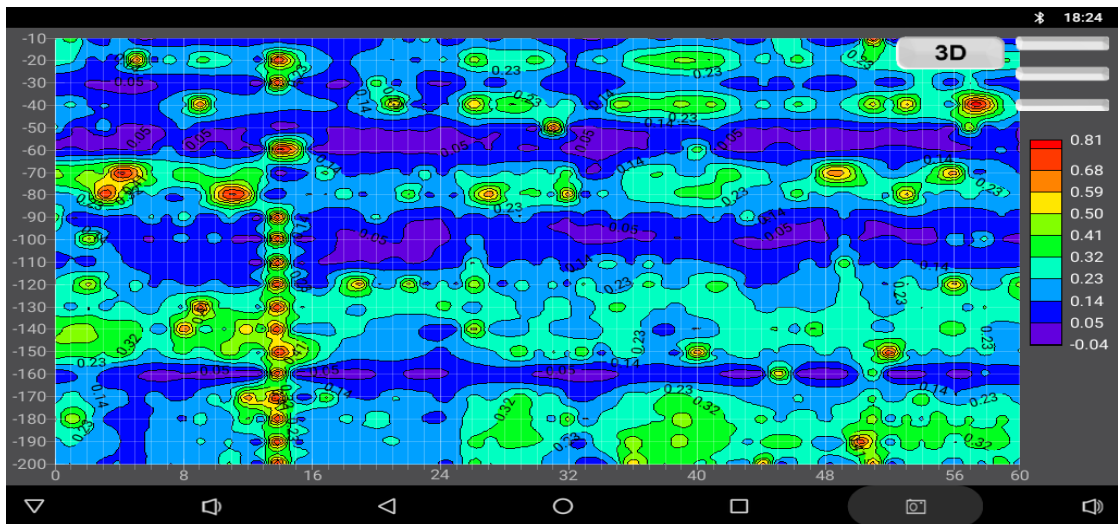


Figure 11: A 3D View of the NEF EM Profile 1 Along Ikah Road, Ofugo Coal Exploration Site

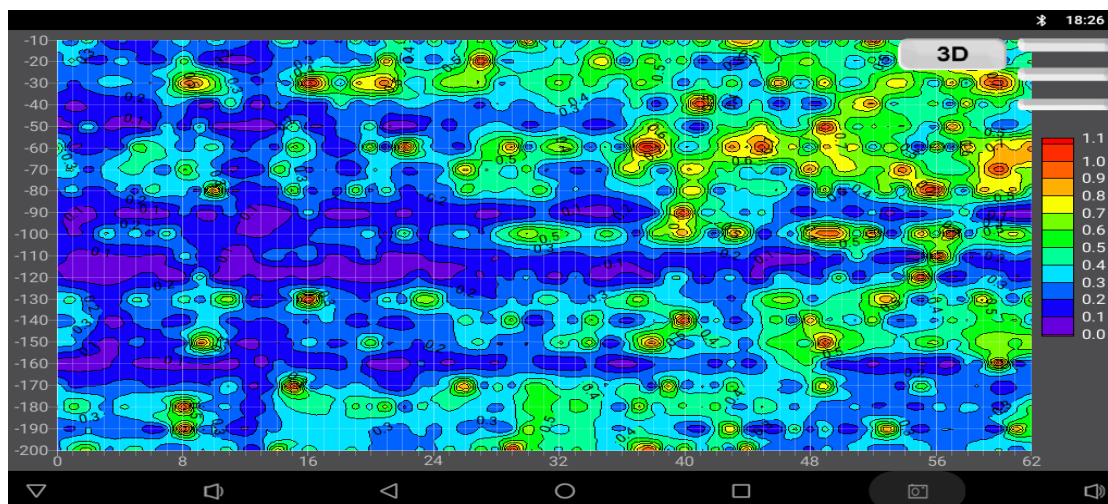


Figure 12: A 3D View of the NEF EM Profile 2 Along Ikah Road, Ofugo Coal Exploration Site

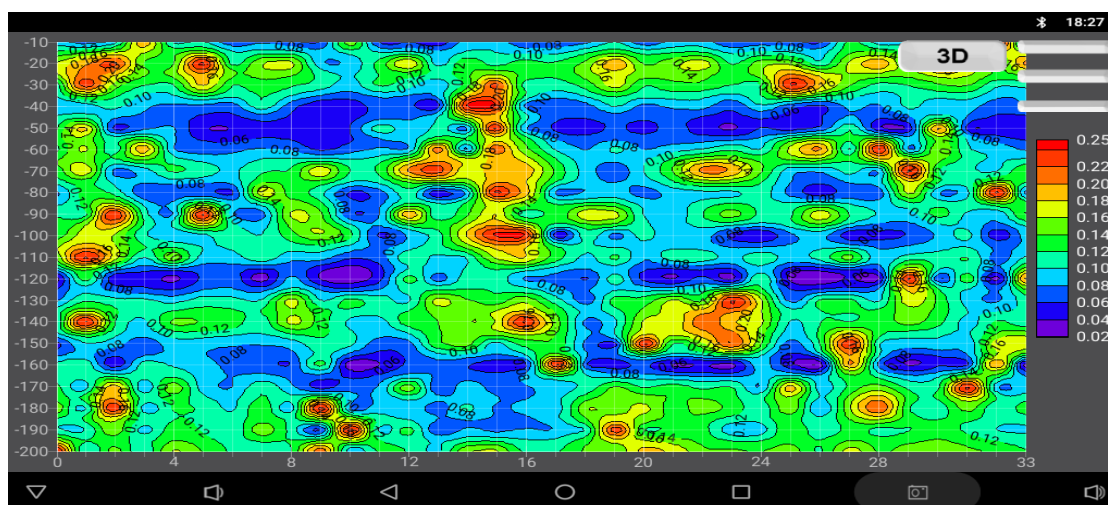


Figure 13: A 3D View of the NEF EM Profile 3 Along Ikah Road, Ofugo Coal Exploration Site

4.2 Electromagnetic (NEF EM) Results

The NEF EM survey results complement the resistivity data by highlighting conductive zones associated with coal seams and possible groundwater presence. The conductive anomalies are characterised by values ranging from 0.06 to 0.2, which are indicative of materials with relatively higher conductivity compared to surrounding formations. The NEF EM response along Profile 1 (Figure 11) shows conductive zones extending from depths of approximately 25 m to 60 m, corresponding closely with coal seam depths identified in the resistivity data. The presence of discrete conductive anomalies at shallower depths and more continuous zones at greater depths suggests vertical connectivity within the coal bearing units.

A notably low value (approximately 0.05) is interpreted as groundwater associated with the coal seam. This is noteworthy because coal seams often act as aquifers or conduits for groundwater flow, particularly when fractured (Sharma, 2017). Profile 2 (Figure 12) exhibits a strong and laterally continuous conductive anomaly extending from 30 m to 50 m depth across much of the profile. This aligns closely with the deeper coal seam identified by VES 3, reinforcing the interpretation of a continuous coal layer at depth. The consistency between NEF EM and resistivity data demonstrates the robustness of the integrated approach. The conductive nature of the anomaly may also indicate partial water saturation, which could influence both resistivity values and mining considerations.

The NEF EM data along Profile 3 (Figure 13) confirms the presence of a conductive layer at depths less than 40 m, consistent with resistivity interpretations. The relatively uniform response suggests a continuous coal seam with minimal structural disruption. Taken together, the NEF EM profiles provide independent corroboration of the coal seam geometry inferred from the resistivity surveys. The ability of the NEF EM method to detect conductive anomalies at depths greater than the effective penetration of the ERT survey underscores its value as a complementary exploration tool, particularly in settings where coal seams may dip below the resolution limits of surface electrical methods.

4.3 Integrated Geophysical Interpretation

The integration of ERT, VES, and NEF EM datasets provides a comprehensive understanding of the subsurface geology (Figure 14). Key observations include consistent identification of coal seams across all methods, depth variation from 13 m to 40 m indicating structural control, thickness variation of 2 to 6 m reflecting depositional heterogeneity, and a southeastward dipping trend supported by VES correlations. The agreement between resistivity and electromagnetic datasets reduces uncertainty and enhances confidence in the interpretation. The results are consistent with regional geological models of coal occurrence within the Mamu Formation (Ehinola et al., 2022).

The resistivity values obtained for coal seams in this study (154 to 366 Ohm m) fall within the range reported for bituminous coal in other parts of the Anambra Basin and comparable sedimentary basins globally. Ehinola et al. (2022) reported similar resistivity signatures for coal deposits in the southern Anambra Basin, while Dahlin and Zhou (2003) documented analogous

values for coal bearing formations in European sedimentary settings. The moderate resistivity of coal in this context reflects its organic composition, porosity, and degree of compaction, which distinguish it from both the overlying clastic sediments and the underlying argillaceous units (Figure 15).

The southeastward dipping trend observed in the coal seam is geologically meaningful and consistent with the structural architecture of the northern Anambra Basin. Reijers and Nwajide (1998) described the basin as an asymmetric syncline with sedimentary beds dipping generally toward the southeast, reflecting the tectonic history of the Benue Trough. The progressive increase in coal seam depth from Profile 1 (13 m) to the deeper occurrences in Profile 2 (40 m at VES 3) corroborates this structural pattern and suggests that deeper coal resources may be accessible further to the southeast (Figure 16).

4.4 Economic and Geological Implications

From an economic perspective, the identified coal seams exhibit characteristics favourable for exploitation: moderate depth (accessible for mining), adequate thickness (2 to 6 m), and lateral continuity across profiles. The shallow depth of the coal seams, particularly in Profile 1 where the top of the seam occurs at 13 m, makes them suitable candidates for open cast mining or shallow underground extraction. The thickness of the seams, ranging from 2 m to 6 m with a maximum of 7.72 m at VES 1, exceeds the minimum economic threshold for coal extraction in most mining operations (World Energy Council, 2016).

However, the presence of groundwater indicated by NEF EM data may pose challenges for mining operations and should be investigated further. The association between coal seams and groundwater, as indicated by the low NEF EM values (approximately 0.05) observed in Profile 1, warrants careful hydrogeological assessment prior to any mining activity. Water inflow during mining can increase operational costs, compromise worker safety, and necessitate dewatering infrastructure. Sharma (2017) noted that coal seams frequently serve as aquifer systems, particularly when fractured or when they interface with permeable sandstone units, as is the case in the study area.

Geologically, the variability in seam depth and thickness reflects the dynamic depositional environment of the Anambra Basin, influenced by fluctuating sea levels and sediment supply during the Maastrichtian period. The cyclic deposition of coal within the Mamu Formation, interbedded with shale and sandstone, is characteristic of paralic environments where peat accumulation occurred in coastal swamps subject to periodic marine inundation (Simpson, 1954; De Swardt and Casey, 1963). The lateral variation in coal thickness observed across the three profiles likely reflects local differences in accommodation space, organic matter supply, and compaction history.

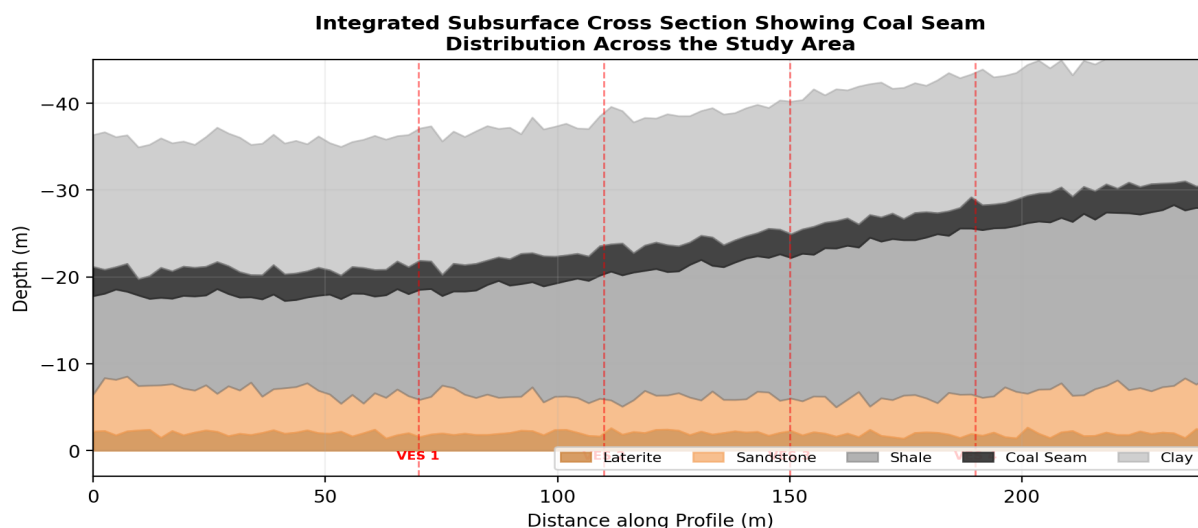


Figure 14: Integrated Subsurface Cross Section Showing Coal Seam Distribution Across the Study Area with VES Correlation Points

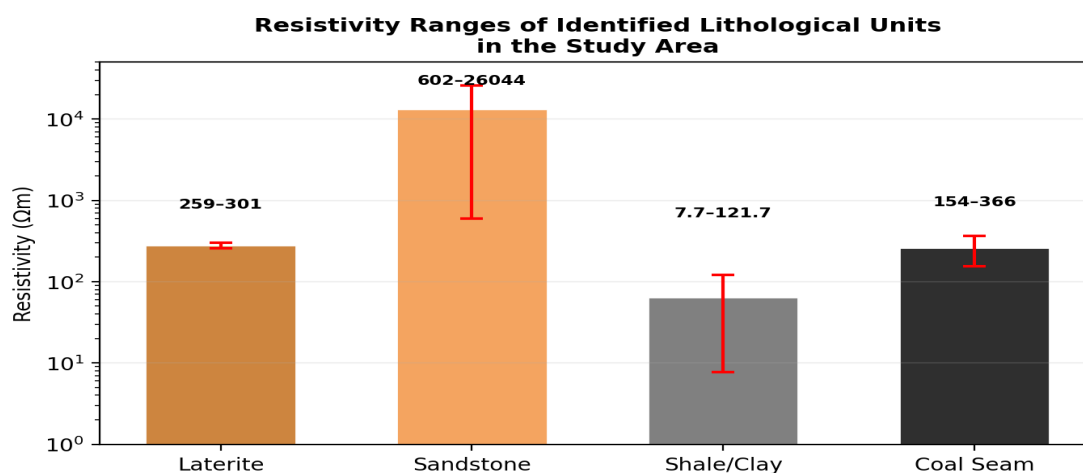


Figure 15: Resistivity Ranges of Identified Lithological Units in the Study Area (Error bars indicate minimum and maximum observed values)

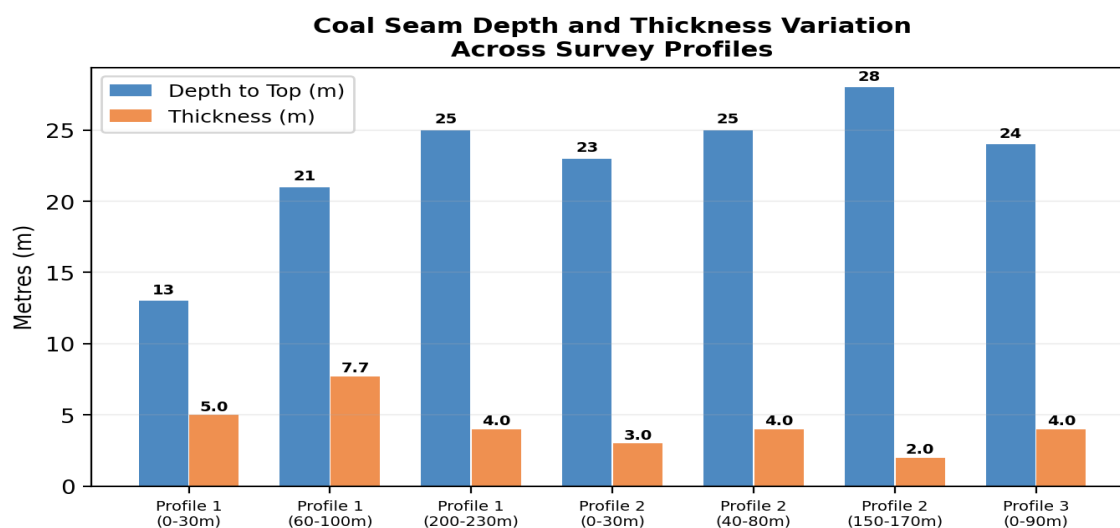


Figure 16: Coal Seam Depth and Thickness Variation Across Survey Profiles

Table 6. Summary of Coal Seam Parameters Across All Survey Methods

Profile / VES	Method	Depth to Top (m)	Thickness (m)	Resistivity (Ohm m)	NEF EM Response
Profile 1 (0–30 m)	ERT	13	< 5	195	0.06–0.15
Profile 1 (60–100 m)	ERT	21	< 5	195	0.08–0.18
VES 1 (70 m)	VES	18.78	7.72	245.42	Confirmed
Profile 2 (0–30 m)	ERT	23	2–4	158	0.10–0.20
Profile 2 (40–80 m)	ERT	25	2–4	158	0.08–0.18
VES 2	VES	38.69	—	153.53	Confirmed
VES 3	VES	72.37	—	235.22	Confirmed
Profile 3 (0–90 m)	ERT	24	3–5	225	0.06–0.15
VES 4	VES	3.55	—	366.42	Confirmed

Source: Authors' field data, 2025

5. Conclusion

This study applied integrated Electrical Resistivity Tomography (ERT), Vertical Electrical Sounding (VES), and Natural Electromagnetic Field (NEF EM) methods to delineate coal seams within Ofugo, Ankpa, Kogi State. The results reveal a stratified subsurface comprising laterite, sandstone, shale/clay, and coal bearing units. Coal seams were consistently identified by moderate resistivity values (154 to 366 Ohm m) and corresponding conductive EM responses (0.06 to 0.2). The seams occur at depths ranging from 13 m to 40 m, with thickness between 2 m and 6 m. Lateral continuity across profiles and a general southeastward dip were observed, indicating structural control on seam distribution.

The integration of geophysical methods improved interpretation reliability and confirmed the presence of economically viable coal deposits within the Mamu Formation. The complementary strengths of ERT (lateral resolution), VES (depth penetration), and NEF EM (conductive anomaly detection) demonstrate the value of multi method approaches in coal exploration. However, further drilling and laboratory analyses are required to validate these findings and assess coal quality, including proximate and ultimate analyses to determine calorific value, ash content, and volatile matter composition.

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