

# INTEGRATING DIGITAL TRANSFORMATION IN GEOSPATIAL COMPUTATIONAL IDENTIFICATION OF Pb-Zn MINERALIZATION ZONES IN ABAKALIKI URBAN USING AEROMAGNETIC AND ELECTRICAL RESISTIVITY TOMOGRAPHY DATA

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## Abstract

An integrated geophysical investigation employing aeromagnetic data, Electrical Resistivity Tomography (ERT), and Induced Polarization (IP) methods was conducted in Abakaliki and its environs to delineate zones of Pb-Zn mineralization. The study area, located within latitudes 6°04'11"N – 6°02'01"N and longitudes 8°04'11"E – 8°01'21"E, spans approximately 16 km<sup>2</sup> in the Lower Benue Trough. High-resolution aeromagnetic data were acquired across the region, while ERT and IP surveys were carried out along coincident profiles at selected sites to allow for integrated interpretation and mutual validation.

To enhance spatial analysis and improve interpretation accuracy, Geographic Information Systems (GIS) and remote sensing tools were utilized for georeferencing, structural lineament mapping, and spatial data integration. The aeromagnetic survey provided regional insights into magnetic anomalies and structural discontinuities, while the ERT and IP techniques offered detailed subsurface resistivity and chargeability distributions. ERT profiles were aligned with IP survey lines using GPS and mobile data collection platforms, ensuring data consistency and real-time field updates.

Visual inspection and 2D/3D visualization of the Total Magnetic Intensity (TMI) map—processed with geophysical modeling software—revealed magnetic intensity values ranging from 21.1 nT to 95.3 nT, indicative of varying lithologies and potential mineralized zones. Lineament analysis using automated edge-detection and image enhancement algorithms further revealed a network of faults, fractures, and veins likely to host mineralization.

Resistivity values within the zones of interest ranged from 4.00 Ωm to 2710 Ωm, while chargeability values varied between 39.3 mV/V and 472 mV/V, reflecting significant lithological contrasts and ore-bearing structures at depths between 100 m and 120 m. The integration of magnetic and geo-electrical data—supplemented with IT-based tools such as GIS platforms, machine learning-assisted anomaly detection, and cloud-enabled data management—proved effective in delineating Pb-Zn mineralization zones, offering valuable insights for future mineral exploration activities in the area.

**Keywords:** Digital geoscience, Digital tools, Digital transformation.

## INTRODUCTION

The Abakaliki district of southeastern Nigeria, situated within the Lower Benue Trough, represents one of West Africa's most prospective intracratonic rift basins for base-metal mineralization. Over the past several decades, stratiform and vein-hosted Pb-Zn

occurrences have been documented along major structural trends in this region, yet the precise subsurface controls and extent of mineralization remain poorly constrained. A combination of complex tectonics—characterized by multiple phases of rifting and transcurrent faulting—and varying lithofacies makes traditional mapping and trenching insufficient for detailed targeting.

Aeromagnetic surveying has long been recognized as an efficient tool for delineating lithological contacts and shallow structural features that may localize mineralization. High-resolution total magnetic intensity (TMI) mapping, in particular, can identify subtle gradients associated with mafic intrusives or fault-bounded blocks that serve as fluid conduits. When complemented by ground-based electrical methods—specifically Electrical Resistivity Tomography (ERT) and Induced Polarization (IP)—it becomes possible not only to map geometry, but also to infer physical properties (e.g., resistivity contrasts and chargeability anomalies) that are diagnostic of sulphide-rich horizons.

Advancements in Information Technology (IT) have further enhanced the efficiency and accuracy of these geophysical methods. Geographic Information Systems (GIS) now enable seamless integration of aeromagnetic, resistivity, and chargeability datasets into a unified spatial framework, supporting better-informed interpretations and geostatistical analyses. Remote sensing, digital elevation models (DEMs), and satellite imagery are employed to identify surface features and lineaments that correspond with subsurface structures. Mobile GIS and GPS-enabled data collection applications allow for real-time georeferencing and field data acquisition, improving logistical coordination and data fidelity.

Moreover, 2D and 3D visualization tools such as Leapfrog Geo and Oasis Montaj facilitate the modeling of geophysical anomalies in relation to geological structures, enhancing the interpretation of buried ore bodies. The application of data fusion techniques and machine learning algorithms (e.g., clustering, support vector machines, and neural networks) also supports more objective anomaly classification, anomaly prioritization, and predictive mineral targeting.

Previous applications of integrated aeromagnetic and geo-electrical surveys in similar shield and rift environments (e.g., the Irish Carboniferous basins; the Otago region of New Zealand) have demonstrated improved targeting of blind polymetallic deposits. However, to date, there is limited published work applying this multi-method, IT-enhanced approach in the Lower Benue context, and even fewer studies that quantitatively integrate all three datasets. This represents a critical gap for both academic understanding and for guiding exploration efforts in a terrain where outcrop is often masked by lateritic cover.

In this study, we (1) acquire and interpret high-resolution aeromagnetic data to identify shallow magnetic lineaments and lithological transitions; (2) perform coincident ERT and IP surveys to characterize subsurface resistivity and chargeability signatures; and (3) integrate these datasets within a geospatial IT framework to delineate and prioritize prospective Pb–Zn mineralization targets. By demonstrating the synergistic value of combining regional-scale magnetic imaging with detailed geo-electrical profiling and IT-based spatial analysis, we aim to refine the structural and stratigraphic model of the Abakaliki area and provide a robust template for future mineral exploration throughout the Lower Benue Trough.

### **Geologic and Tectonic Summary of the Study Area (Lower Benue Trough)**

The **Benue Trough** is a NE-SW trending, failed intracratonic rift basin located in the Central African Mobile Belt, between the West African and Congo cratons. It is part of the **West and Central African Rift System (WCARS)** a network of Mesozoic passive basins formed through extensional tectonics related to the opening of the South Atlantic.

Several models explain its formation, including:

- **Rift/graben models** (King, 1950; Cratchley and Jones, 1965)
  - **Mantle plume/crustal thinning** models (Olade, 1975; Fairhead and Okereke, 1986)
  - **Wrench faulting** as a dominant mechanism (Benkhelil, 1982, 1986)
- Geographically, the trough is divided into:

- **Lower Benue Trough**
- **Middle Benue Trough**
- **Upper Benue Trough**

In the **Lower Benue Trough**, basin development involved at least **two tectonic phases**:

1. **First phase** (Aptian–Santonian): Initial rifting, sedimentation, and minor folding (Cenomanian), followed by major deformation and igneous intrusions during the Santonian.
2. **Second phase** (Santonian–Maastrichtian): Formation of the **Anambra Basin** and **Afikpo Syncline** through faulting and warping.

Sedimentation occurred in **three cycles**, mainly controlled by marine transgressions/regressions and tectonic activity:

#### **1. Asu River Group (Aptian–Cenomanian)**

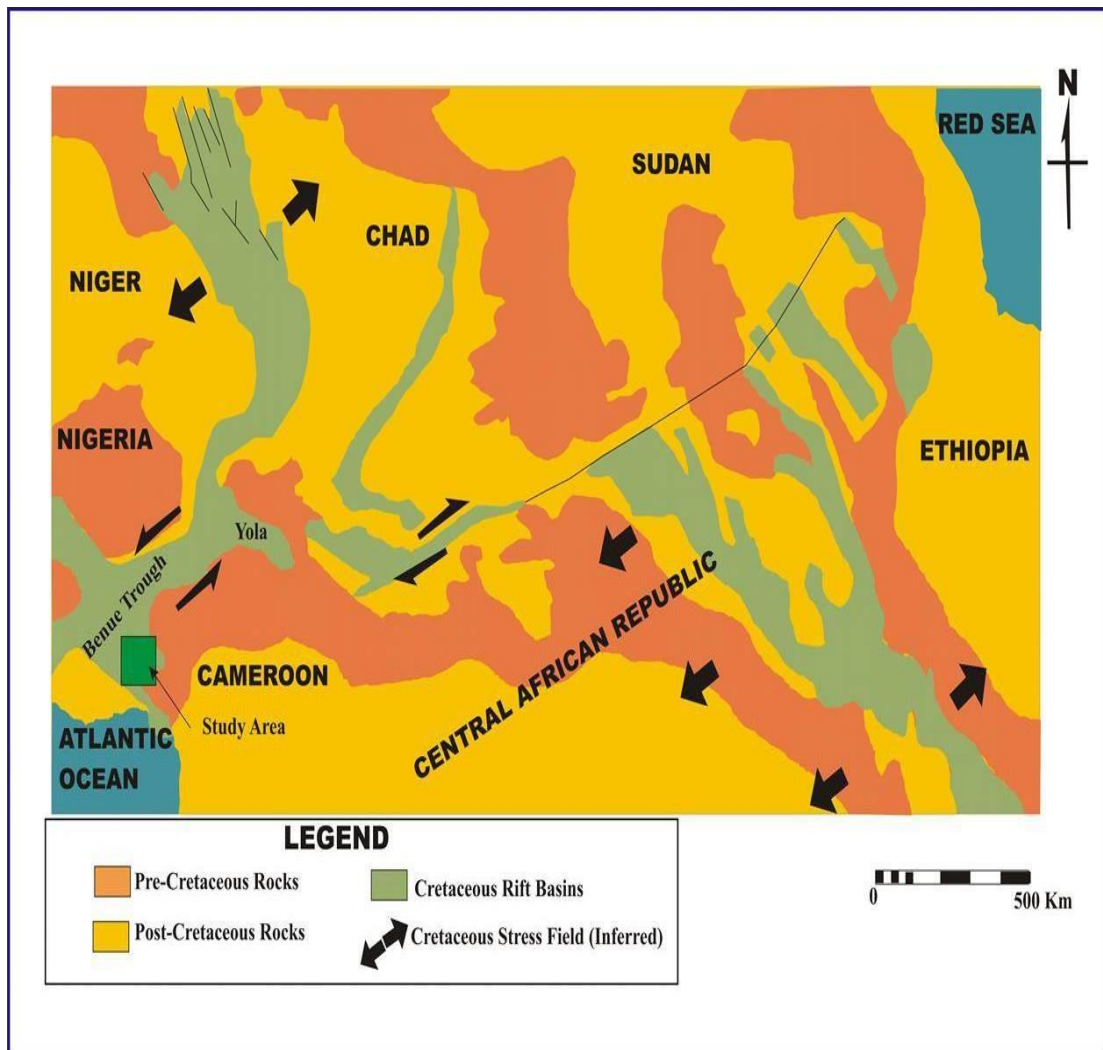
- First sedimentary phase

• ~1500–3000 m thick sequence of arkosic sandstones, marine shales, siltstones, limestones

- Represents initial rift fill
- Intruded by Santonian magmatism
- Subdivided into **Mamfe/Awi**, **Abakaliki**, and **Awe Formations**

## 2. Eze-Aku Group (Cenomanian–Turonian)

- Marine fossiliferous calcareous sandstones, shales, and limestones
- Intruded by igneous rocks
- Marks extensive marine transgression due to Atlantic–Tethys connection Only the **Asu River** and **Eze-Aku Groups** are present in the specific study area.



**Fig. 1** Map of the West and Central African Rift System (WCARS) showing the location of the study area

TIME (Ma)	TECTONICS	AGE	FORMATION
33.9	POST INVERSION THERMAL SAG	Eocene	Ameki
55.8		Paleocene	Imo
61.7		Late Maastrichtian - Danian	Nsukka
65.5		Middle Maastrichtian	Ajali
67.5		Late Campanian - Early Maastrichtian	Mamu
77.1		Early Campanian	Nkporo
83.5		INVERSION	Santonian
85.8	Coniacian		Awgu
89.3	Late RIFT	Turonian	Eze-Aku
93.5	Early POST RIFT	Cenomanian	Odukpani
99.6	Late SYN-RIFT	Albian	Awe
112		Abakaliki	
125		Early Aptian	Aw

**Fig. 2** Stratigraphic succession of lower Benue Trough and Anambra Basin in south-eastern Nigeria (Modified after Nwajide, 1990)

### METHODOLOGY

The field data for this research was acquired from ten measurement profiles, 300m each through the survey area. The well pegged geophysical grid in Figure 3 was established from an east-west trending baseline 300m long at a bearing of 90°, while the profiles, parallel to each other and to the baseline with 100m spacing were approximately perpendicular to the transmitter and to the strike direction. The field data was then acquired by systematically traversing along these profiles at a 10m interval with an ABEM Wadi VLF receiver, Model-9133001869, operating on the VLF principle of recording tipper responses at every measurement station using radio waves from transmitters at remote distance. The ABEM Wadi receiver requires no physical contact with the transmitter and the ground during VLF survey as it operates on induction mechanism.

The optimal configuration of VLF survey as in Figure 4 is to have the geologic strike oriented parallel to the transmitter direction so that a vertical magnetic component is generated for any Conductivity contrast by the propagating horizontal and concentric magnetic and orthogonal electrical fields due to induction. Thus, the DMB transmitter located in Germany that is oriented to the north from the site and of 26.9 kHz VLF frequency was chosen for this survey in consideration to the two prevailing fracture sets in the Abakaliki Basin trending northwest and northeast respectively, with subordinates trending north directly. The survey area entirely covering Amata Village is in the vicinity of already existing mines in Ihietutu. The VLF-EM prospecting is fundamentally based on the primary EM wave impedance over 2-D structures and this wave impedance depends upon the orientation of the EM field components with respect to the geologic strike of the 2-D geologic structures.

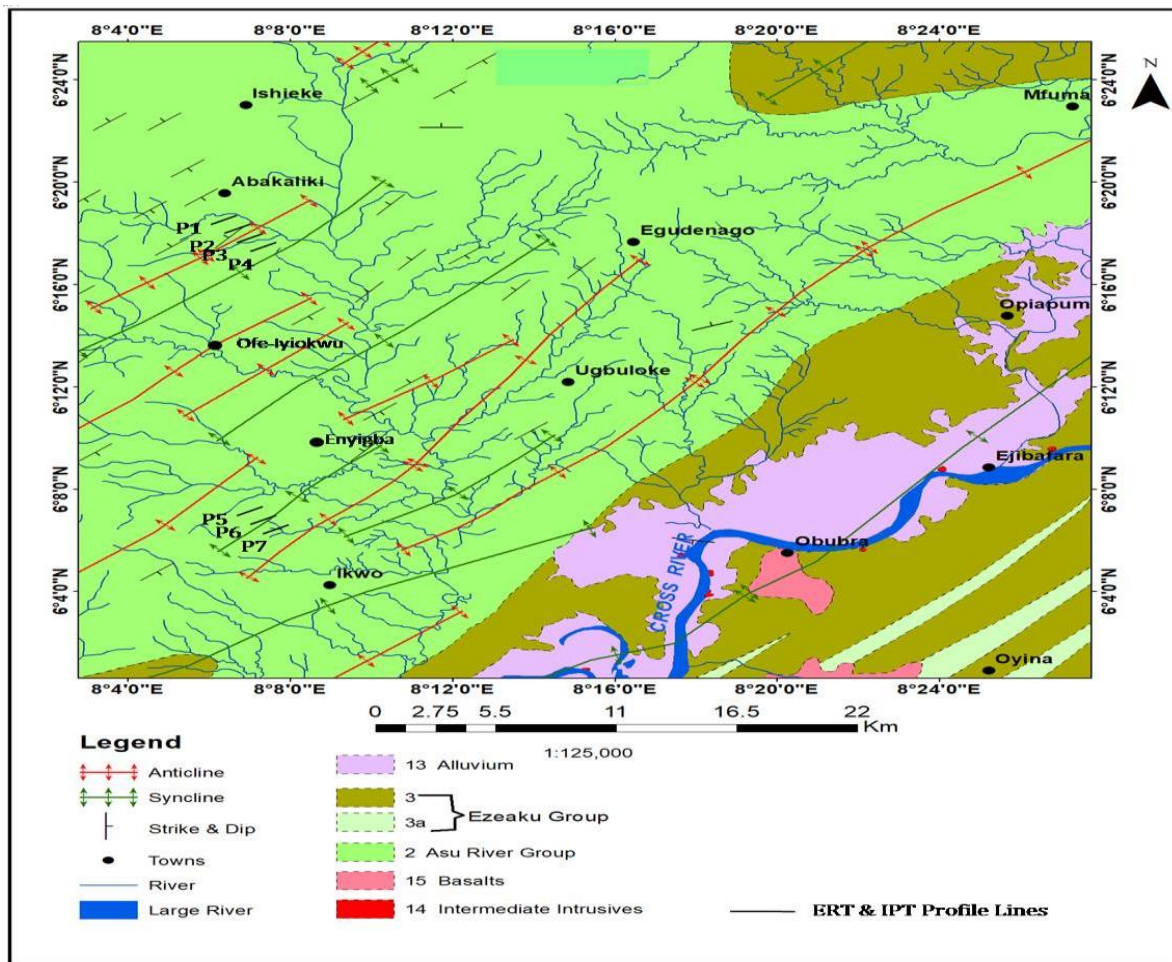


Fig. 3 Geological map of the study area showing the two major groups of sediments (drawn from Arc GIS)

## RESULTS AND DISCUSSIONS

### Aeromagnetic Data

Visual inspection of the Total Magnetic Intensity (TMI) map reveals color variations throughout the study area that represents aeromagnetic intensity values that range from 21.1 nT to 95.3 nT (Fig. 4). These variations in intensity values are a reflection of the rock type. The TMI map displays three dominant magnetic ranges of high, intermediate and low occurring within the study area. High magnetic intensity with values ranging from 63 nT to 95.3 nT are observed mainly at the southern and northern parts of the TMI map and is underlain by Cretaceous sedimentary rocks (Asu River Group and Eze-Aku Group). Magnetic highs are also noticeable at the western portion of the map around Ofe-Iyiokwu and separates two zones of magnetic lows to the north and south, respectively (Fig. 4). Since barren sedimentary rocks are effectively non-magnetic, the high magnetic response observed in these areas is attributed to the presence of mineral-bearing structural lineaments occasioned by the tectonic deformational events that affected the study area in Cenomanian and Santonian times. In addition to the presence of lineament structures, the high positive magnetic intensity values observed at the southeastern part of the map around Obubra is due to the presence of intermediate and basic igneous intrusive as shown on the geological map. The intrusive structures are mainly basaltic in composition and occur as batholiths, sills or dykes. These magnetic anomaly contours are characterized by highly positive, long wavelength signatures that trend slightly in a NE-SW direction parallel to the orientation of the Benue Trough (Fig. 4). On the other hand, low and intermediate magnetic anomalies with intensity values ranging from 21.1 nT to 61 nT are dominant at the central portion of the map. These anomalies appear to assume an E-W and NE-SW orientation and represent magnetic response from barren sedimentary rocks (Fig. 4).

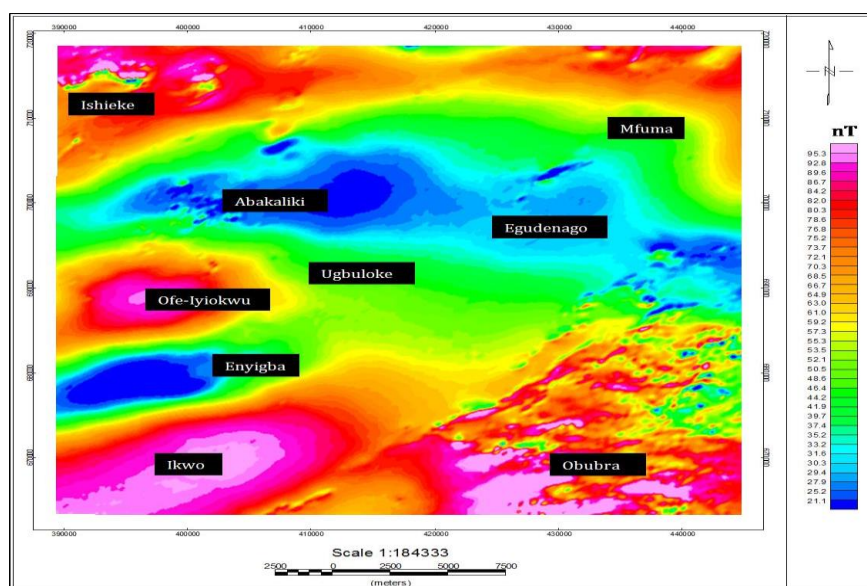
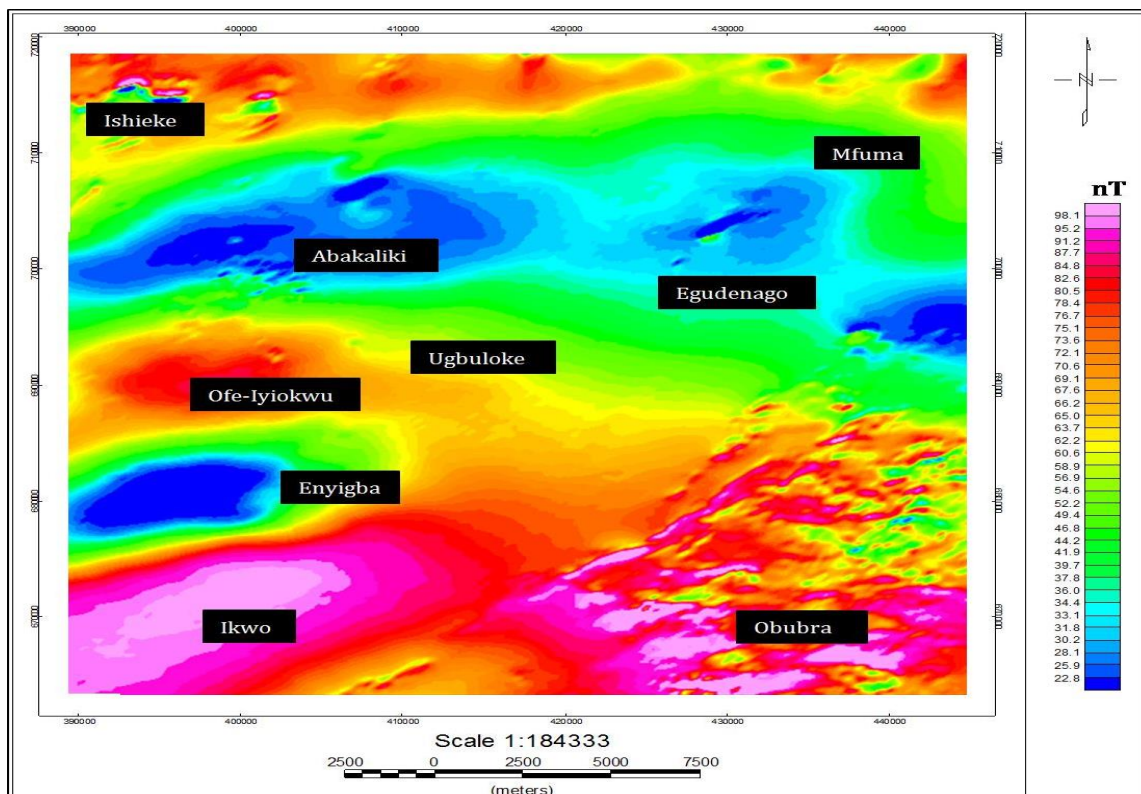


Fig. 4 Total magnetic intensity (TMI) contour map of the study area

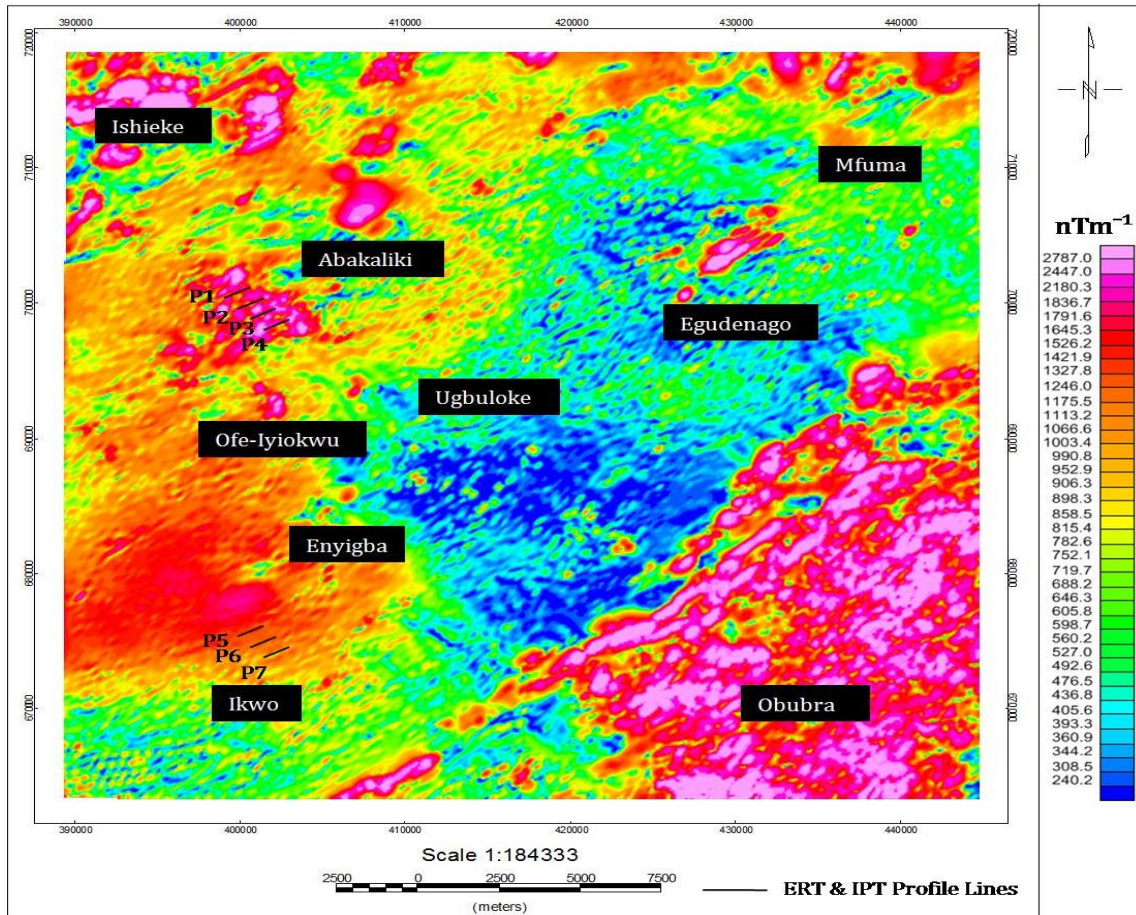
The reduction-to-equator of the TMI image did not show any significant shift in the position of the anomalies. This could be due to the geographical position of the study area as a mid to low latitude zone. In this map, the low and high magnetic anomaly contours are characterized by a NE-SW and E-W orientation, which coincides with the basinal trend (Fig. 5). Also, the high magnetic anomaly contour observed around Ofe-Iyiokwu moved horizontally eastbound and is characterized by positive, long wavelength magnetic signatures.



**Fig. 5** RTE-TMI inverted image of the study area

High values of analytical amplitudes are observed at the southeastern, northwestern and western sections of the AS image around Obubra, Ishieke, Enyigba, Abakaliki and Ofe-Iyiokwu, and occupy about 75% of the map area (Fig. 6). Patches of low and intermediate analytical amplitudes are observed within the areas of large amplitudes particularly in Abakaliki and Ishieke. Areas with such high analytical amplitudes correspond with zones of significant metallic mineral deposits. Small scale mining activities are presently ongoing in parts of Enyigba, Abakaliki, and Ishieke. In Obubra and Opiapum, economic and sub-economic quantities of industrial minerals have also been reported and exploited. It is therefore plausible to conclude that the high analytical amplitudes picked-up in these locations are as a result of the presence of mineral ore bodies and intrusive structures within the underlying geological formation.

These minerals include deposits of galena, sphalerite and barite occurring in fractures and vein structures that are mostly enclosed by wet shaly formations.

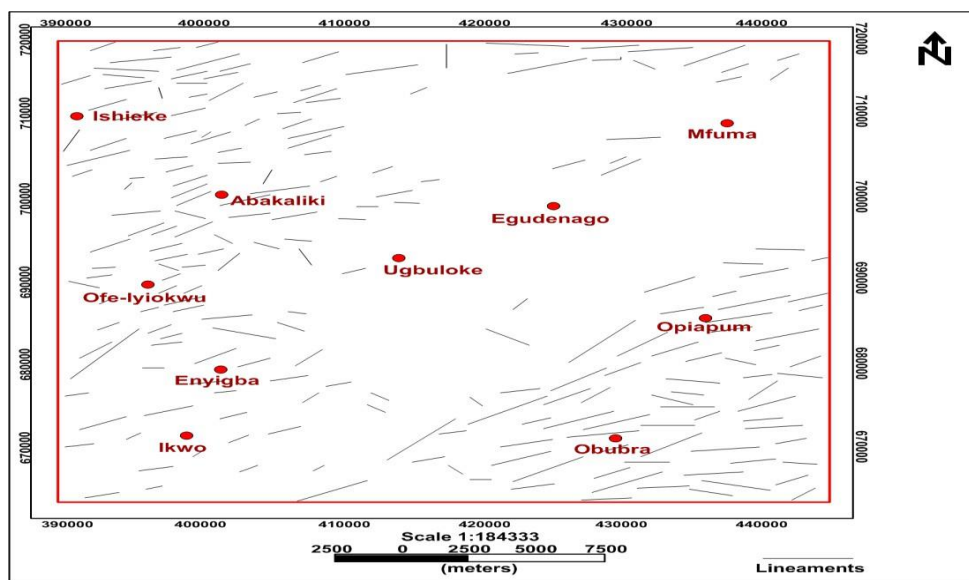


**Fig. 6** Analytical signal (AS) map of the study area

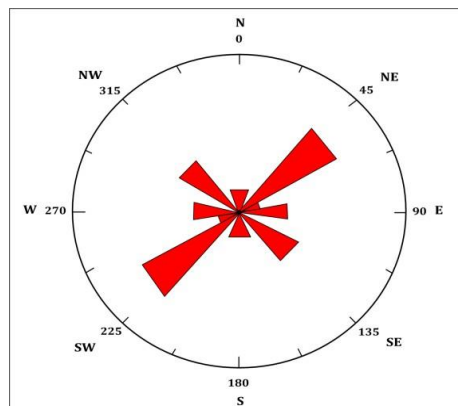
The lineament map shows that the area is dissected by numerous (possible) mineral bearing structural lineaments and magnetic discontinuities (Fig. 7), which may occur in the form of faults, fractures or veins. The size and extent of the structural lineaments varies across different locations and appears to be densely distributed in the northwestern part of the map around Ishieke and Abakaliki, the western/southwestern part of the map around Ofe-Iyiokwu and Enyigba and the southeastern portion of the map area around Obubra and Opiapum (Fig. 7). These areas are associated with high positive magnetic signatures and analytical amplitudes. This suggests a relationship between the locations of structural lineaments and metalliferous ore deposits. Lineaments sparsely occur at the central and northwestern sections of the map around Ugbuloke, Egudenago and mfuma. These areas are characterized by low magnetic anomaly values.

The lineament map depicts NE-SW as the principal trend direction of sub-surface lineaments with minor E-W, ENE-SWS, N-S and NW-SE trends (Fig. 8). The NE-SW and ENE-SWS lineations are interpreted as the landward extensions of the Charcot and Chain pre-

oceanic fractures that were formed during the Pan- African Orogeny (<800 million years) whereas the minor NW-SE lineaments are associated with the pre- Pan African Orogeny (>800 million years). The NE-SW lineations are parallel to the Benue Trough and Cameroon Volcanic Line (CVL) and could be genetically related in origin. It is possible that they were formed by the same geodynamic force that led to the break-up of the African and South-American continents in Early Cretaceous period. Generally, field observations indicate that the NW-SE and sometimes the N-S lineaments are the mineralized trends (Oha et al., 2016). Therefore, to properly locate vein structures and hence, delineate ore bodies within them, geophysical exploration lines must be drawn in a NE-SW or E-W direction, orthogonal to the predominant mineralized linear direction (NW-SE and N- S).

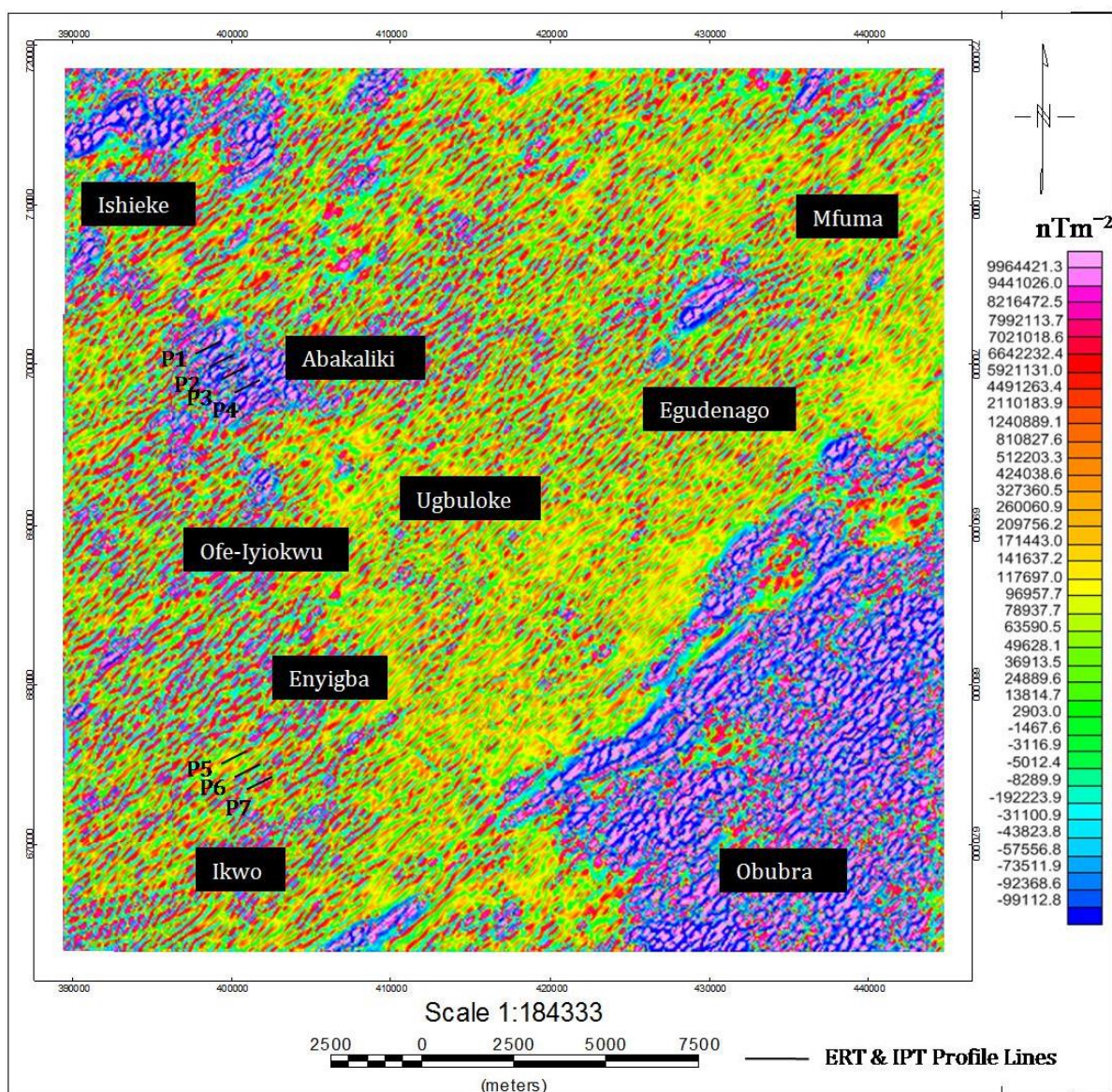


**Fig. 7** Map of the study area showing the distribution and extent of sub-surface structural lineaments



**Fig. 8** Rose diagram showing major and minor lineament trends

In the Second Vertical Derivative (SVD) image, we observe that the red, pink, blue and green colors have been well exposed and differentiated unlike in the RTE-TMI and TMI images (Fig. 9). The boundary between these colors represents different magnetic sources that occur at diverse depths. The map shows the possible occurrence of shallow magnetic bodies at its northwestern, western and partly its southwestern parts. The southeastern axis around Obubra and Opiapum also shows signatures that supports the occurrence of shallow magnetic structures. The shallow sources are igneous intrusive and vein hosted mineral deposits.



**Fig. 8** SVD image of the study area showing areas of possible occurrence of shallow bodies

## **GROUND GEOPHYSICAL DATA INTERPRETATION**

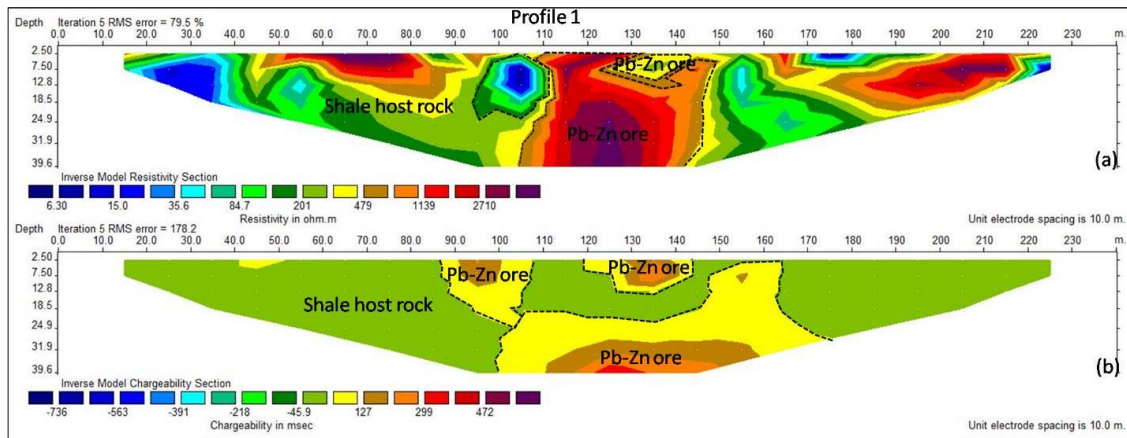
Electrical Resistivity Tomography (ERT), and Induced Polarization Tomography (IPT) were conducted at selected locations in the study area. The ERT surveys were carried out along the IPT lines to allow integrated interpretations and provide for corroborative evidence. Areas of possible occurrence of shallow magnetic structures were the focus of ground geophysical survey. Accordingly, Abakaliki and Ikwo were selected for sub-surface investigation using electrical method. The purpose is to delineate shallow magnetic structures, map possible ore bodies as well as unravel their concealed geometry.

The shallow scale investigations include interpretations of resistivity and IP data of profiles 1, 2, 3, and 4 for the Abakaliki area and Profiles 5, 6, and 7 for the Ikwo area. All profiles were drawn in a NW-SE direction orthogonal to the prevalent linear trend (NE-SW) within the study area. The locations of the profile lines are indicated in the AS and SVD maps, with a 30 m spacing between the lines.

### **The Abakaliki Area**

#### **Profile 1**

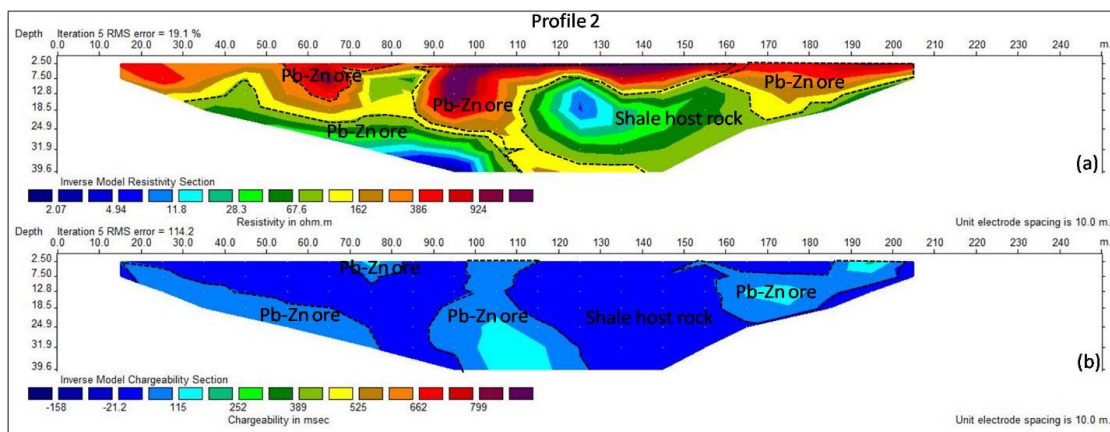
Profile 1 has a total spread length of about 230 m and is located in Abakaliki, at the western part of the study area. The resistivity and chargeability trace display the geometry of the sub-surface geology down to a depth of about 39.6 m (Figs 9a and b). In this pseudosection, in chargeability section, three main shallow bodies were recognized with their centers at 95 m, 130 m and 135 m, respectively (Fig. 9b). The spatial disposition of these bodies is as a result of the tectonic deformational event that affected the study area in Santonian time. These bodies are chiefly associated with moderate to high resistivity values that ranges from 201 to 3000  $\Omega\text{m}$  within a contrasting resistivity background (Fig. 9a). These high resistivity values are associated with high chargeability signatures (127 ms to 500 ms), which suggests that the bodies are not artifacts but an indication of conductive materials related to Pb-Zn sulphide mineralization in the vicinity of the shales of the Asu River Group, which are characterized by low to moderate resistivity (84.7 to 200  $\Omega\text{m}$ ) and low chargeability values (-218 ms to -50 ms) (Figs. 9a and b). The unusual high resistivity exhibited by these bodies is attributed to their highly disseminated pattern and/or low concentration of the metallic minerals.



**Fig. 9** Sub-surface geophysical sections along Profile 1 (a) Inverse resistivity pseudosection (b) Inverse chargeability pseudosection

### Profile 2

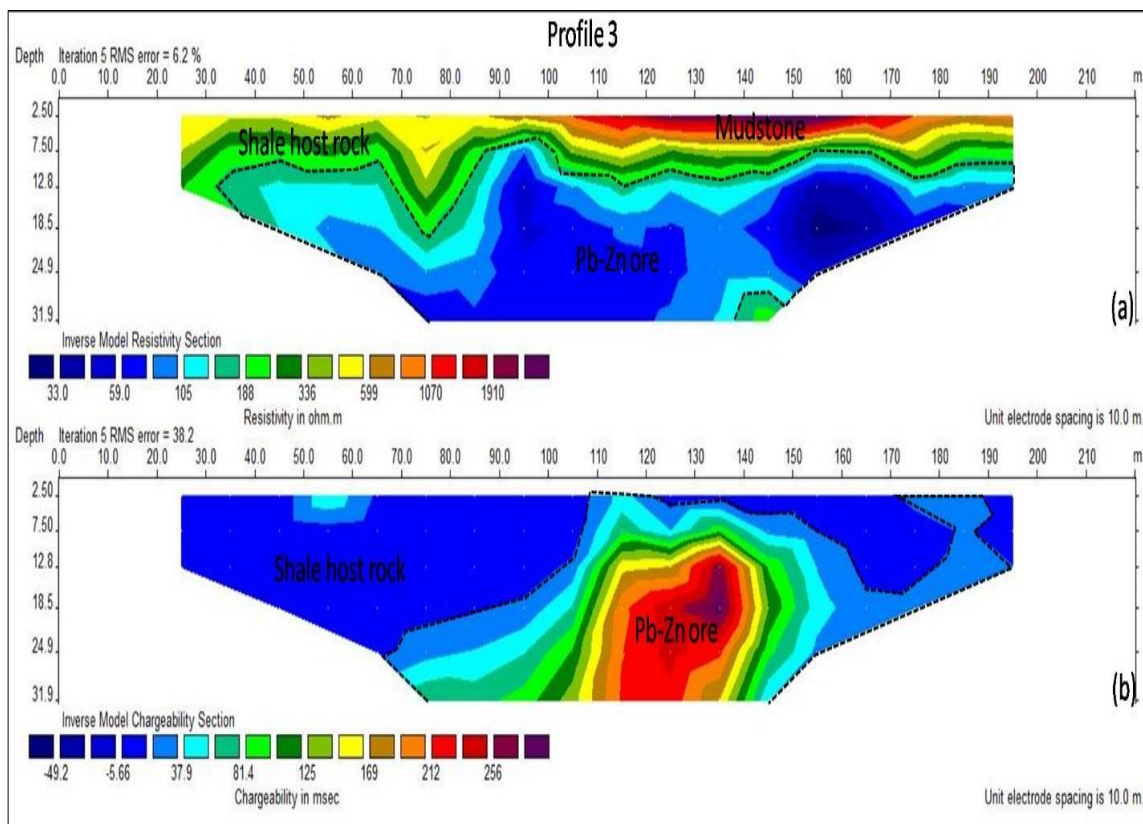
Profile 2, is situated SE of profile 1, shows a more complex pattern of lateral resistivity distribution as revealed by the color variations in the pseudosection (Fig. 10a). Four superficial sub-surface structures of mainly high resistivity values were observed along this profile (Figs 10 a and b). These bodies are shallow emplaced and occur at depths that are generally less than 4 m. Similar to Profile 1, these shallow structures display high resistivity (about 100 to 1000  $\Omega$ m) and moderate chargeability values (11-5 to 250  $\Omega$ m), which also suggests that the Pb-Zn minerals occur in disseminated form within the ore body. Generally, the shale host rock imaged in this profile is characterized by a lesser resistivity (28.3 to 67.6  $\Omega$ m) and lower chargeability values (-158 to 100 ms) (Figs 10a and b).



**Fig. 10** Sub-surface geophysical sections along Profile 2 (a) Inverse resistivity pseudosection (b) Inverse chargeability pseudosection

### Profile 3

Profile 3 is drawn parallel to Profile 2, also to the SE, and in comparison, with Profiles 1 and 2, it reveals the sub-surface geometry down to a lesser depth (31.9 m) (Figs 11a). Only one major IP anomaly, with a lateral extent of about 120 m, was identified in the inverse model chargeability section of this profile which is chiefly associated with low resistivity values that ranges from 30 to 150  $\Omega\text{m}$  (Figs 11a and b). This structure shows an outstanding high IP anomaly at about 10 m within the shallow portions of the sedimentary rock units, which are characterized by moderate resistivity and low chargeability values (Fig 11b). We therefore interpret this anomaly as a massive Pb-Zn mineral ore. The maximum depth of this ore body could not be ascertained due to the restricted penetrative depth of the electrical method, which is caused by limited spreading space. The non-conductive zones characterized by light and dark green coloration, and a deep blue background on the resistivity and chargeability sections respectively, is indicative of the shale host rock. Unlike Profiles 1 and 2, the topmost dry mudstone unit, characterized by very high resistivity values (150 to 300  $\Omega\text{m}$ ) is imaged in this profile and occurs within 0 to 10 m of the profile line (Fig. 11a).

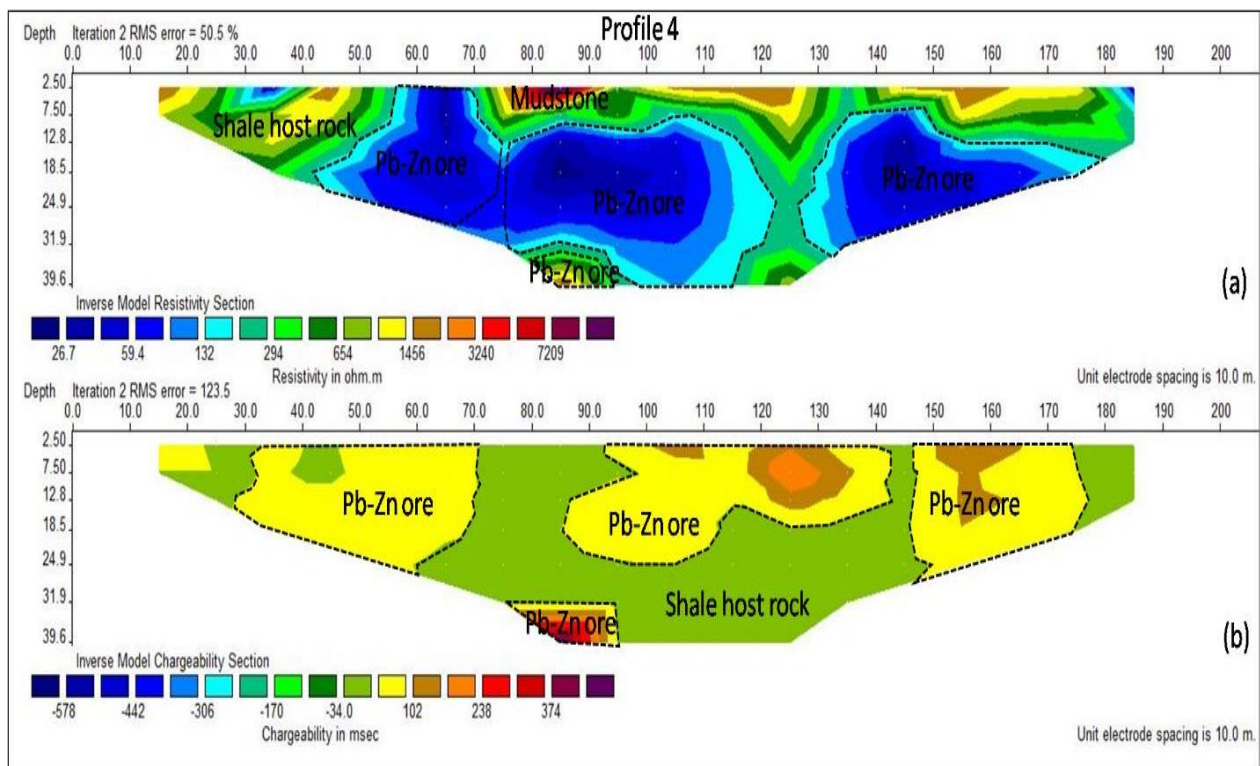


**Fig. 11** Sub-surface geophysical sections along Profile 3 (a) Inverse resistivity pseudosection (b) Inverse chargeability pseudosection

### Profile 4

Profile 4 is located 30 m parallel to Profile 2 in a SE direction. Although the profile reveals a number of anomalies, its imaging depth is limited to 39.6 m (Figs 12a and b). These anomalies, occurring at 30 to 70 m, 80 to 95 m, 90 to 140 m, and 150 to 170 m (in the chargeability section), are disseminated at various points along the profile line (Fig. 12b). Three of these anomalies occur close to the surface at depths that are generally <10 m (Figs 12a and b). Only one deposit is deep seated and appears to have a dimension that is less than that of the shallower bodies although it possesses a higher chargeability value. These bodies are characterized by low resistivity (26.7 to 250  $\Omega$ m) and high chargeability values (100 to 400 ms), a typical signature of Pb-Zn deposits.

In this profile, the shale host rock show contrasting resistivity and chargeability with the delineated ore bodies. The high resistivity signature observed at the uppermost part of the resistivity trace between 75 and 90 m of the profile line indicates the dry top mudstone unit.



**Fig. 11** Sub-surface geophysical sections along Profile 4 (a) Inverse resistivity pseudosection (b) Inverse chargeability pseudosection

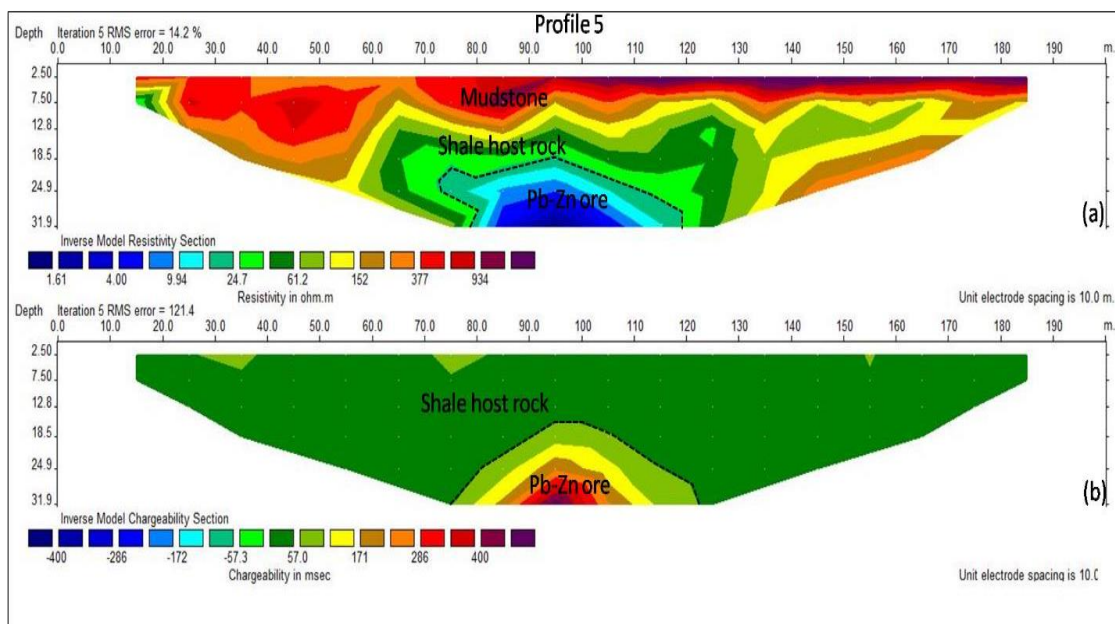
### The Ikwo Area

Three parallel profiles, labeled 5, 6, and 7, were traversed within the area. The

resulting two-dimensional resistivity and chargeability sections show the existence of shallow magnetic ore bodies within the area.

### Profile 5

Information about the sub-surface condition of Profile 5 in the Ikwo area is obtained from resistivity and IP investigations. A total spread length of about 190 m for this profile imaged the sub-surface up to a depth of about 31.9 m (Figs 12a and b). Only one major anomaly was observed within this profile. It corresponds to a zone of low resistivity (1.61 to 10  $\Omega\text{m}$ ) and high chargeability (100 to 500 ms), located at the center, within the deeper portions of the shale bedrock (Figs 12 a and b) and has a geophysical signature that is characterized by moderate resistivity and low chargeability values (Fig. 12b). This anomaly is consistent with those in Profiles 3 and 4, and is interpreted as Pb-Zn sulphide mineralization. This deposit is enclosed within the shale bedrock that exposed between a surface distance of 55 and 170 m along the resistivity section (Fig. 12a). The mudstone layer is clearly indicated as the high resistivity zone at the top 15 m of the resistivity pseudosection (Fig. 12a). This layer is only shown as two patches of moderate chargeabilities occurring at a surface distance of 30 to 40 m and 70 to 80 m of the IP section (Fig. 12b).

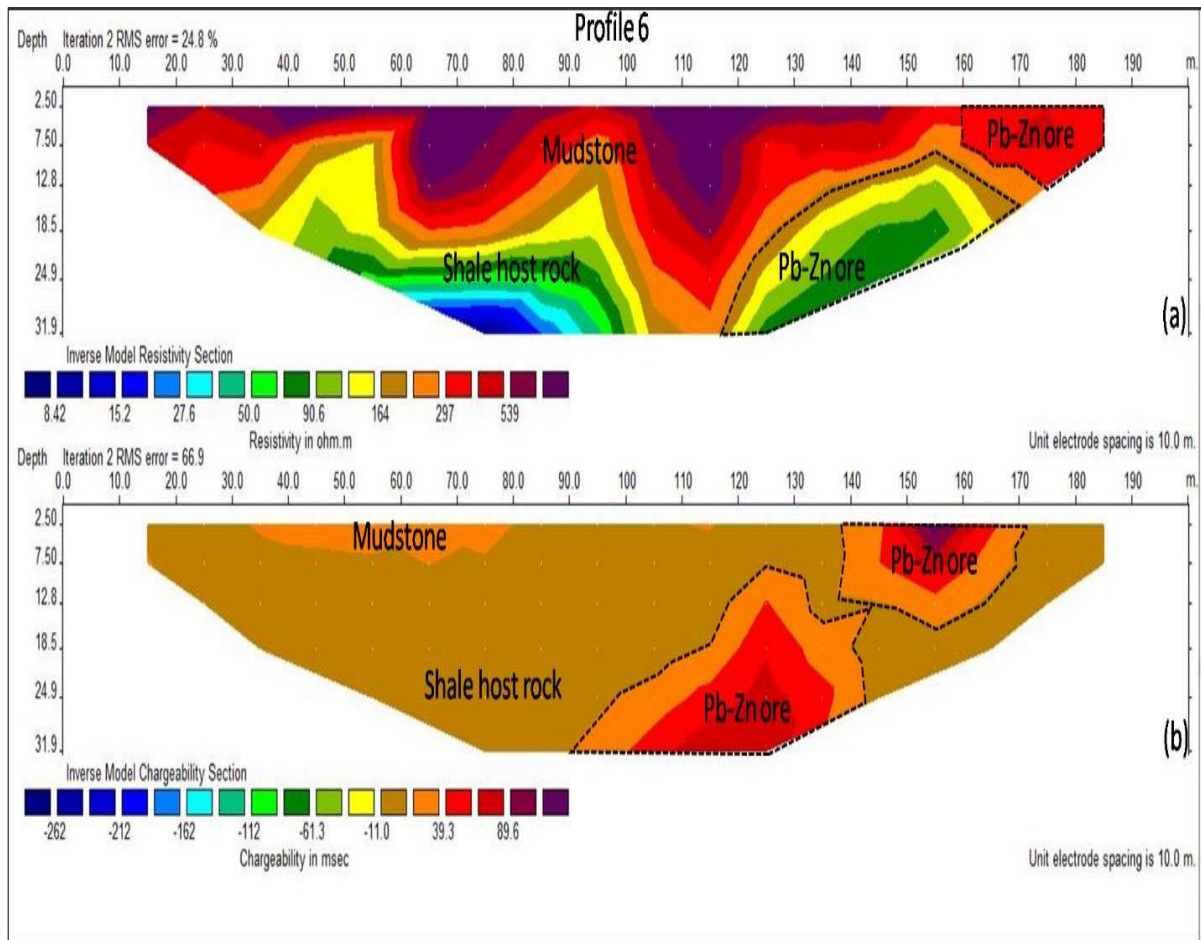


**Fig. 12** Sub-surface geophysical sections along Profile 5 (a) Inverse resistivity pseudosection (b) Inverse chargeability pseudosection

### Profile 6

Similarly, Profile 6 displays two Pb-Zn ore deposits; an upper superficial and highly disseminated mineral lode, and a lower massive mineral lode (Figs 13a and b). These ore bodies occur at 140 to 170 m and 90 to 140 m, respectively along the IP profile line. Although both ores show relatively high chargeability values (50 to 100 ms), the first shallow Pb-Zn

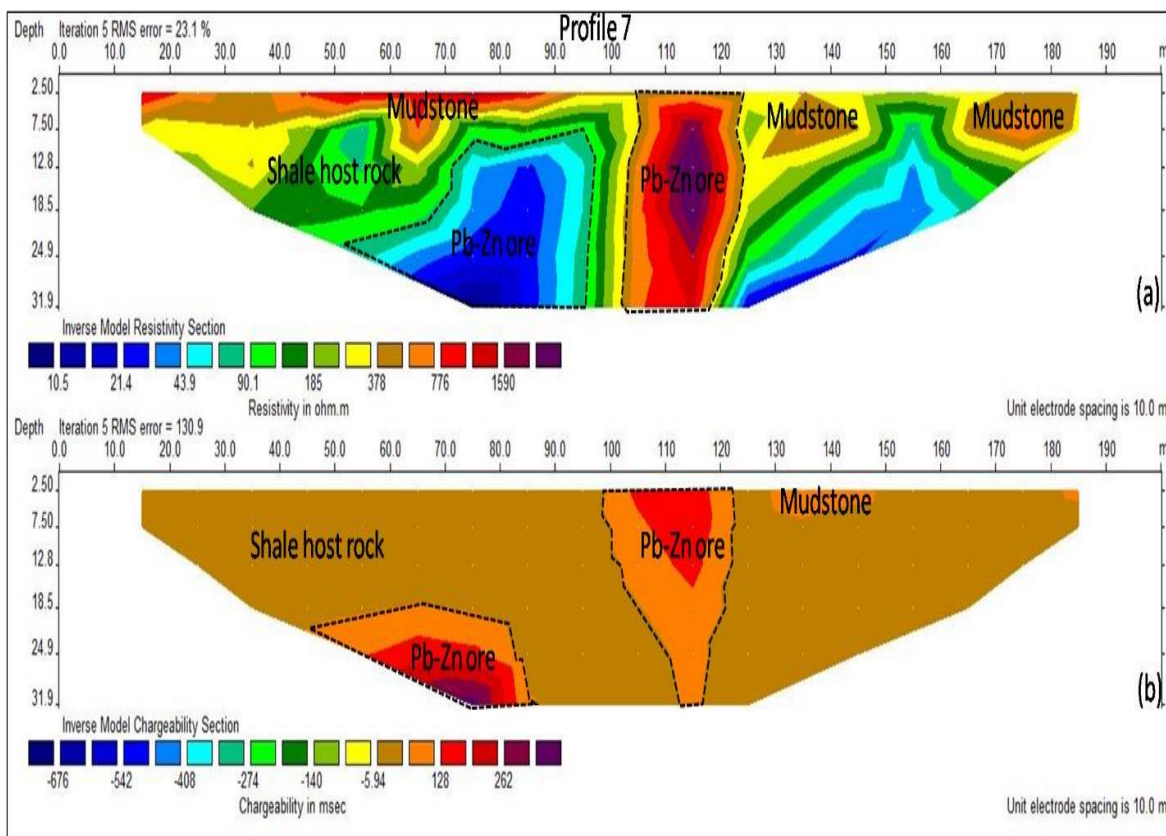
ore is characterized by high resistivity values that vary between 290 and 600  $\Omega\text{m}$  in contrast to the low resistivity signature of the second Pb-Zn ore body. Overall, the resistivity and chargeability of the enclosing shale host rock is moderate and low, respectively (Figs 13a and b). Unlike in Profiles 4 and 5, the top, dry and high resistivity mudstone layer attained a higher depth of about 30 m within the sub-surface as shown by the inverse resistivity model section, although it tends to vary although the profile section (Fig. 13a).



**Fig. 13** Sub-surface geophysical sections along Profile 6 (a) Inverse resistivity pseudosection (b) Inverse chargeability pseudosection

**Profile 7**

The sub-surface resistivity and chargeability model of Profile 7 captures the presence of two distinct vein housed Pb-Zn ore deposits (Figs 14a and b) occurring with their centers at 65 m and 110 m, with a lateral extent of 40 m and 20 m, respectively. The deposit occurring between 100 and 120 m of the profile line is highly disseminated with a low Pb and Zn mineral concentration. This is reflected by its high resistivity (500 to 2000  $\Omega$ m) and high chargeability (100 to 200 ms) values (Figs 14a and b). The geometry of mineral structure as imaged by the resistivity and chargeability pseudosections shows that this deposit is emplaced as a vertical dyke within a moderate resistivity and low chargeability host formation, which comprises the Asu River shales. The second deposit, on the other hand, shows a diagnostic low resistivity zone indicated by blue coloration between a horizontal distance of 50 and 95 m along the resistivity section (Fig. 14a). This zone corresponds to an area high chargeability anomaly in the IP section, and is interpreted as massive Pb-Zn deposit occurring within a moderate resistivity and low chargeability background of shale rocks (Fig. 14b). The mudstone layer is indicated at the topmost portions of the resistivity and chargeability sections.



**Fig. 14** Sub-surface geophysical sections along Profile 7 (a) Inverse resistivity pseudosection (b) Inverse chargeability pseudosection.

## CONCLUSION

Integrated geoelectrical investigations comprising Electrical Resistivity Tomography (ERT) and Induced Polarization (IP) surveys were conducted at selected sites within the study area to delineate shallow magnetic structures and characterize Pb-Zn mineralization. ERT profiles were acquired along the same transects as IP lines to facilitate joint interpretation and cross-validation, with geospatial alignment ensured using GPS-enabled mobile data collection systems. Abakaliki and Ikwo were chosen as primary investigation zones based on preliminary geophysical anomalies derived from aeromagnetic data and remote sensing analysis within a Geographic Information System (GIS) environment. All survey lines were oriented NW–SE, orthogonal to the dominant NE–SW structural fabric of the region, as interpreted from satellite imagery and lineament extraction algorithms.

Inversion results processed and visualized using advanced geophysical modeling software delineate four distinct vein systems characterized by variable resistivity (4–2710  $\Omega\text{m}$ ) and chargeability (39.3–472 ms) signatures, with lateral extents ranging from 20 to 40 m. 3D subsurface visualization of these anomalies enhanced structural interpretation and provided improved insights into ore continuity. Ore occurrences were mapped predominantly between 100–120 m depth. Zones of weak mineralization were marked by higher resistivity (500–2000  $\Omega\text{m}$ ) and elevated chargeability (100–200 ms), indicative of disseminated sulfide phases.

These geophysical signatures, when integrated and analyzed using spatial correlation tools within a GIS framework, effectively map the distribution and geometry of concealed ore bodies. The application of IT-based tools significantly improved the precision and interpretive clarity of the investigation, underscoring the value of combining ERT-IP surveys with digital geospatial technologies in structurally controlled Pb-Zn exploration within the Lower Benue Trough.

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