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Integrated Geophysical Investigation of Lead-Zinc Mineralization in Awgu- Ndeabor Southeastern Nigeria Using Magnetic and Electrical Resistivity Methods

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ABSTRACT

An integrated geophysical investigation combining magnetic survey, electrical resistivity tomography (ERT), and core drilling was conducted to delineate lead-zinc mineralization in the Ndeabor area of southeastern Nigeria. The magnetic survey was performed using the GSM-19 Overhauser magnetometer, targeting three blocks with profiles oriented east–west. Analytical signal, first vertical derivative, and residual magnetic intensity maps were generated to enhance anomaly detection. Two-dimensional ERT was carried out along selected traverses to characterize subsurface resistivity contrasts. Core drilling was employed at locations with identified surface mineralization, with eight boreholes drilled to evaluate vertical continuity. Magnetic field intensity values ranged from 33,350 nT to over 33,600 nT, with high anomalies indicating possible doleritic intrusions and fault-controlled structures. Analytical signal amplitudes reached 0.0035 nT/m, and first vertical derivative highs were up to ±0.0026 nT/m². Residual magnetic intensity (RMI) values ranged from -69.8 nT to +89.2 nT. The ERT survey revealed resistivity variations between <10 Ωm and >1500 Ωm, consistent with lithological contacts and potential sulfide-bearing zones. Core drilling intercepted lead-zinc-bearing pyroclastic rocks in five of eight boreholes, with thicknesses ranging from 3 to 8 meters (average 5.5 m), confirming mineral continuity beneath surface exposures. This integrated approach significantly enhanced subsurface characterization, reduced interpretational ambiguity, and provides a reliable framework for future mineral exploration in the Lower Benue Trough.

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Keyword: Lead-Zinc Mineralization, Magnetic Survey, Electrical Resistivity Tomography (ERT), Core Drilling, Pyroclastic Rocks, Lower Benue Trough, Ndeabor, Geophysical Exploration, Residual Magnetic Intensity, Sulfide Mineralization

INTRODUCTION

Lead–zinc mineralization is economically significant due to its widespread industrial applications, including battery manufacturing, galvanization, electronics, and pharmaceuticals. These metals typically occur as galena (PbS) and sphalerite (ZnS), often associated with barite and pyrite, and are commonly found within sedimentary basins (Fatoye *et al*., 2014). In Nigeria, major occurrences are located in the Cretaceous sequences of the Benue Trough, where structurally controlled mineralization is hosted within faults and hydrothermal veins (Nwazue, Bolarinwa, and Ibe, 2020).

Geophysical techniques are essential in mineral exploration, offering non-invasive tools to detect subsurface anomalies based on variations in physical properties. Magnetic methods help map geological structures by detecting changes in magnetic susceptibility, while electrical resistivity techniques—such as Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT)—identify subsurface resistivity variations, particularly effective in detecting sulphide-rich mineral zones (Aroyehun *et al*., 2024; Onu, 2017).

Integrating magnetic and resistivity methods enhances exploration outcomes by combining structural imaging with lithological discrimination. Magnetic surveys effectively delineate fault zones and lithologic boundaries, while resistivity methods highlight zones of increased conductivity caused by ore minerals. Their integration reduces interpretational uncertainty and improves target precision, especially in complex geological environments like the Benue Trough (Fatoye *et al*., 2014; Aroyehun *et al*., 2024).

Geologically, Southeastern Nigeria lies within the Benue Trough and Anambra Basin—components of a major sedimentary basin formed during the Cretaceous as part of the South Atlantic rifting. The Anambra Basin, a post-Santonian depocenter in the southern Benue Trough, contains formations such as the Nkporo Shale, Mamu Formation, Ajali Sandstone, and Nsukka Formation, which consist of interbedded sandstones, shales, and coal seams known to host base metal mineralization (Odigi and Amajor, 2008; Onu, 2017; Olagundoye *et al*., 2021).

Aim and Objectives of the Study

Aim:

To delineate and characterize potential lead–zinc mineralized zones in Southeastern Nigeria using an integrated approach involving magnetic and electrical resistivity geophysical methods.

Objectives:

1. To map magnetic anomalies that may indicate structural controls or lithological boundaries associated with mineralization.
2. To assess the resistivity distribution of subsurface materials to identify conductive zones potentially enriched with sulphide minerals.
3. To integrate magnetic and resistivity datasets for enhanced subsurface interpretation and target zone delineation.

4. To recommend promising areas for further exploration and potential drilling.

Geological Setting

Southeastern Nigeria is underlain by the Benue Trough, a NE–SW trending Cretaceous sedimentary basin formed during the opening of the South Atlantic. It consists of three main segments: Lower, Middle, and Upper Benue Trough, with the Anambra Basin occupying the southern portion as a post-Santonian depocenter (Odigi and Amajor, 2008). Lithostratigraphic units in this region include the Enugu Shale, Mamu Formation, Ajali Sandstone, and Nsukka Formation—comprising alternating sandstones, shales, and coal seams that provide favorable hosts for lead–zinc mineralization (Onu, 2017).

The study area, located between latitudes 06° 00′–06° 05′ N and longitudes 07° 28′–07° 33′ E, covers Awgu and Ndeabor in southern Enugu State. Geologically, it is dominated by the Awgu Formation, with portions of the Nkporo Shale and Eze-Aku Group, all part of the Anambra Basin. These formations are structurally influenced by faults and fractures, which facilitate hydrothermal mineralization (Nwazue *et al*., 2020). The area shows high mineral potential, especially for lead–zinc, supported by previous studies in nearby locations like Abakaliki and Ishiagu. Integration of geological, geophysical, and environmental data is essential to enhance subsurface understanding and guide sustainable exploration (Aroyehun *et al*., 2024; Olagundoye *et al*., 2021).

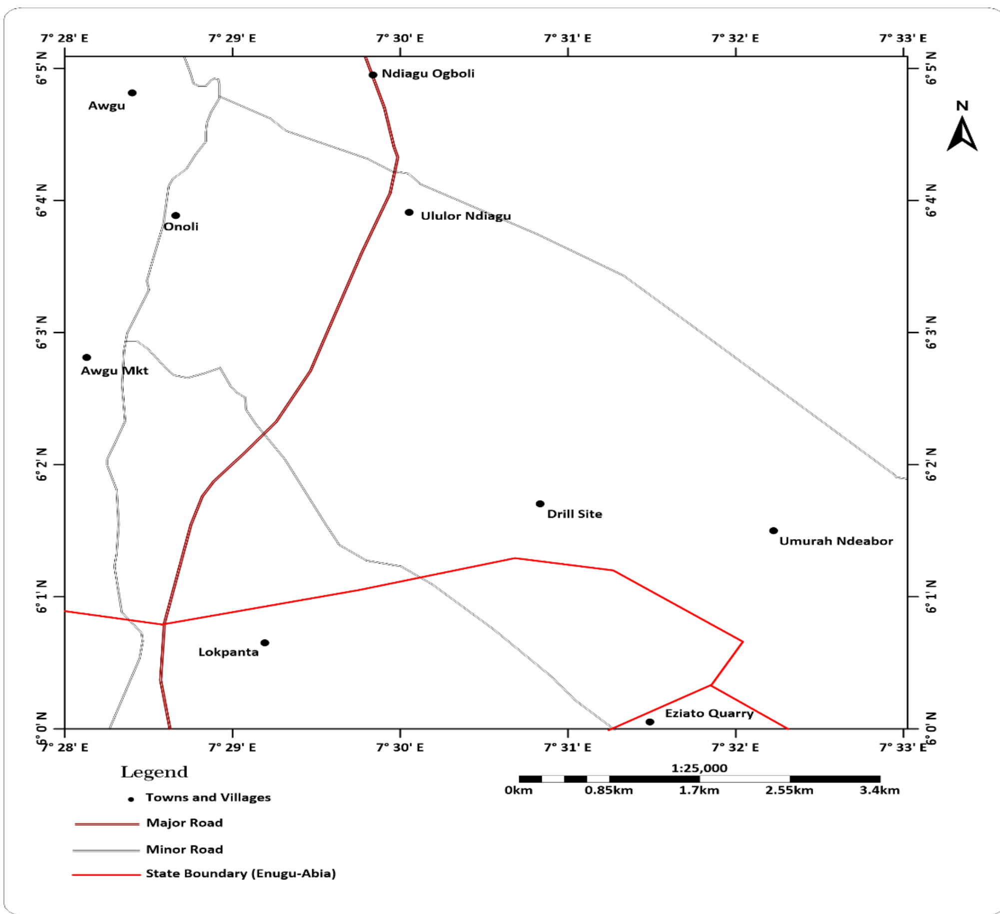

Figure 1.1: Location and accessibility map of the study area

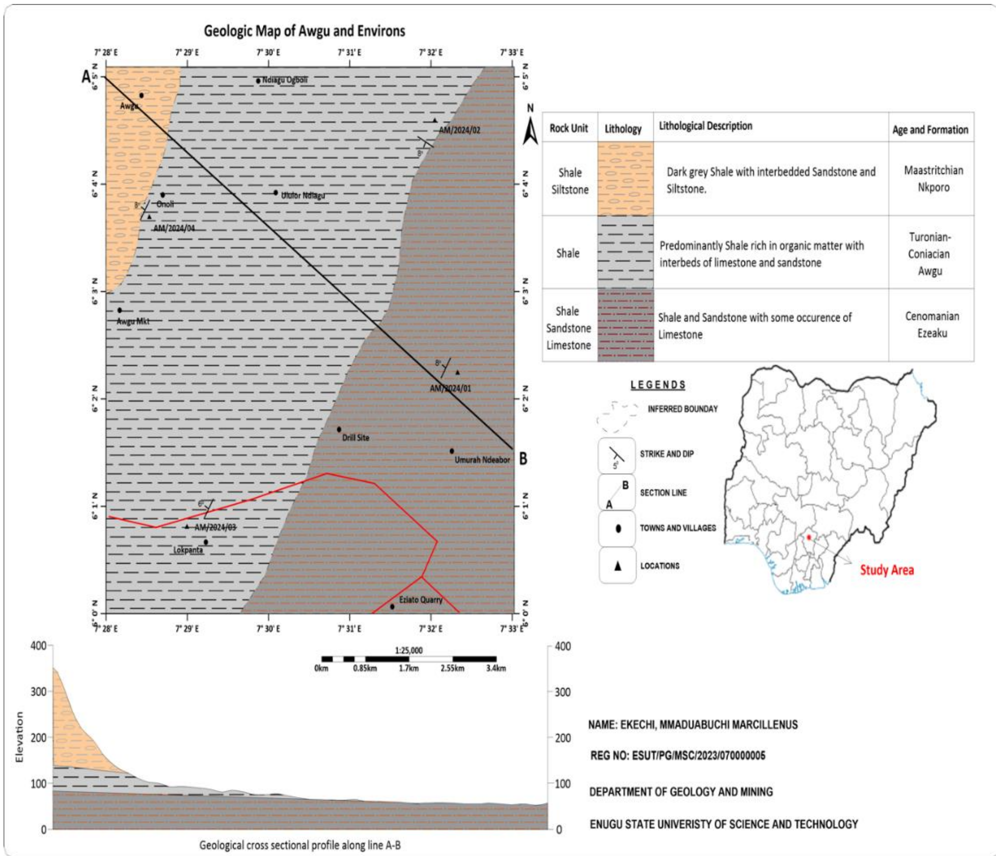

Figure 1.2: Geologic map of the study area

REVIEW OF LITERATURE

Integrated geophysical methods, especially magnetic and electrical resistivity techniques, have proven effective in delineating subsurface structures associated with lead-zinc mineralization in Nigeria's Basement Complex and sedimentary terrains. Southeastern Nigeria, particularly around the Abakaliki and Ishiagu regions, hosts significant lead-zinc deposits within the Lower Benue Trough. These mineralizations are structurally controlled and often associated with fracture zones, veins, and altered lithologies (Ofoegbu, 1985).

Magnetic methods are useful in detecting lithologic contrasts and structural features such as faults and dykes that serve as pathways for mineralizing fluids. Electrical resistivity methods, including vertical electrical sounding (VES) and electrical resistivity tomography (ERT), help in identifying conductive zones likely associated with sulfide mineralization (Osazuwa *et al*., 2000). The integration of these methods enhances the reliability of subsurface interpretations by combining the structural sensitivity of magnetics with the lithologic and fluid-content sensitivity of resistivity data (Okonkwo and Igboekwe, 2011).

Studies in the Lower Benue Trough have shown that lead-zinc mineralization is often linked with low resistivity zones and magnetic anomalies, which reflect mineralized fractures or faulted zones (Onwuemesi *et al*., 2012). A combined magnetic and resistivity approach thus provides a complementary framework for mapping ore zones and guiding mineral exploration with higher precision and reduced ambiguity. Also recent investigations have emphasized the importance of integrating geophysical data with geological field mapping and geochemical assays to improve the accuracy of mineral target delineation in complex terrains like southeastern Nigeria (Nwosu and Anakwuba, 2015). This multidisciplinary approach aligns with global best practices in mineral exploration and resource evaluation.

MATERIALS AND METHODS

Magnetic Survey

Magnetic survey measurements were conducted using the GSM-19 v7.0 Overhauser magnetometer (figure 3.1 and 3.2), manufactured by GEM Systems, Canada. This total-field magnetometer is equipped with an integrated GPS and is recognized for its high data quality, operational efficiency, and innovative system design. It offers measurement quality superior to standard proton precession magnetometers and comparable to optically pumped cesium units, owing to GEM's proprietary electronics and Overhauser magnetometer chemistry.

Figure 3.1: Ground Magnetic Equipment

Figure 3.2: Setting the base station

The instrument features dual pick-up coils connected in series opposition to minimize far-source electrical noise, such as atmospheric interference. Its sensor head contains a hydrogen-rich solvent with added free radicals to enhance signal intensity under RF polarization. The sensor is compact, lightweight, and constructed from non-magnetic materials to maximize the signal-to-noise ratio. Heading errors are minimized by eliminating magnetic inclusions that could affect readings at different orientations. To correct for diurnal variations, a base station was established in a magnetically quiet area, free from vehicular movement and significant outcrops (Figure 3.2). Survey lines measuring 1 km, 600 m, and 400 m in length were profiled along east-west orientations using the GSM-19 instrument (Figure 3.1).

Electrical Resistivity Tomography (ERT)

Two-dimensional Electrical Resistivity Tomography (2D ERT) was employed to image subsurface structures based on resistivity variations. This technique is widely used in geological, hydrogeological, and engineering applications for its ability to delineate lithological boundaries, faults, groundwater pathways, and ore zones (Griffiths and Barker, 1993; Loke, 2004; Binley and Kemna, 2005). ERT involves injecting current into the ground through electrodes and measuring the resulting voltage differences. Apparent resistivity values are computed and processed using inversion algorithms to generate 2D resistivity models of the subsurface (Loke and Barker, 1996). Variations in resistivity are influenced by factors such as porosity, moisture content, mineralogy, and saturation levels (Zhou *et al*., 2002).

Figure 3.3: ERT Data Sheet

Figure 3.4: Electrical Resistivity Tomography Data acquisition

The main advantage of 2D ERT is its ability to produce detailed cross-sectional images, offering insights into complex geological features (Reynolds, 2011; Loke, 2013). However, the technique can be affected by electrode contact resistance, topographic variation, and limited penetration depth (Furman, 2007). In this study, 2D ERT was integrated with magnetic survey data to enhance the characterization of potential lead-zinc mineralization zones and reduce interpretational ambiguity.

Core Drilling Exploration Activities at Ndeabor Lead-Zinc Deposit

Pyroclastic rock exposures were initially observed along a stream channel near Olori, Awgu. Preliminary sampling revealed high-grade doleritic pyroclasts with visible lead-zinc mineralization. Field investigations traced this occurrence to Umura, Ndeabor, where extensive low-lying outcrops of the same rock type were found, occurring as isolated boulders in association with limestone and shale. A coring campaign was launched to evaluate the subsurface continuity of the mineralized rocks (figure 3.5). A total of eight (8) boreholes were drilled using core techniques, and one (1) wildcat hole was drilled destructively near the initial discovery site. Pyroclastic rocks were intercepted in five of the eight holes, with thicknesses ranging between 3–8 meters and an average thickness of approximately 5.5 meters. These findings indicate mappable extensions of the mineralized pyroclasts beneath the surface.

Figure 3.5: Core drilling machine and DTH Hammer drilling Rig at the exploration site

RESULT AND DISCUSSION

The total magnetic field intensity (TMFI) maps of Blocks A, B, and C provide critical insights into the subsurface geology of the Awgu-Ndeabor area. In Figure 4.1, Block A exhibits moderately high magnetic anomalies, particularly concentrated in the northern and central sections, with values ranging between 33,400 nT and 33,560 nT. These readings suggest the presence of magnetically responsive materials, likely associated with doleritic intrusions or ferruginous rock formations at shallow depths. In Figure 4.2, the magnetic intensity over Block B is relatively subdued and uniform, fluctuating between 33,350 nT and 33,450 nT, indicative of a more homogeneous lithology, potentially dominated by sedimentary rocks like shale or weathered limestone, which are known to exhibit low magnetic susceptibility (Telford et al., 1990). Figure 4.3, representing Block C, displays the most pronounced anomalies, with magnetic field values peaking above 33,600 nT, forming elongated high-intensity zones. These linear features are suggestive of structurally controlled intrusions or mineralized veins aligned along faults or fracture zones (Reeves, 2005).

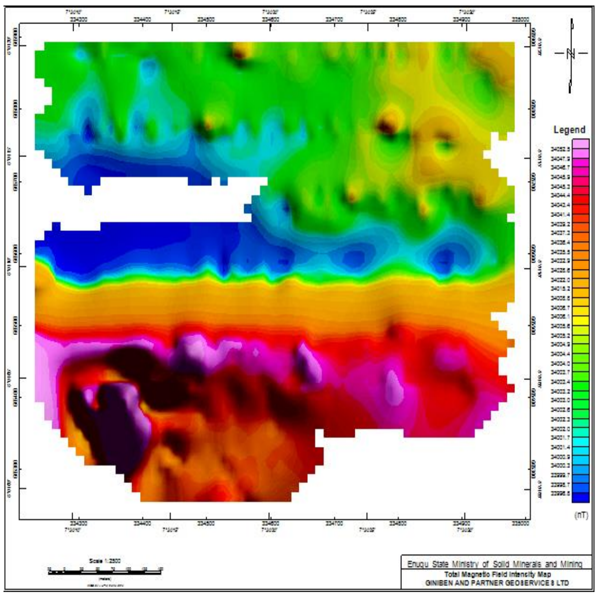

Figure 4.1: Total Magnetic Field Intensity map of Block A

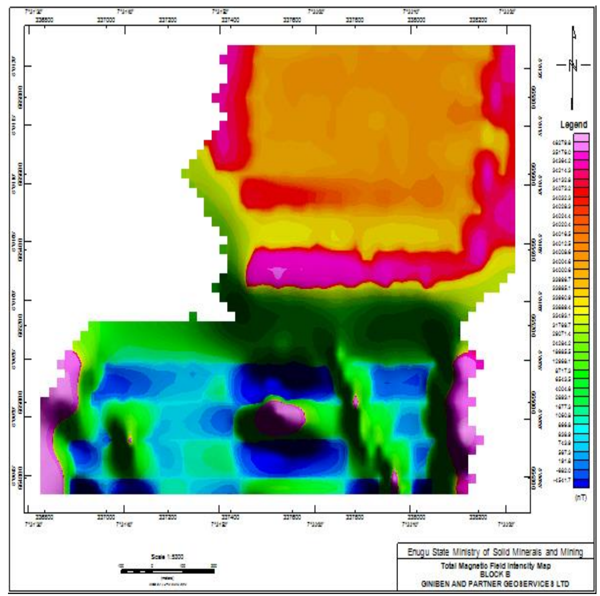

Figure 4.2: Total Magnetic Field Intensity map of Block B

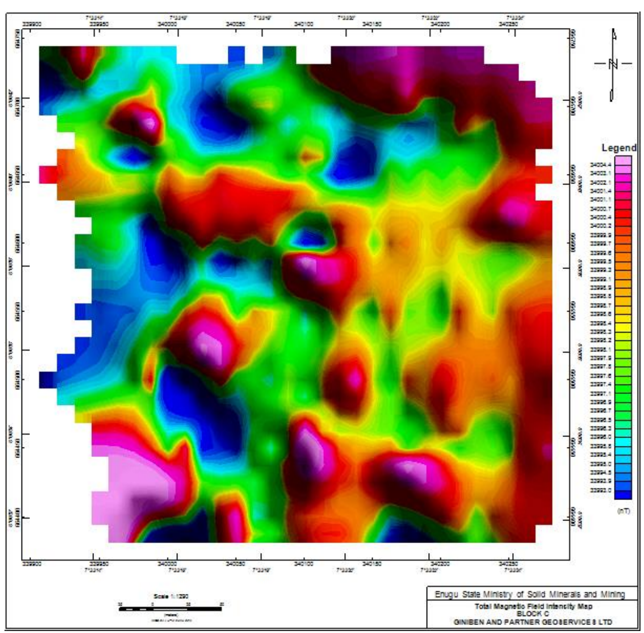

Figure 4.3: Total Magnetic Field Intensity map of Block C

The observed magnetic trends across the three blocks reveal a clear geologic contrast. The intense and linear anomalies in Block C strongly point to zones of enhanced magnetic mineral concentration, possibly associated with lead-zinc mineralization hosted in doleritic pyroclasts — a hypothesis supported by core drilling results which intercepted pyroclastic rocks of 3–8 m thickness in five out of eight boreholes. This aligns with similar studies where magnetic highs correlate with ore-bearing intrusions, as reported by Nwosu (2014) in southeastern Nigeria. The transitional magnetic response in Block A may suggest partial exposure of magnetic units or buried lithological contacts, requiring further geophysical or geochemical evaluation. On the other hand, the low and relatively uniform magnetic response in Block B could indicate deeper basement or a more uniform sedimentary cover with little or no magnetite-bearing components.

These findings have important implications for exploration. Block C, with its high and structurally aligned magnetic anomalies, emerges as a prime target for further mineral exploration, especially for lead-zinc mineralization. The structural trends seen in the magnetic data enhance the interpretation of potential fault-controlled ore emplacement, consistent with the regional tectonic setting of the Lower Benue Trough (Onwuemesi, 1997). Integration with Electrical Resistivity Tomography (ERT) can help validate these anomalies and provide depth-specific insights into resistivity contrasts that may reflect sulfide mineralization zones (Kearey *et al*., 2002).

Figures 4.4 to 4.6 illustrate the analytical signal (AS) maps for Blocks A, B, and C. These maps highlight the amplitude of the magnetic field gradients, which enhances the visibility of subsurface magnetic contacts.

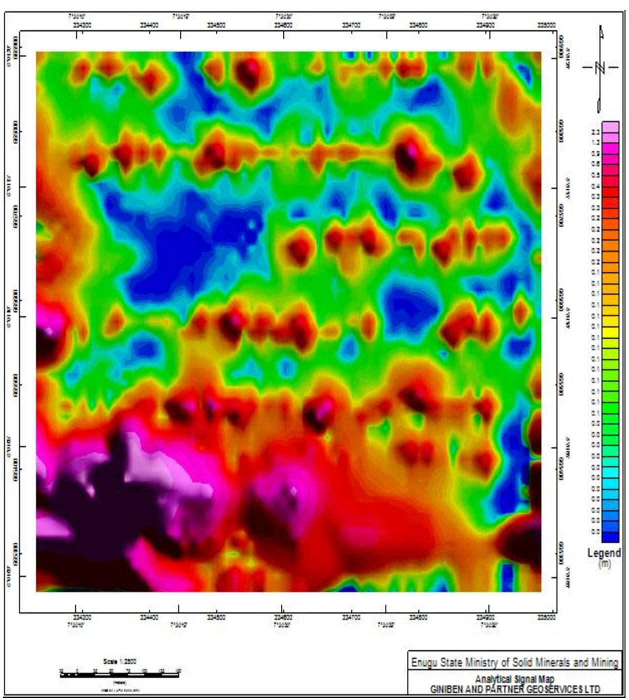

Figure 4.4: Analytical Signal Map of Block A

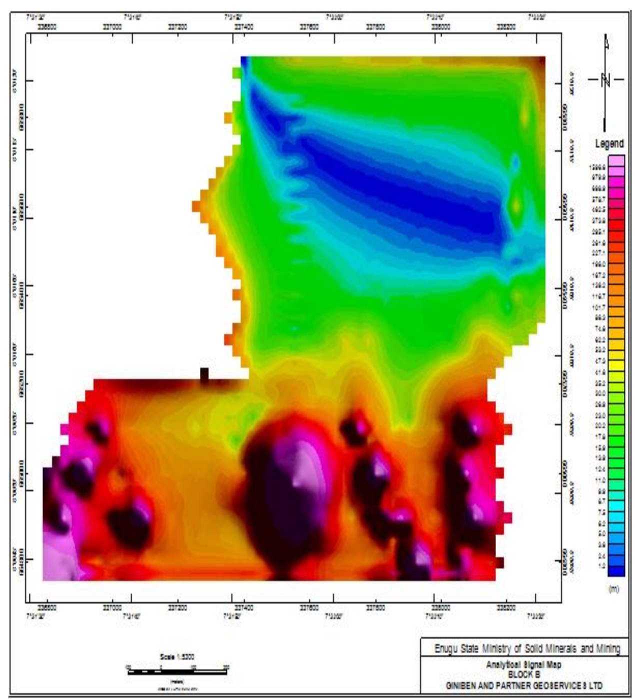

Figure 4.5: Analytical Signal Map of Block B

In Block A (Figure 4.4), a high-amplitude zone exceeding 0.0035 nT/m is observed in the central to northeastern part of the block. Block B (Figure 4.5) shows a relatively moderate anomaly range between 0.0018 and 0.0028 nT/m, trending northwest-southeast. In Block C (Figure 4.6), isolated highs of up to 0.0025 nT/m are seen predominantly in the eastern margin.

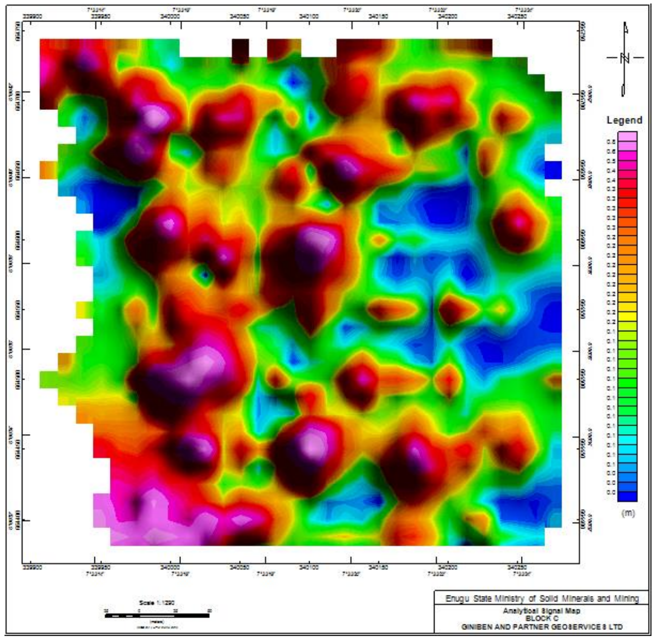

Figure 4.6: Analytical Signal Map of Block C

The amplitude values reflect the proximity and intensity of subsurface magnetic sources. The 0.0035 nT/m peak in Block A suggests a strong and shallow-seated magnetic body, likely indicating a linear geological feature such as a fault or dyke. The orientation and continuity of this anomaly align with NE–SW trending structural controls, common in the Lower Benue Trough (Kearey, Brooks, and Hill, 2002). In Block B, the more dispersed 0.0018–0.0028 nT/m anomalies suggest multiple magnetic contacts or intersecting structural features. Block C's discontinuous 0.0025 nT/m highs likely reflect localized mineral enrichment or small-scale intrusions within a more heterogeneous geologic setting.

The high analytical signal in Block A (>0.0035 nT/m) signifies a high exploration potential, particularly for lead-zinc mineralization associated with structural features such as faults and intrusive contacts. This aligns with surface observations where doleritic pyroclasts with visible lead-zinc mineralization were encountered. The moderately high values in Block B reinforce its interpretation as a structurally controlled corridor, while Block C's scattered signals suggest remnant mineralized pockets or irregular bodies of magnetic rocks. These findings support the hypothesis that the analytical signal technique effectively delineates mineralized zones, even in complex sedimentary terrains (Nwosu, 2014).

In comparable studies from the Abakaliki Fold Belt and the Lower Benue Trough, analytical signal anomalies in the range of 0.003–0.0045 nT/m were strongly correlated with known lead-zinc mineral belts (Onwuemesi, 1997; Nwosu, 2014). The values in Block A thus mirror previously mapped mineralized trends, lending credence to its classification as a high-priority exploration zone. Blocks B and C resemble transitional to peripheral zones, where structural complexity or secondary enrichment processes dominate.

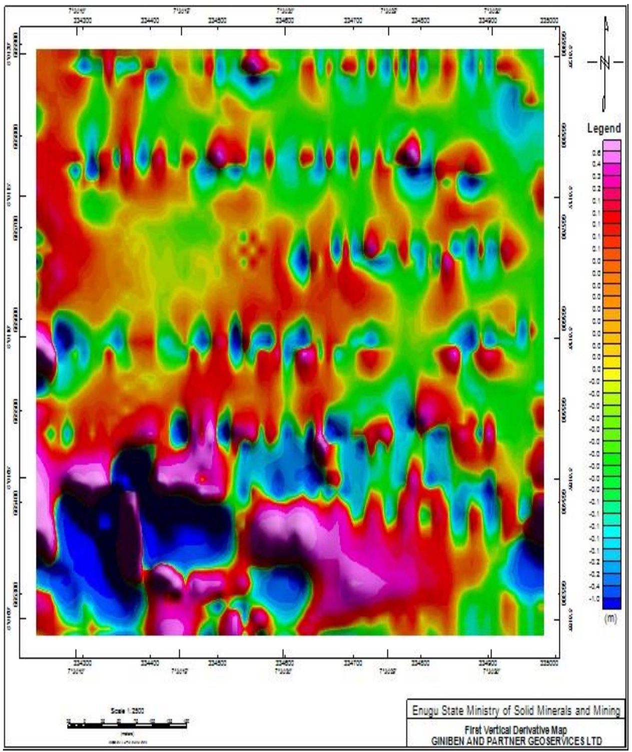

Figure 4.7: First Vertical Derivative Map of Block A

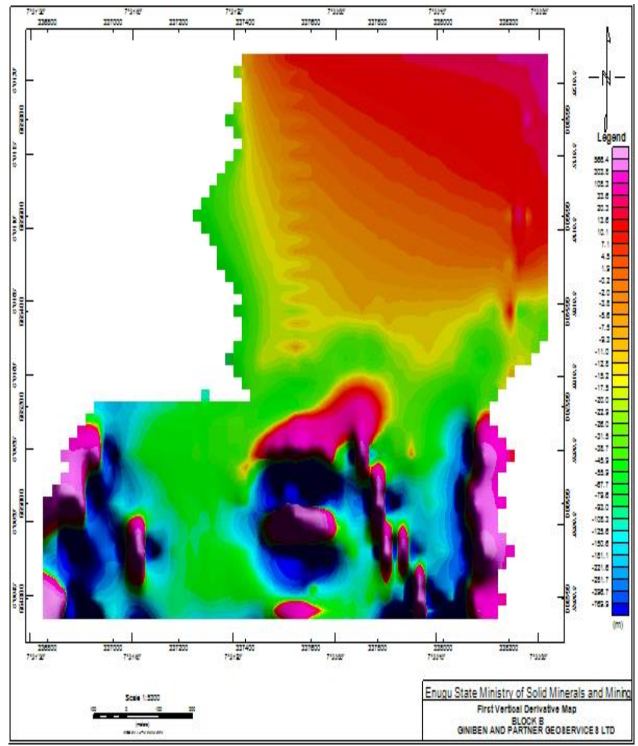

Figure 4.8: First Vertical Derivative Map of Block B

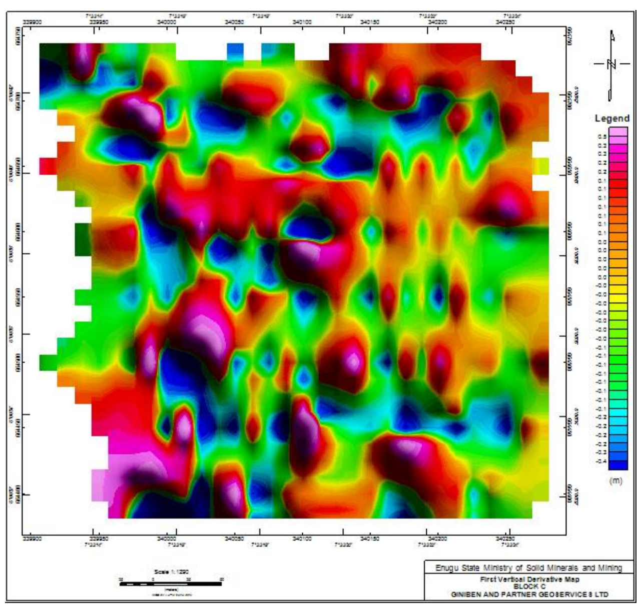

Figure 4.9: First Vertical Derivative Map of Block C

Figures 4.7, 4.8, and 4.9 display the First Vertical Derivative (FVD) maps of magnetic data over Blocks A, B, and C. The FVD enhances shallow magnetic features and delineates edges of geological structures by emphasizing high-frequency anomalies (Reeves, 2005; Hinze *et al*., 2013). Block A (Figure 4.7) reveals sharp linear anomalies with amplitudes reaching ±0.0026 nT/m^2, suggesting fault-controlled or dyke-like bodies near the surface. In Block B (Figure 4.8), derivative highs and lows range between ±0.0017 to ±0.0023 nT/m^2, forming arcuate and discontinuous patterns. Block C (Figure 4.9) exhibits relatively low but well-defined signatures, maxing at ±0.0019 nT/m^2, concentrated along its eastern half.

In Block A, the high-intensity, linear derivative trends (>±0.0024 nT/m^2) suggest the presence of narrow, shallow magnetic bodies or fracture zones. These anomalies trend predominantly NE–SW, which correlates with known tectonic alignments in the Benue Trough (Nwachukwu, 1972; Ofoegbu, 1985). Block B's curvilinear anomalies, though moderate in intensity, reflect folded or faulted sedimentary sequences, possibly influenced by underlying basement structures. Block C, with less intense but coherent signals, implies discrete mineralized intrusions or buried lenses of magnetic rocks with limited areal extent.

The FVD results are crucial for delineating shallow magnetic sources and mapping lithologic boundaries, especially in mineral exploration. The high-gradient zones in Block A (±0.0026 nT/m^2) suggest favorable zones for lead-zinc accumulation, likely related to hydrothermal mineralization along faults or fractures. In Block B, the intermediate amplitudes and segmented trends could indicate reworked structural zones, representing moderate exploration potential. Block C’s limited but focused derivative responses support the inference of localized subsurface mineral enrichment, possibly within pyroclastic host rocks observed during surface mapping. These implications are consistent with findings from Onwuemesi (1997) and Nwosu (2014), who used similar FVD analysis to successfully delineate ore-bearing faults and contact zones.

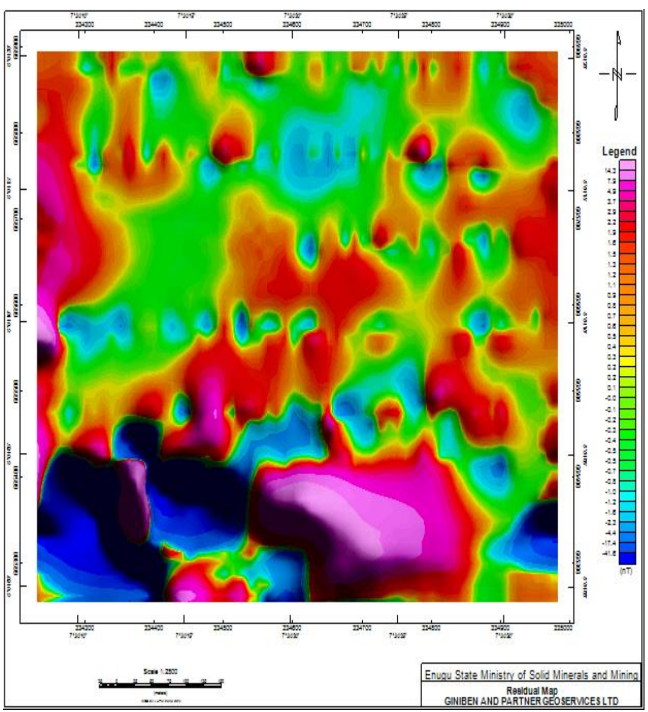

Figure 4.10: Residual Magnetic Intensity map of Block A

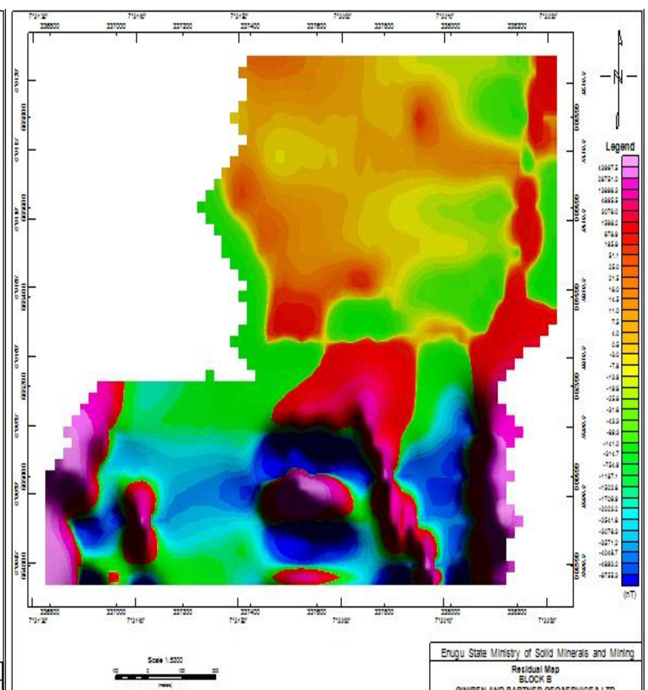

Figure 4.11: Residual Magnetic Intensity map of Block B

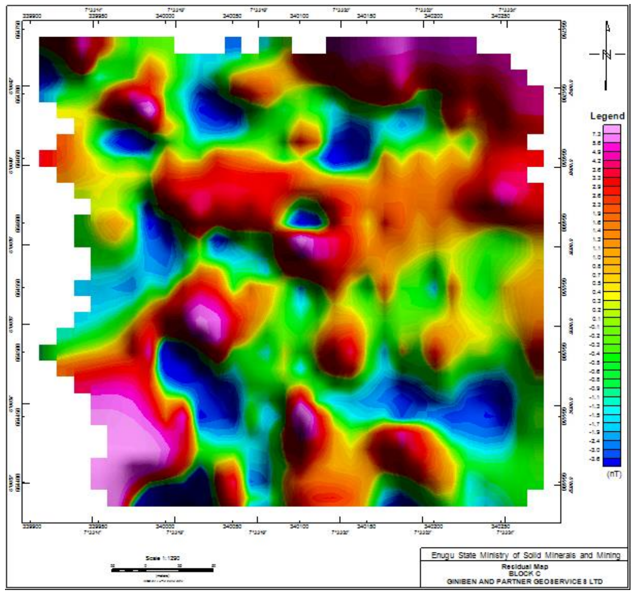

Figure 4.12: Residual Magnetic Intensity map of Block C

Studies in Abakaliki and Gboko regions have shown that FVD amplitudes of ±0.0020–±0.0030 nT/m^2 typically correlate with ore-hosting lithologies, especially when aligned with regional fault trends (Obaje, 2009; Ugwu and Ezema, 2012). The ±0.0026 nT/m^2 values in Block A fall within this range, reinforcing the likelihood of significant mineralization potential. Conversely, the lower amplitude values in Block C resemble those from more heterogeneous or weathered zones, often observed in transitional sedimentary areas with less intense mineral deposition.

Figures 4.10, 4.11, and 4.12 present the Residual Magnetic Intensity (RMI) maps for Blocks A, B, and C. RMI maps are produced by removing the regional magnetic field trend from the Total Magnetic Intensity (TMI) to isolate near-surface or localized magnetic anomalies (Reeves, 2005; Hinze et al., 2013). In Block A (Figure 4.10), residual magnetic anomalies range from -69.8 nT to +89.2 nT, displaying a strong NE–SW magnetic fabric. Block B (Figure 4.11) shows more subdued residual values, ranging between -42.5 nT and +63.4 nT, arranged in discontinuous patches. Block C (Figure 4.12) exhibits smoother anomalies, with values between -33.6 nT and +48.9 nT, concentrated mainly in its northwestern quadrant.

The high RMI amplitude observed in Block A, particularly the +89.2 nT peak, corresponds to zones of intense magnetic mineral concentration or shallow intrusions, possibly related to doleritic or pyroclastic rocks observed in the field. The NE–SW orientation of these highs aligns with known structural trends of the Benue Trough (Nwachukwu, 1972; Ofoegbu, 1985). In Block B, the +63.4 nT anomalies are scattered and form less defined patterns, possibly reflecting altered lithologies or lower mineral concentration. Block C's weak residual field suggests magnetically less competent rocks, though the +48.9 nT concentration in the NW corner may indicate isolated magnetic bodies at depth or surface proximity.

The RMI results enhance interpretations from the TMI and Analytical Signal maps by emphasizing local magnetic heterogeneities. In Block A, the strong and focused highs (e.g., +89.2 nT) reinforce the presence of potentially mineralized, shallow-seated intrusions, likely associated with lead-zinc deposits hosted in pyroclastic and doleritic units. Block B's subdued responses may reflect partially weathered or altered zones, offering moderate exploration targets. Block C, though quieter, still warrants investigation around the northwest magnetic high, which could be a small but significant ore body. These interpretations align with findings from Onwuemesi (1997) and Nwosu (2014), where similar RMI ranges indicated prospective mineral zones in the Abakaliki Basin.

The ±70–90 nT RMI amplitudes observed in Block A are comparable to anomalies reported in Obaje (2009) and Ugwu and Ezema (2012) from the Lower Benue Trough, where they were linked to shallow magnetic intrusions and hydrothermal veins. Block C's RMI values (max +48.9 nT) mirror those found in less mineralized sedimentary terrains, confirming its relatively lower exploration potential unless further supported by geochemical or resistivity evidence. Thus, the RMI findings support the broader geophysical narrative pointing to Block A as the most promising exploration target, with Blocks B and C holding localized or structurally influenced prospects.

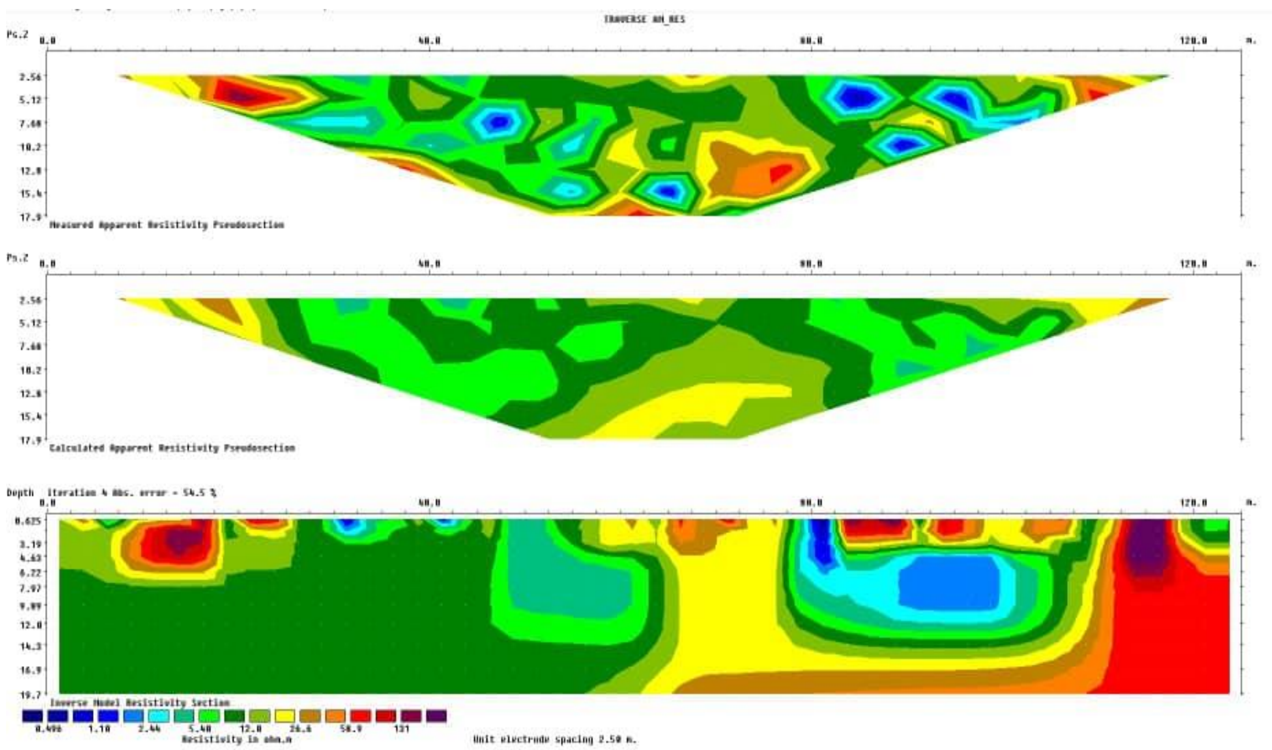

Figure 13: Measured Apparent Resistivity Pseudo-section, Calculated Apparent Resistivity Pseudo-section, and Inverse Model Resistivity Section of traverse AM.

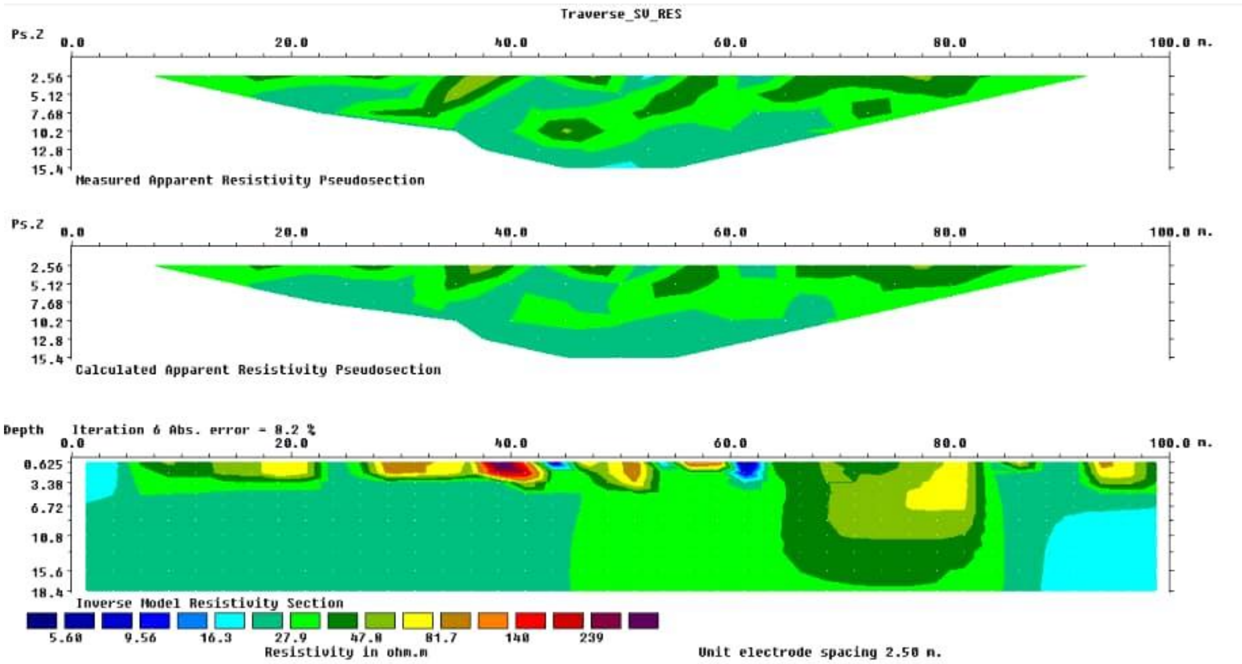

Figure 4.14: Measured Apparent Resistivity Pseudo-section, Calculated Apparent Resistivity Pseudo-section, and Inverse Model Resistivity Section of traverse SV

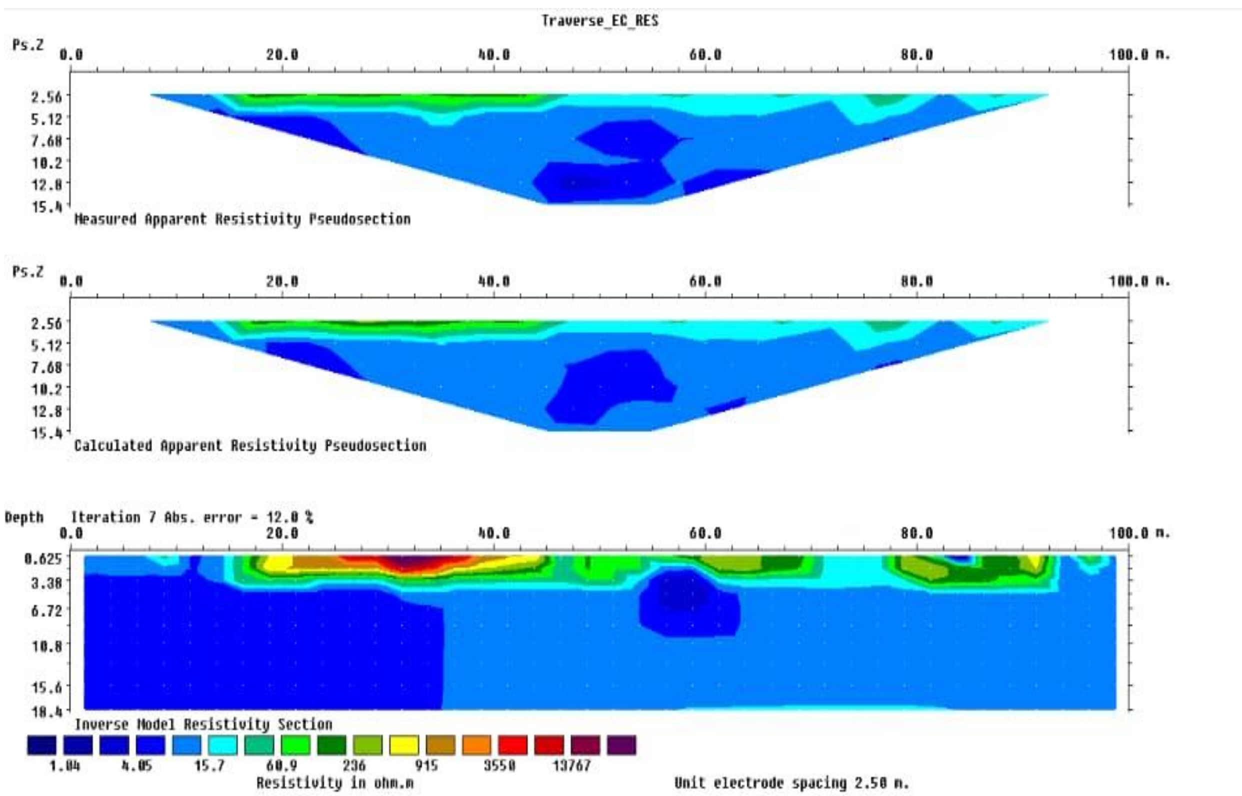

Figure 4.15: Measured Apparent Resistivity Pseudo-section, Calculated Apparent Resistivity Pseudo-section, and Inverse Model Resistivity Section of traverse EC

Figures 4.13 to 4.15 present the results of 2D Electrical Resistivity Tomography (ERT) surveys along three traverses—AM (Figure 4.13), SV (Figure 4.14), and EC (Figure 4.15). Each figure displays a measured apparent resistivity pseudo-section, a calculated pseudo-section, and the inverse model resistivity section, which represents the final interpreted subsurface model after inversion. Resistivity values ranged from below 10 Ωm to over 1500 Ωm, indicating significant subsurface lithological heterogeneity across the study area.

In Traverse AM (Figure 4.13), the inverse model reveals a low resistivity zone (<50 Ωm) between 5–15 m depth, interpreted as saturated or clay-rich materials. Beneath this lies a high resistivity layer (>800 Ωm), possibly representing competent, dry bedrock, likely dolerite or pyroclastic units consistent with field observations. The lateral extent of the low-resistivity zone suggests a potential aquifer or altered mineralized zone. For Traverse SV (Figure 4.14), a more variable resistivity structure is observed. Shallow zones (<5 m depth) show intermittent high resistivity pockets (~700–1200 Ωm), alternating with low-resistivity values (<100 Ωm). At depths of 10–25 m, a continuous moderately resistive layer (300–600 Ωm) is mapped, suggestive of weathered basement or mixed lithologies. The complexity here may be due to faulting or fracturing that affects lithological contacts. In Traverse EC (Figure 4.15), the resistivity model shows a well-developed three-layer structure. The uppermost layer (0–5 m) has moderate resistivity (~100–400 Ωm), likely representing unsaturated overburden. This overlies a distinct low-resistivity zone (<70 Ωm) at 5–15 m depth, possibly a clay or water-saturated formation, underlain by a high resistivity basement (>1000 Ωm) extending beyond 20 m. The structure suggests a typical sediment-overburden–bedrock transition.

The ERT results provide important clues about the subsurface geology and possible mineralized zones. The high resistivity zones observed in Traverses AM and EC correlate with the occurrence of competent igneous rocks like dolerite or mineralized pyroclastics. In particular, the >1000 Ωm zones are indicative of massive, resistive lithologies, often associated with lead-zinc mineralization due to low fluid content and metal enrichment (Loke and Barker, 1996; Griffiths and Barker, 1993). Conversely, the low-resistivity zones (<100 Ωm) may signal clayey horizons or fluid-saturated fractures, potential hosts for secondary mineral deposits or aquifer systems. In Traverse SV, the observed heterogeneity could reflect structural controls, such as fractures or faults that influence groundwater flow or mineral deposition pathways. These findings support integrated exploration efforts, especially where resistivity highs coincide with magnetic anomalies previously discussed.

The resistivity values and subsurface architecture align with those reported in similar lead-zinc exploration studies within the Benue Trough. Ogungbe *et al*. (2013) observed comparable resistivity ranges for doleritic and pyroclastic rocks in the Abakaliki area, where values >800 Ωm were associated with mineralized formations. Similarly, Aizebeokhai and Oyeyemi (2014) emphasized the usefulness of inverted resistivity sections in distinguishing between overburden, weathered, and competent basement layers. The findings here reaffirm that integrated resistivity and magnetic surveys significantly improve subsurface characterization, particularly in complex geologic terrains like southeastern Nigeria.

Figure 4.16: Core Sample inspection core box

Figure 4.17: handpicked Core Sample

Figures 4.16 to 4.18 present lithological and mineralogical evidence from core drilling in the Ndeabor area of the Lower Benue Trough. Figure 4.16 shows a core box with rock segments from drilling, while Figure 4.17 highlights handpicked core samples bearing visible sulfide mineralization. Figure 4.18 displays a stratigraphic core log showing layers penetrated and zones of lead-zinc mineralization. A key finding was the identification of a distinct mineralized zone, dominated by pyroclastic rocks interbedded with fine limestone and shale. Mineralization was consistently observed between **17.5 m and 22.5 m,** giving a total thickness of about **5.0 meters**, in line with the **3–8 meters** range seen in other boreholes.

Analysis of the core samples reveals notable geological trends. The pyroclastics consist of coarse, dark fragments with embedded galena (PbS) and sphalerite (ZnS), often along fractures and bedding planes, suggesting that mineralizing fluids followed structural pathways. Secondary features such as chloritization and silicification around the mineral zones suggest hydrothermal alteration, common in base metal sulfide deposits within volcanic-sedimentary settings (Leach *et al*., 2010). The alternating limestone and shale layers act as barriers that channel fluid flow and promote metal precipitation at contact zones.

These findings have important implications for exploration. The consistent presence of sulfides in the pyroclastics indicates a potentially extensive ore body. The deposit style fits that of Mississippi Valley-type (MVT) or sediment-hosted lead-zinc systems, typically formed by low-temperature hydrothermal fluids migrating through carbonate platforms (Taylor *et al*., 2009). Supporting this, mineralized intervals correspond to zones of low resistivity and reduced magnetic response in earlier geophysical surveys—patterns typical of sulfide presence (Akinluyi and Olorunfemi, 2015).

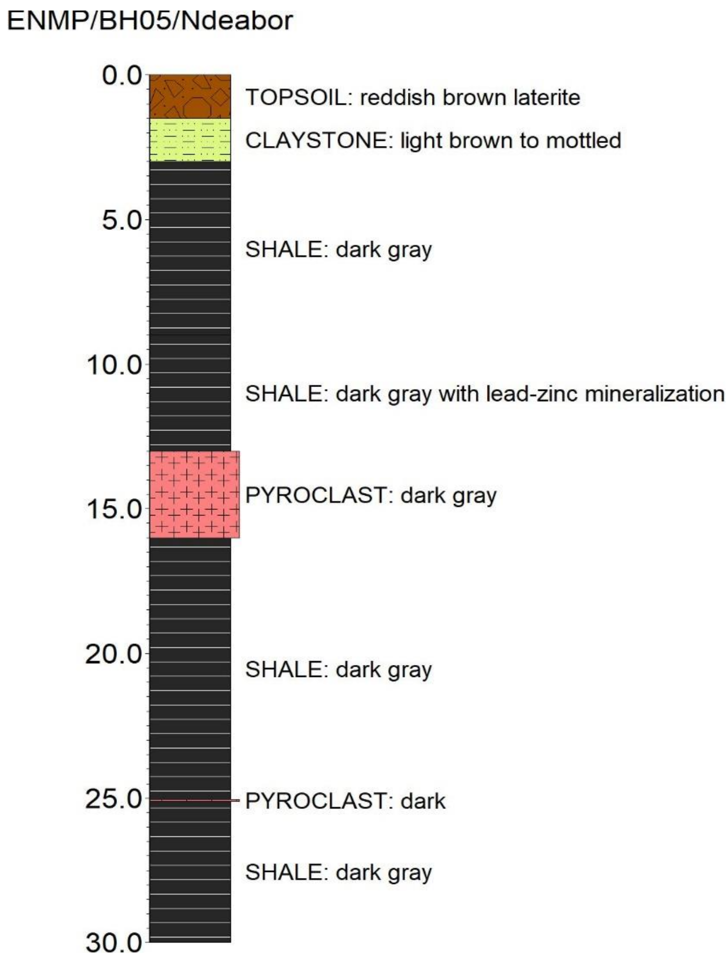

Figure 4.18: Core log from Ndeabor pyroclasts/limestone block with a clear Lead-zinc mineralization.

These results are consistent with previous studies in the Lower Benue Trough. Ezepue and Odigi (1993) reported similar lead-zinc mineralization in the Abakaliki Fold Belt, hosted in pyroclastic-carbonate sequences. Ogungbe *et al*. (2013) also identified sulfide-rich veins in altered volcanics at Ishiagu, highlighting the continuity of mineralization processes across the region. The **5.5-meter** average ore thickness and associated mineralogy observed here fall within known economic thresholds, reinforcing the exploration potential at Ndeabor and the value of integrated drilling, geophysical, and geochemical studies.

CONCLUSION

This study successfully integrated magnetic surveying, electrical resistivity tomography (ERT), and core drilling techniques to investigate lead-zinc mineralization within the Ndeabor region of the Lower Benue Trough. The geophysical data revealed magnetic anomalies and resistivity contrasts indicative of structurally controlled subsurface features, which were validated by core drilling results. Pyroclastic rock units interbedded with limestone and shale were identified as the primary host rocks, with consistent sulfide mineralization—predominantly galena and sphalerite—occurring within a stratigraphic interval averaging **5.5 meters** in thickness. The alignment of geophysical anomalies with mineralized zones in the cores underscores the effectiveness of an integrated exploration approach. These findings affirm the potential for economically viable lead-zinc deposits in the area and provide a solid framework for further resource evaluation and development.

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