

Application of Magnetic Geophysical Techniques in Investigating Subsurface Deposits in Parts of Kogi State, North-Central Nigeria

Oliver U. Ekwueme*, Samuel E. Edu and Segun O. Olayemi

16 January 2025/Accepted: 16 February 2026 /Published: 20 February 2026

Abstract: *The aeromagnetic data of the Idah and Angba areas were interpreted qualitatively and quantitatively. Source Parameter Imaging (SPI) and Forward and Inverse modeling techniques were employed in quantitative interpretation to determine the thickness of the sedimentary Basin and magnetic susceptibilities. Qualitatively, the first vertical derivative map shows areas of higher intensity (higher signal) in the north-central, west, and east of the study area. In comparison, the south region has a lower intensity (lower signal). In addition, the reduction-to-pole map shows some elliptical bodies, indicating the shapes of magnetic anomalies centered symmetrically on the body. Results from SPI estimated depth ranges from 431.5 m (shallow magnetic bodies) to 6494.3 m (deep lying magnetic bodies). Forward and inverse modeling estimated depths for profiles 1-5 were 526 m, 461 m, 4347 m, 1751 m, and 6847 m, respectively, with respective susceptibility values of 0.0003, 0.0879, 0.0800, 0.0004 and 0.0700 which indicate intermediate and basic igneous rocks (diorite, andesite and gabbro or basalts) and basic sedimentary rocks (sandstone and limestone). The maximum depths obtained from the four methods applied show sufficiently thick sediments suitable for hydrocarbon accumulation.*

Keywords: *Aeromagnetic data, Idah and Angba, FVD, RTP, Upward continuation, SPI, forward and inverse modeling, anomalous source.*

Oliver U. Ekwueme*

Department of Physics, Federal University of Technology, Akure Nigeria

Email: ouekwueme@futa.edu.ng

<https://orcid.org/0009-0005-0949-8073>

Samuel E. Edu

Department of Physics, Federal University of Technology, Akure, Nigeria

Email: benguslala2@gmail.com

Segun O. Olayemi

Department of Physics, Federal University of Technology, Akure, Nigeria

Email: olayemiphy192778@futa.edu.ng

1.0 Introduction

Magnetic surveying is a widely applied geophysical technique for investigating subsurface geological structures through measurements of spatial variations in the Earth's magnetic field caused by contrasts in rock magnetic properties. Among potential-field methods, aeromagnetic surveys provide rapid regional coverage and cost-effective characterization of basement configuration and structural features relevant to mineral and hydrocarbon exploration. Aeromagnetic survey aids in identifying major basement surface structures, which reveal encouraging exploration areas that could be studied in greater detail using seismic geophysical surveys. The Earth's magnetic field acts on the magnetic minerals in the crust, inducing a secondary field which reflects the distribution of the minerals. The main magnetic field induces a field that varies slowly from one place to another, while the crustal field, the portion of the magnetic field associated with the magnetism induced by the Earth's main magnetic field, varies more rapidly. The aeromagnetic survey is the oldest potential field method used for hydrocarbon exploration. The aeromagnetic method plays a distinguished role among geophysical methods for its rapid coverage and low cost per unit area explored. The main purpose of the aeromagnetic survey is to detect minerals or

rocks that have unusual magnetic properties, which reveal themselves by causing anomalies in the intensity of the Earth's magnetic field. The aeromagnetic survey is used to map anomalies in the Earth's magnetic field that are correlated with the underlying geological structure. Faults usually show up as abrupt changes or close spacing in the orientation of the contours, as revealed by magnetic anomalies. For hydrocarbon exploration, residual magnetic anomaly maps are useful because they identify intrusives, lava flows, and igneous plugs, which are areas to be avoided (Selley, 1998). The thickness of sediment required for hydrocarbons to form or generate varies from place to place. Consequently, aeromagnetic data interpretation has become an essential preliminary tool for delineating prospective sedimentary basins prior to detailed seismic investigations

Exploration for mineral and hydrocarbon resources has remained a major economic priority in Nigeria, particularly as the country seeks to diversify exploration activities beyond traditionally productive regions. The bedrock of Nigeria's economy before the discovery of oil had been the solid minerals and agricultural sectors, but currently, it is the oil and gas sector. Nigeria's economy remains strongly dependent on oil and gas revenues, thereby necessitating the identification of new prospective sedimentary basins. As the hydrocarbon potential of the prolific Niger Delta becomes depleted or, in the near future, may be exhausted due to continued exploitation, attention needs to be shifted to other sedimentary Basins. The Anambra Basin, in particular Idah and Angba, is one of the Basins suspected to have high hydrocarbon potential, alongside other economic mineral deposits. The Anambra Basin of Nigeria is a major tectonic feature in West Africa. It is an elongated rifted depression that trends NE-SW from the south, where it merges with the Niger Delta, to the north, where its sediments are part of the Chad Basin successions. Within this

geological framework, the Idah and Angba regions represent under-investigated segments of the basin with potential structural and stratigraphic conditions favorable for hydrocarbon accumulation.

Several aeromagnetic investigations have been conducted across different parts of the Anambra Basin using diverse analytical approaches to estimate sediment thickness, structural trends, and magnetic source characteristics. There are some published works in the Anambra Basin based on aeromagnetic data interpretations which employed different methods (Onuba *et al.*, 2011; Anyanwu and Mamah, 2013; Adetona & Abu, 2013; Ugwu *et al.*, 2013; Oweh *et al.*, 2015; Obiora *et al.*, 2015; Okiwelu *et al.*, 2015; Onwe *et al.*, 2015; Nwosu, 2015; Obiora *et al.*, 2016). The publications are based on depths to basements/magnetic source bodies over the Anambra Basin and Lower Benue Trough, in which Idah, Angba, and environs fall. However, no specific work has been carried out in the Idah and Angba area. Onuba *et al.* (2011) evaluated aeromagnetic anomalies of the Okigwe Area, Southeastern Nigeria, using regional-residual separation and slope methods. Their results obtained using slope methods indicate that the average depth of deeper magnetic sources ranges from 2.0 km to 4.99 km, while the average depth of shallower magnetic sources ranges from 0.4 km to 1.99 km. However, they did not recommend hydrocarbon exploration in the area because the average sediment thickness is low. Anyanwu and Mamah (2013) carried out a structural interpretation of Abakiliki – Ugep, using Airborne magnetic and Landsat Thematic Mapper (TM) Data. The results of the 2-D spectral analysis revealed two depth models: the shallower magnetic source bodies range in depth (D1) from 0.035 km to 1.285 km with an average depth of 0.656 km, while the deeper magnetic source bodies range in depth (D2) from 1.585 km to 4.136 km with an average depth of 3.096 km. The shallower



magnetic anomalies resulted from basement rocks that intruded into the sedimentary rocks, while the deeper magnetic anomalies are associated with intra-basement discontinuities associated with faults. They concluded that the average sedimentary thickness of 3.096 km estimated in the study area may favour hydrocarbon generation. But they did not obtain susceptibility values that determine the type of minerals in the area. Adetona and Abu (2013a) estimated sediment thickness in the lower Benue Basin and upper Anambra Basin, Nigeria, using both spectral depth determination and source parameter imaging (SPI). Spectral depth analysis of their result shows that a maximum depth above 7 km was obtained within the Cretaceous sediments of Idah, Ankpa, and below Udegi at the middle of the study area. Minimum depths of 188.0 meters to 452 meters were observed around the basement regions. Results from source parameter imaging show a minimum depth of 76.983 meters and a maximum sedimentation thickness of 9.847 km, which also occur within the Idah, Ankpa, and Udegi axes. Still, they did not identify the magnetic susceptibility values of rock minerals in the area. Obiora *et al.* (2015) interpreted the aeromagnetic data of the Nsukka area both qualitatively and quantitatively. Standard Euler deconvolution, Source Parameter Imaging (SPI), and Forward and Inverse modeling techniques were employed in the quantitative interpretation to determine the depth/thickness of the sedimentary Basin, magnetic susceptibilities, and the type of mineralization prevalent in the area. Forward and inverse modeling estimated depths for profiles 1-5 were 1644 m, 2285 m, 1972 m, 2193 m, and 1200 m, respectively, with corresponding susceptibility values of 0.0031, 0.0073, 1.4493, 0.0069, and 0.0016, which indicate the dominance of iron-rich minerals. Results from SPI estimated depth ranges from 151.6 m (outcropping and shallow magnetic bodies) to 3082.7 m (deep lying magnetic bodies). Depths of shallow magnetic

sources resulting from lateritic bodies in the outcrops within the study area, as estimated by Euler depths for the four different structural indices (SI = 0.5, 1, 2, 3), range from 9.47 m to 124.02 m; 22.51 m to 125.29 m; 39.05 m to 120.30 m; 7.99 m to 128.93 m, respectively. They concluded that depths of 35 m to 150 m are good potential water reservoirs for Nsukka and environs, and depths of 1644.0 m to 3082.7 m show sufficiently thick sediments suitable for hydrocarbon accumulation. But they did not determine the presence of faults or lineaments in the region. Onwe *et al.* (2015) estimated sedimentary thickness in the eastern Anambra Basin through qualitative and quantitative interpretation of aeromagnetic data. Their enhancement of magnetic anomalies associated with faults and other structural discontinuities was achieved using a band-pass filter. Their Qualitative interpretation was based on visual inspection of the anomaly contour map, while the quantitative interpretation was estimated using Peters' half-slope method. Interpretation of the results shows that the basin floor was characterized by block faults whose widths range from 15 km to 45 km, trending in the Northeast-Southwest and East-West directions, with an average sedimentary thickness of 4.56 km. Still, they did not determine the types of minerals prevalent in the area of interest. Collectively, these studies demonstrate the effectiveness of aeromagnetic techniques in estimating basement depth and structural configuration within the Anambra Basin. However, variations in analytical methods and study objectives have resulted in incomplete characterization of certain regions, particularly regarding integrated determination of magnetic susceptibility, structural geometry, and detailed subsurface interpretation. Despite previous investigations within the Anambra Basin and adjoining regions, detailed aeromagnetic interpretation focusing specifically on the Idah and Angba areas remains limited. In particular, integrated analysis combining depth estimation, magnetic susceptibility evaluation,



and structural characterization has not been comprehensively undertaken for this locality. This study aims to investigate subsurface structures within the Idah and Angba areas of Kogi State using qualitative and quantitative interpretation of aeromagnetic data. Specifically, the study seeks to: (i) determine the geometry, dip, and nature of magnetic source bodies; (ii) estimate basement depth and sedimentary thickness; and (iii) evaluate magnetic susceptibility values to infer lithological characteristics and hydrocarbon prospectivity. The findings of this study are expected to contribute to improved geological understanding of the Anambra Basin by providing detailed subsurface characterization of an underexplored region. The integration of multiple aeromagnetic interpretation techniques will enhance exploration models for hydrocarbon and mineral resources and provide baseline geophysical information for future seismic and

geological investigations in north-central Nigeria.

1.1 Location of the Study Area

The study area is located within the Idah and Angba regions of Kogi State in North-Central Nigeria and forms part of the Anambra sedimentary Basin.

The area is bounded by Latitude $7^{\circ} 00'N$ to $7^{\circ} 30'N$ and Longitude $6^{\circ} 30'E$ to $7^{\circ} 30'E$. Two aeromagnetic maps covered the study area, and they are represented by sheets numbers 267 and 268. The study area is about 6050 square kilometres. Part of the area lies within the sedimentary terrain, and part within the basement complex. The area lies within the Anambra Basin. Fig. 1 is the map of Nigeria showing the study area. The geographical position of the study area makes it strategically important for understanding basin evolution and assessing hydrocarbon potential within inland sedimentary basins of Nigeria

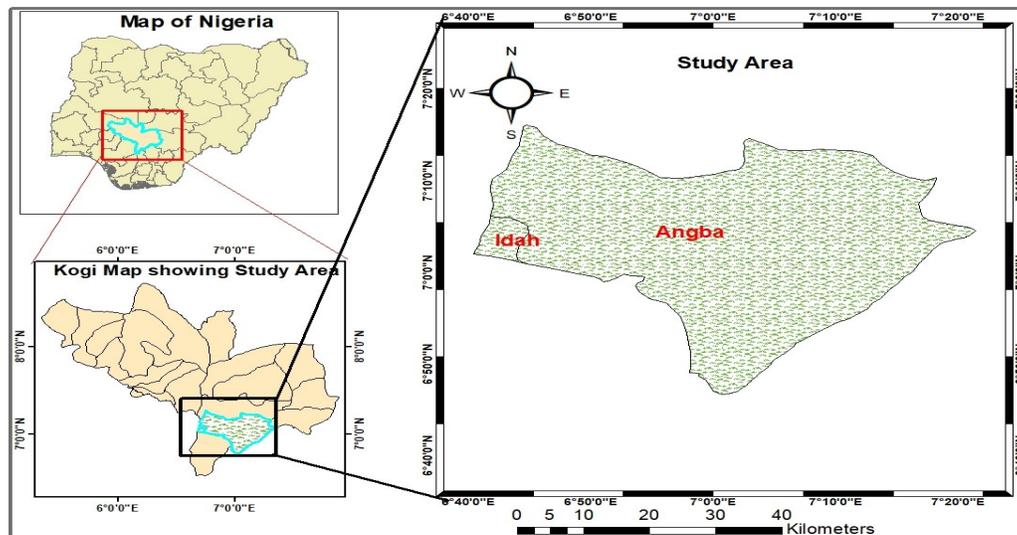


Fig. 1: Map of Nigeria showing the study area (Ekwueme, 2025)

1.2 Geology of the Study Area

The study area lies within the Anambra Basin (Fig. 1), one of the major sedimentary basins in southeastern Nigeria characterized by complex stratigraphic and tectonic evolution. The stratigraphy of this basin has been extensively

documented in previous studies (Obiora *et al.*, 2015; Adetona & Abu, 2013; Odumoso *et al.*, 2013; Adeigbe & Salufu, 2009). The basin comprises a sequence of major lithostratigraphic units, including the Enugu Shale, Agwu Shale, Mamu Formation, Ajali



Sandstone, Nsukka Formation, and Imo Shale. These units are commonly grouped into four principal formations: the Mamu Formation, the Ajali Sandstone, the Nsukka Formation, and the Imo Shale (Nwajide & Reijers, 1995; Onwuemesi, 1995).

Sedimentation within the basin occurred across four main physiographic zones: the Cross River Plains, the Escarpment, the Plateau, and the Anambra Plains. The sedimentary succession attains an estimated thickness of more than 3,900 m and consists predominantly of shale, sandstone, limestone, and coal deposits. These sediments were formed in a range of depositional environments, spanning marine, brackish, and continental settings. Economically, the basin is significant due to the presence of coal, natural gas, glass sands, and potential hydrocarbon resources (Obiora *et al.*, 2015).

The depositional history of the basin began during the Campanian–Maastrichtian with the accumulation of marine-to-paralic shales of the Enugu and Nkporo Formations, followed by the coal-bearing sequences of the Mamu Formation. Overlying these are the fluviodeltaic sandstones of the Ajali and Owelli Formations, which also occur as lateral equivalents of the Mamu Formation in several locations. During the Paleocene, marine conditions led to the deposition of the Imo and Nsukka Formations, which the Eocene Nanka Sandstone subsequently overlay. Basinward, toward the Niger Delta, the Akata Shale and Agbada Formation represent stratigraphic equivalents of these Paleocene deposits.

The Imo Shale records a renewed phase of marine transgression in the Paleocene. It is characterized by appreciable organic matter content, suggesting potential as a hydrocarbon source rock, although maturity levels within the Anambra Basin are generally limited. The Enugu and Nkporo Shales are interpreted as brackish-water marsh-to-prodelta deposits formed during the Late Campanian–Early Maastrichtian. Their deposition reflects a

shallow marine environment that transitioned into low-energy, channelized marsh systems.

A regressive phase followed, during which the coal-bearing Mamu Formation and the overlying Ajali Sandstone were deposited. The Mamu Formation extends north–south from the Calabar Flank, curving westward around the Ankpa Plateau and terminating near Idah along the Niger River. Notable exposures of the Nkporo Shale occur at Leru, while the Ajali Sandstone represents peak regression under a concave shoreline configuration. Sedimentation during this period was influenced by converging littoral drift systems, as evidenced by the development of tidal sand waves, particularly along the Enugu–Port Harcourt expressway.

The Enugu Shale is well-exposed around Enugu, especially near the Onitsha Road flyover. In contrast, the Mamu Formation is prominently displayed at Miliken Hills, with clear sections visible along roadcuts and along the left bank of the Ekulu River. A geological map of the study area is presented in Fig. 2.

1.3 Source of Aeromagnetic Data

The aeromagnetic dataset used in this study was acquired during a nationwide airborne geophysical survey conducted by the Nigerian Geological Survey Agency (NGSA) in 2009. The aeromagnetic data were obtained using a 3x Scintrex CS3 cesium vapour magnetometer. Fugro Airborne Surveys conducted the airborne geophysical survey. Aeromagnetic surveys were flown at 500m line spacing and 80m terrain clearance. The average magnetic inclination and declination across the survey area were -11.6° and -1.5° , respectively. The geomagnetic gradient was removed from the data using the International Geomagnetic Reference Field (IGRF) in 2009, and the data were collected in digitized form (X, Y, Z).

The X and Y represent the Northing (longitude in meters) and Easting (latitude in meters), respectively, and Z represents the magnetic intensity measured in nanotesla (nT).



2.0 Methods and analysis of data

Both qualitative and quantitative interpretation techniques were employed to analyze the aeromagnetic data. Qualitative interpretation involved visual examination of the Total Magnetic Intensity (TMI) grid to identify anomaly patterns and structural trends within the study area. The TMI data were processed

and presented as colour-shaded maps to enhance visualization of magnetic variations. Quantitative interpretation was subsequently carried out using Source Parameter Imaging (SPI) and forward and inverse modeling techniques to estimate subsurface depths, geometry, and magnetic susceptibility contrasts.

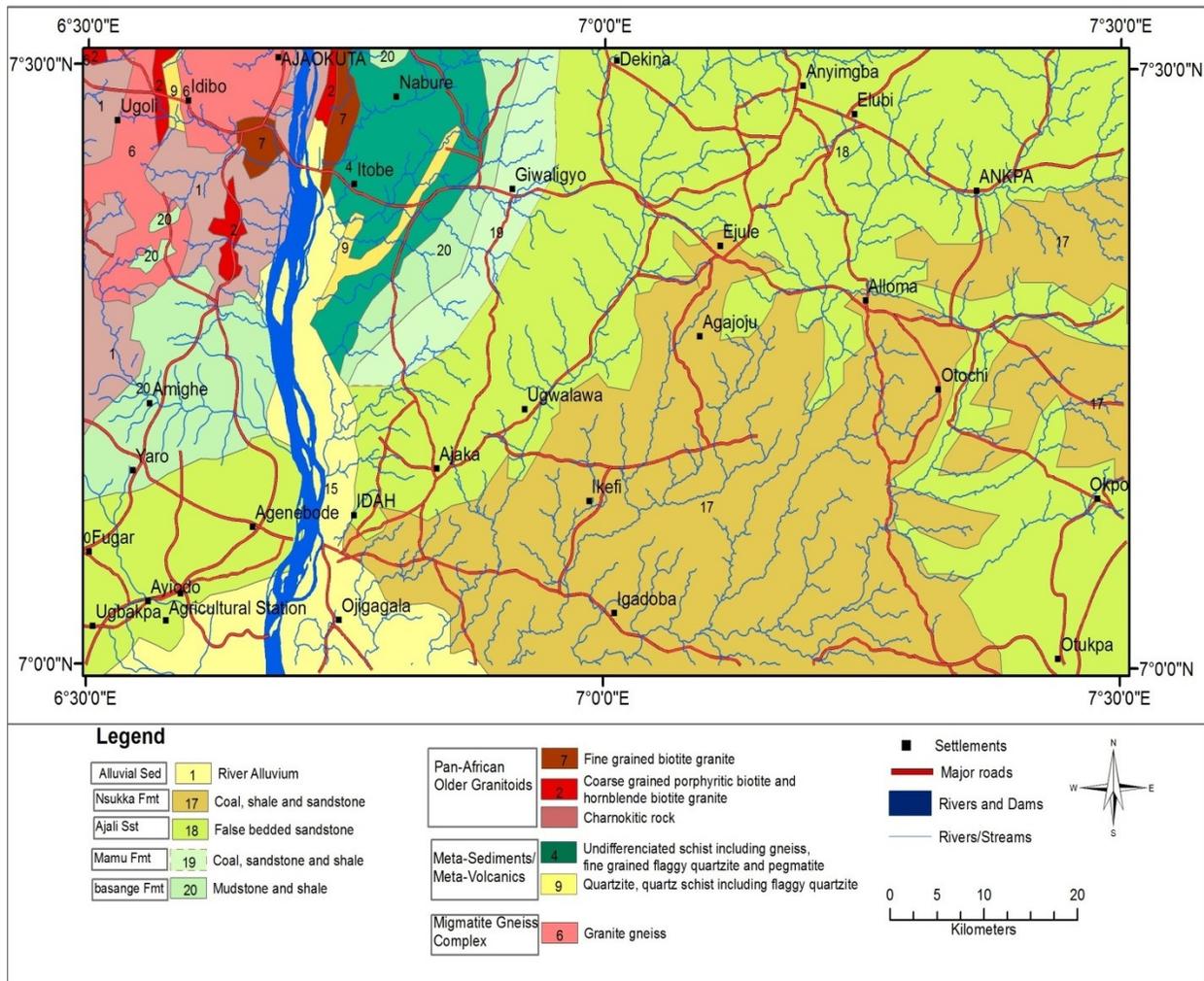


Fig. 2: Geology map of the study area.

Prior to quantitative interpretation, several data enhancement and filtering procedures were applied to improve anomaly resolution and facilitate accurate structural interpretation. The initial stage of quantitative interpretation involved applying mathematical filtering techniques, including reduction-to-pole (RTP), upward continuation, and first vertical

derivative (FVD), to the observed magnetic data. Each filtering technique serves a distinct purpose in enhancing anomaly characteristics and improving interpretation reliability.

The general purpose is to enhance anomalies of interest and to gain some basic information on source location or magnetization. The upward projection (upward continuation) operation



smooths anomalies observed at the ground surface by projecting them mathematically upward above the original datum (Reeves, 2005). Reduction-to-pole transformation was applied to reposition magnetic anomalies directly over their causative sources by correcting for magnetic inclination and declination effects. Upward continuation smooths short-wavelength anomalies by mathematically projecting the magnetic field to higher elevations, thereby emphasizing deeper geological sources (Reeves, 2005).

Application of the reduction-to-pole filter simplified anomaly geometry, producing predominantly positive anomalies centered above magnetized bodies as expected under conditions of vertical magnetic inclination. The first vertical derivative helped sharpen anomaly edges and enhance shallow features (Reeves, 2005).

Source Parameter Imaging (SPI) is an automated interpretation technique used to estimate depth and structural parameters of magnetic sources from gridded magnetic data based on analytic signal theory. The estimate of the depth is independent of the magnetic inclination, declination, dip, strike, and any remanent magnetization. Estimation of source parameters can be performed on gridded magnetic data. This has two advantages. First, this eliminates errors caused by survey lines that are not oriented perpendicular to strike. Second, there is no dependence on a user-selected window or operator size. Consequently,

$$\begin{aligned} \text{Depth} &= \frac{1}{K_{max}} = \frac{1}{(\sqrt{(\partial Tilt/\partial x)^2 + (\partial Tilt/\partial y)^2})_{max}}, \end{aligned} \tag{1a}$$

where the Tilt is given as

$$\begin{aligned} \text{Tilt} &= \arctan\left(\frac{\partial T/\partial Z}{\sqrt{(\partial T/\partial X)^2 + (\partial T/\partial Y)^2}}\right) = \\ \arctan\left(\frac{\partial T/\partial Z}{HGRAD}\right) \end{aligned} \tag{1b}$$

where T represents the total magnetic intensity, $\partial T/\partial x$, $\partial T/\partial y$, and $\partial T/\partial z$ denote spatial derivatives of the magnetic field along the x-, y-, and z-directions, respectively, and HGRAD represents the horizontal gradient magnitude (Thurston and Smith, 1997). The depth is displayed as an image. The original SPI method works for two models: a dipping thin dike and a sloping contact. The SPI method utilizes first- and second-order derivatives of the magnetic field; therefore, careful data filtering is required to minimize amplification of noise inherent in derivative operations. The horizontal derivatives (dx, dy) and vertical derivatives (dz) were first calculated from the TMI grid; these parameters, along with the tilt derivative, are then used to compute the SPI grid.

Forward modeling involved comparing the calculated field of a hypothetical source with that of the observed data; the model was adjusted to improve the fit for a subsequent comparison. The technique is used to estimate the source geometry or the distribution of magnetization within it using a trial-and-error approach. Inverse modeling involved the direct determination (as opposed to trial-and-error or indirect determination) of some parameters of the source from the measured data. In this method, it is customary to constrain some parameters of the source in some way, realizing that every anomaly has an infinite number of permissible sources leading to an infinite number of solutions. The software used for modeling and inversion of the anomalies is powerful. Potent is a program for modeling the magnetic and gravitational effects of subsurface. It provides a highly interactive 3-D environment that, among other applications, is well-suited for detailed ore-body modeling in mineral exploration. The main concepts in potent include: Observation, Inversion, Model, Visualization, and Calculation. Interpretation of magnetic field data using potential starts with observation of the image of the observed data (Obiora *et al.*, 2015).



3.0 Results and Discussion

3.1 Results

The processed aeromagnetic data were interpreted using both qualitative and quantitative approaches to characterize subsurface structural features and estimate magnetic source parameters within the study area. The results are presented through enhanced magnetic maps, depth estimation outputs, and forward-inverse modelling analyses, with interpretations supported by Figs. 3–9 and Table 1.

3.1.1 Qualitative interpretation

Qualitative interpretation of the aeromagnetic data was conducted using the Total Magnetic Intensity (TMI) map (Fig. 3) to identify regional magnetic patterns and structural trends within the study area. The TMI map (Fig. 3) was generated from digitized XYZ aeromagnetic data obtained from the Nigerian Geological Survey Agency (NGSA) and processed using Oasis Montaj software. The total magnetic intensity was produced from digitized data (XYZ data) collected from the Nigerian Geological Survey Agency (NGSA) using the Oasis Montaj software. The observed magnetic intensity range reflects significant

variations in subsurface lithology and basement configuration, indicating heterogeneous magnetic source distributions across the study area (Fig. 3). The magnetic intensity of the area ranges from a minimum of -114.331 nT to a maximum of 153.799 nT. The area is marked by both high and low magnetic signatures, which could be attributed to several factors, including variations in magnetic susceptibility, depth, strike, and lithology. The closely spaced, sub-parallel linear contours observed in the northern and southern portions of the TMI map (Fig. 3) suggest the presence of fault systems or fracture zones that may control subsurface structural deformation.

Most of the anomalous features trend in the East-West direction, while minor ones trend Northeast-Southwest. The elliptical contour closures seen in the study area suggest the presence of magnetic bodies. The main trend of the lineaments is East-West, while a few trend Northeast-Southwest. The dominant East-West structural trend observed in Fig. 3 corresponds with regional tectonic orientations reported within the Anambra Basin and may represent reactivated basement-controlled structures influencing sediment deposition.

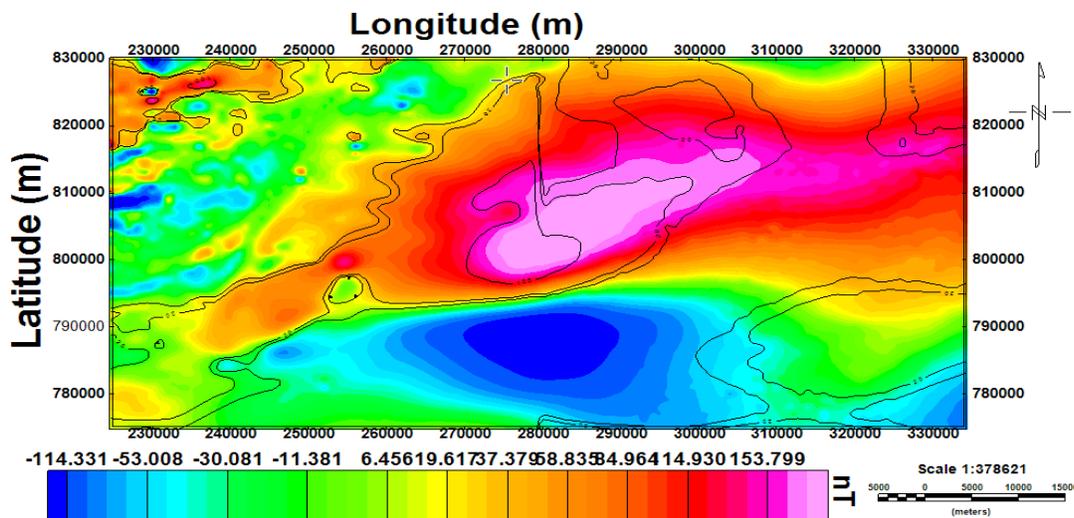


Fig. 3: Total magnetic intensity map of the study area.



The upward continuation map (Fig. 4) was generated to emphasize deeper magnetic sources by attenuating short-wavelength anomalies associated with shallow structures. The smoother anomaly patterns observed in Fig. 4 indicate dominance of deeper regional magnetic sources relative to near-surface contributions.

By projecting to a higher plane, we effectively smooth the anomalies observed at the ground surface. The first vertical derivative map (Fig. 5) enhances shallow magnetic features by sharpening anomaly boundaries and improving delineation of structural edges. The shape of any magnetic anomaly depends on the inclination and declination of the main

magnetic field of the Earth. Thus, the same magnetic body will produce an anomaly of a different shape depending on its position and orientation. By implementing Reduction to Pole (RTP) Enhanced edge definition in Fig. 5 reveals possible fault contacts and lithological boundaries not clearly visible in the original TMI map (Fig. 3). Application of the Reduction-to-Pole (RTP) filter produced anomalies centered directly above their causative sources, thereby simplifying interpretation of magnetic body locations (Fig. 6). The RTP map (Fig. 6) confirms the structural trends identified in the TMI map (Fig. 3), validating the dominance of East–West-oriented magnetic lineaments.

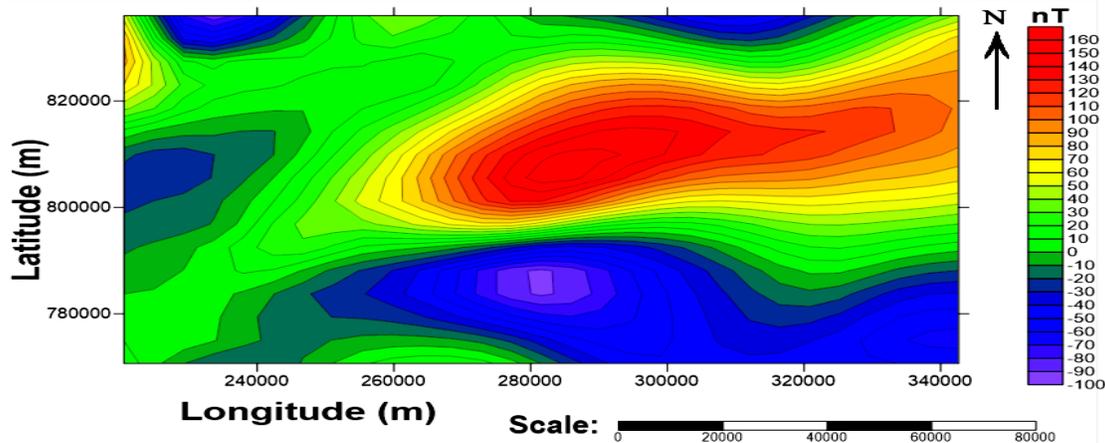


Fig. 4: Upward continuation produced from the TMI map.

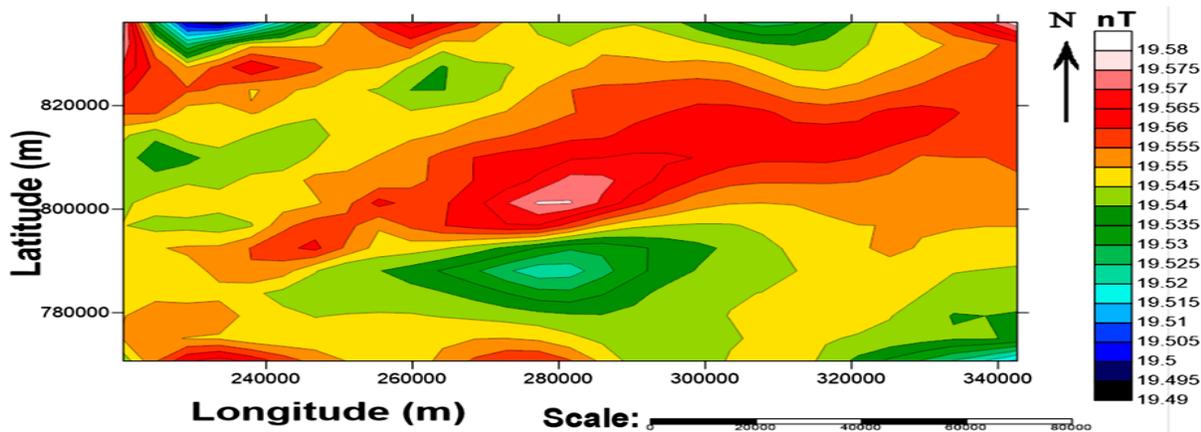


Fig. 5: First vertical derivative produced from the TMI map.



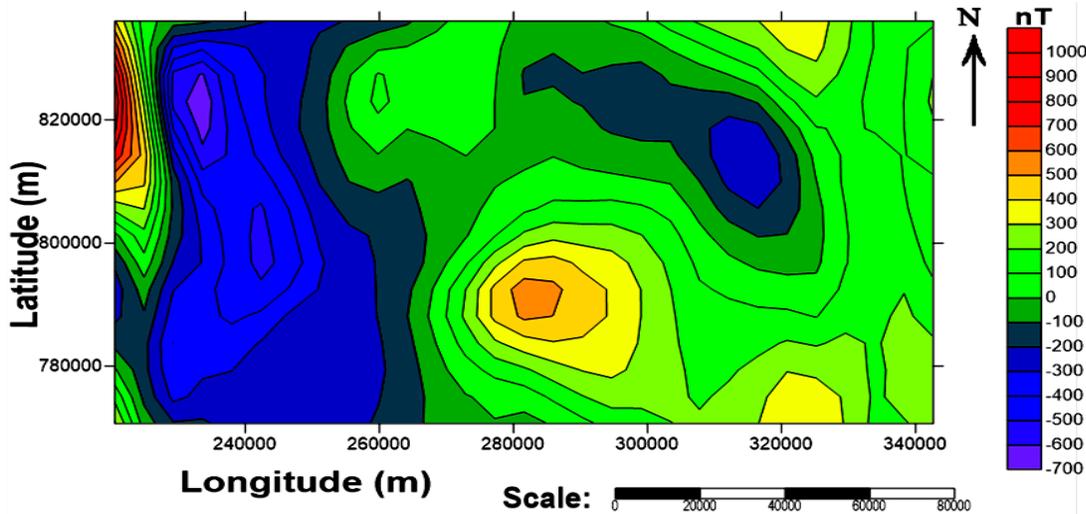


Fig. 6: Reduction to Pole produced from TMI map.

3.1.2 Quantitative interpretation:

Quantitative interpretation of the aeromagnetic data involved Source Parameter Imaging (SPI) depth estimation and forward-inverse modeling analyses to determine subsurface geometry and magnetic susceptibility distribution.

3.1.2.1 Interpretation of the source parameter imaging result

Source Parameter Imaging (SPI) analysis was performed using Oasis Montaj software to

estimate depths to magnetic sources and visualize basement morphology. The SPI grid image and legend (Fig. 7a) display spatial variations in magnetic source depth represented by colour contrasts. Negative legend values correspond to increasing depth below the surface. Blue colours indicate deeper magnetic sources and thicker sedimentary cover, whereas pink, purple, orange, and yellow colours represent relatively shallow magnetic bodies.

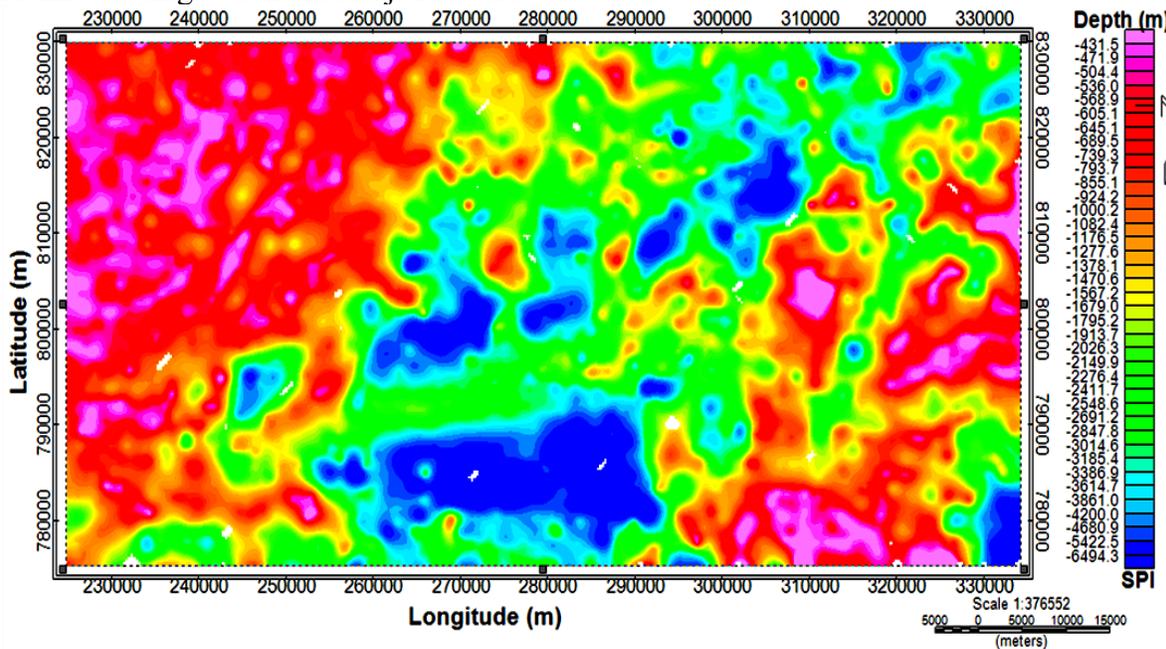


Fig. 7a: 2-D Source parameter imaging (SPI) grid and legends of the study area



The negative values on the numbers in the legend signify depth. The blue colour in the legend shows areas of thicker sediments or deep-lying magnetic bodies. The pink, purple, orange, and yellow colours in the SPI legends indicate areas of shallower sediment or near-surface lying magnetic bodies. The depth of the magnetic source ranges from 431.5 m to 6494.3 m. The estimated depth range of 431.5 m to

6494.3 m suggests significant variation in sedimentary thickness, with deeper zones potentially favorable for hydrocarbon maturation conditions. The three-dimensional SPI visualization (Fig. 7b) highlights two principal depth regimes characterized by elongated deep-source spikes and shorter shallow-source spikes, representing variations in basement relief across the study area.

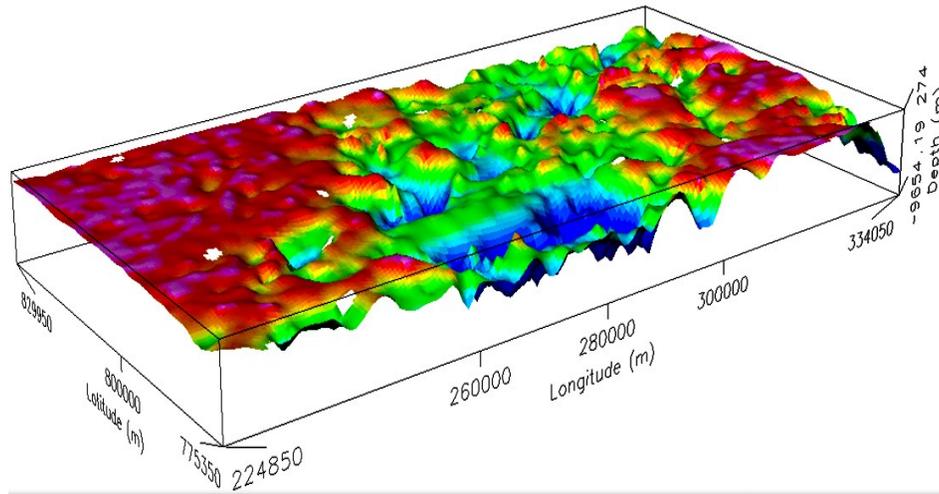


Fig. 7b: 3-D Source parameter imaging (SPI) grid and legends of the study area

3.1.2.2 Interpretations of the forward and inverse modeling results

Five representative profiles were extracted from the residual magnetic map (Fig. 8) to perform forward and inverse modeling of

magnetic anomalies. Fig. 8 shows the profile taken from the residual magnetic map of the study area, and part of the subsets are shown in Figs. 9(a-c).

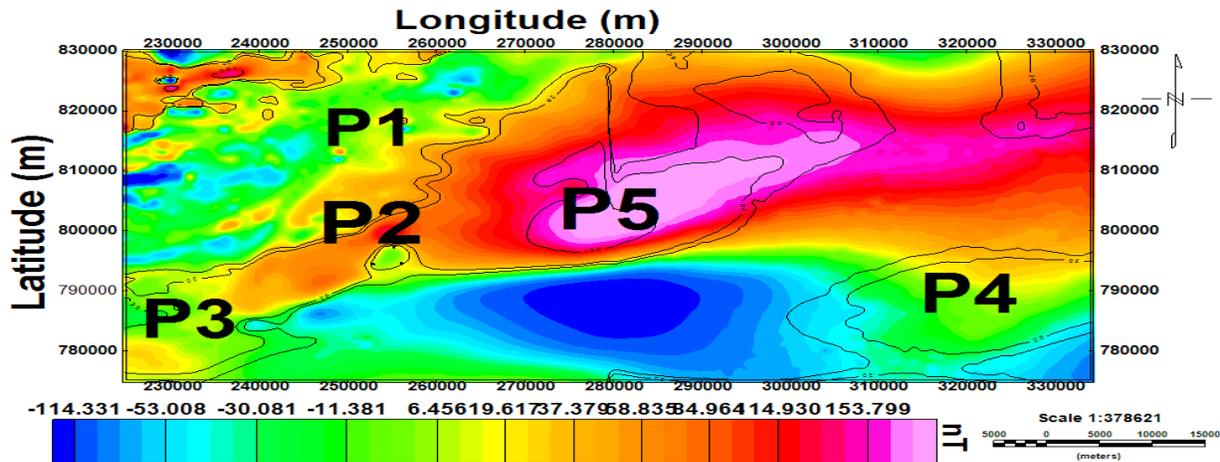


Fig. 8: Total magnetic contour grid map showing five profiles



Selected modeled profiles are presented in Figs. 9a–9c to illustrate representative subsurface geometries derived from the inversion process. As a result, the blue curves represent the observed field, while the red curves represent the calculated fields from the model. During the forward modeling session, the shape, position, and physical properties of the model were adjusted to obtain good agreement between the calculated and observed fields. The field was calculated by interpolation at the actual observation points (the only points where the observed field is known). Potent, therefore, automatically calculated the field from the model in response to the changes made to the model. The observed values are depicted as an image and as a single N-S and E-W profile. During forward modeling, subsurface body geometry, depth, and magnetic susceptibility were

iteratively adjusted until the calculated magnetic response closely matched the observed anomaly profiles (Figs. 9a–9c). Model fit quality was evaluated using root-mean-square (RMS) error values between observed and calculated fields. An RMS error value below 10 was adopted as the acceptable threshold indicating satisfactory agreement between observed and modeled magnetic responses. The RMS value of less than ten was set as an acceptable error margin for the inversion results. These modeled susceptibility values and depths collectively indicate the coexistence of sedimentary and igneous bodies within the study area, suggesting complex basement architecture influencing magnetic anomaly distribution. parameters, including geometry, depth, and inferred lithology, is presented in Table 1.

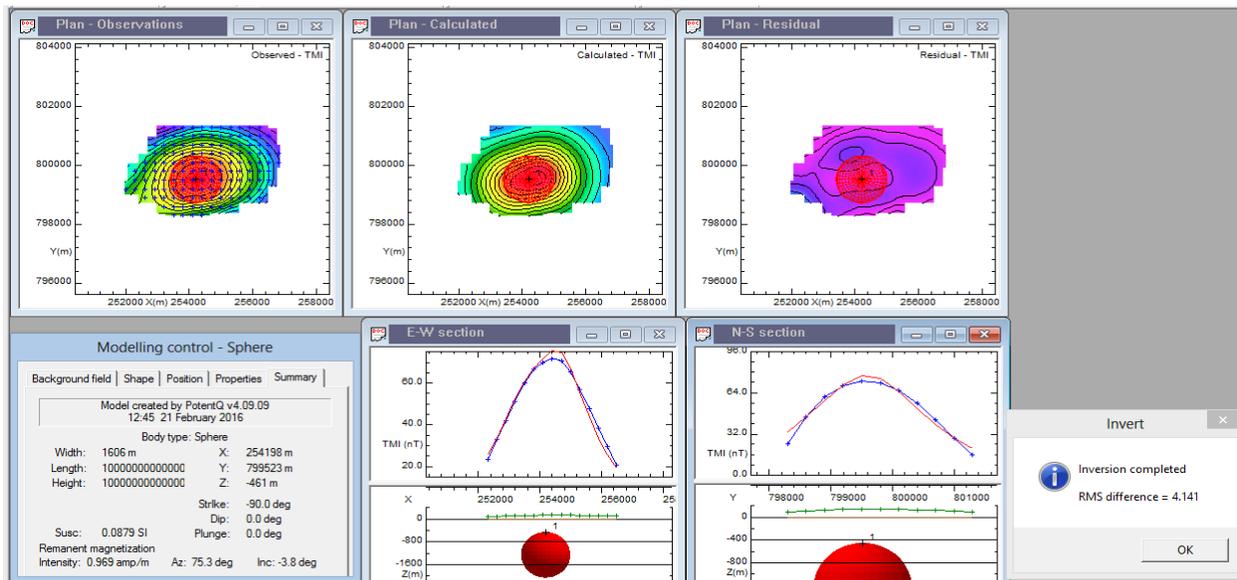


Fig. 9a: Model (sphere) result of profile 2.

The sub profiles in each model show the variations in field values with distance across the modeled area or at modeled points. Profiles P1 and P4, taken around the north-western and south-eastern parts of the study area, were modeled by a sphere shape and a rectangular prism emplaced at depths of 526 m and 1751 m, respectively. The bodies have magnetic

susceptibilities of 0.0003 and 0.0004, respectively, suggesting that the bodies causing the anomaly are typical of basic sedimentary rocks, such as sandstone and limestone (Telford *et al.*, 1990). Profiles P2 and P3, taken in the west and southwest part, were modeled by sphere shapes emplaced at depths of 461 m and 4347 m with susceptibility values of



0.0879 and 0.0800, respectively, suggesting that the bodies causing the anomaly are typical of intermediate igneous rocks; diorite and andesite (Telford *et al.*, 1990). The Profile P5 taken in the north central was modeled as an ellipsoid, emplaced at a depth of 6847 m, with a magnetic susceptibility of 0.0700, revealing

basic igneous rocks (gabbro or basalt), Telford *et al.* (1990). Regions represented by blue colours in the modeling map (Fig. 8) could not be reliably modeled, likely due to extremely low magnetic contrasts or insufficient anomaly amplitude for stable inversion solutions. A comprehensive summary of modeled body

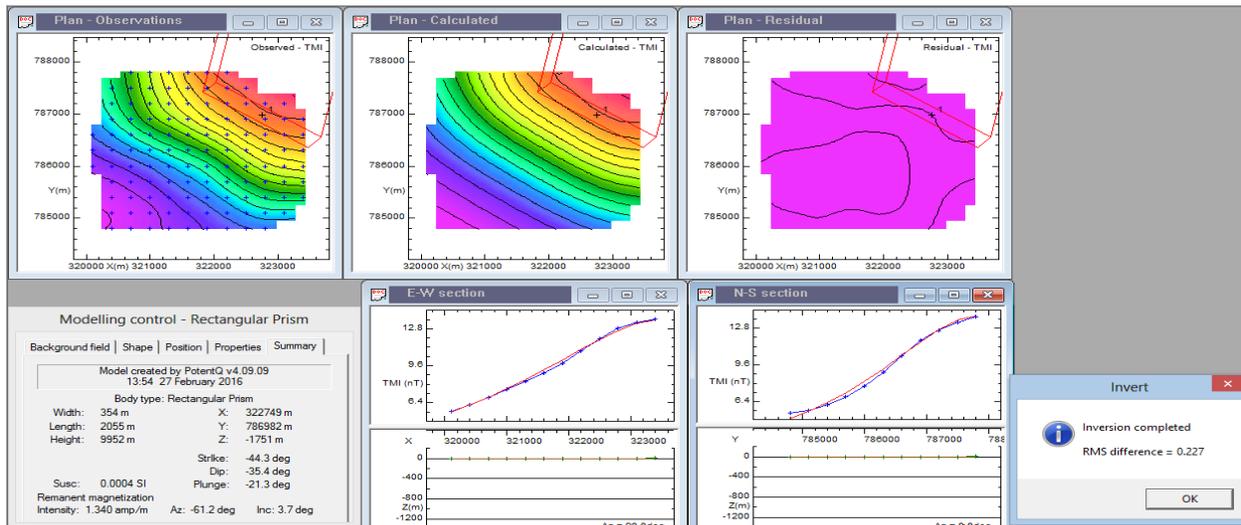


Fig. 9b: Model (Rectangular prism) result of profile 4.

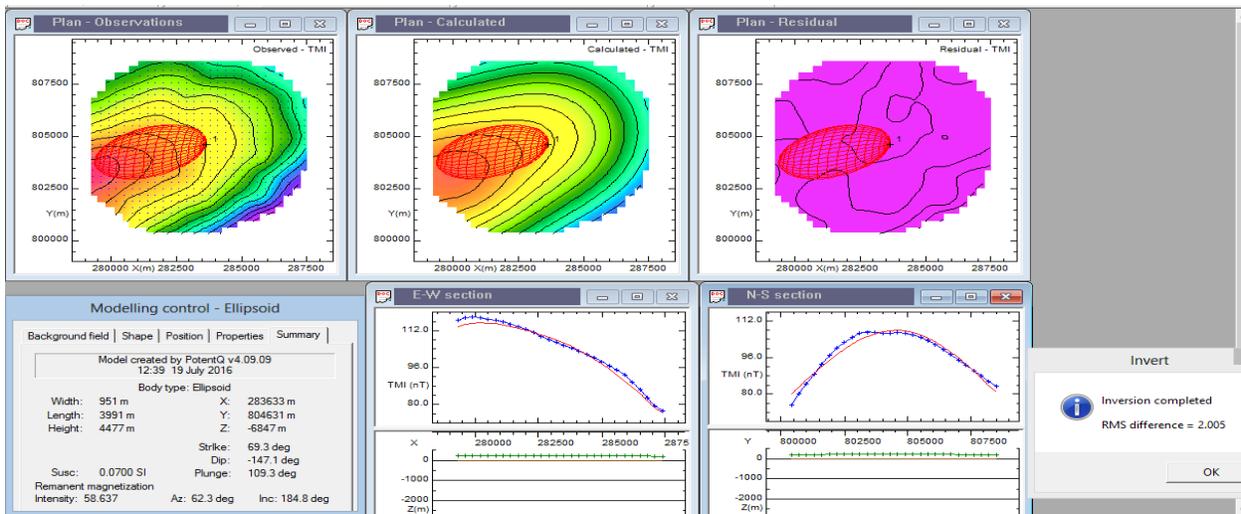


Fig. 9c: Model (Ellipsoid) result of profile 5

3.2 Discussion

Qualitative interpretation of the aeromagnetic data was performed through visual analysis of the Total Magnetic Intensity (TMI) map, regional magnetic trends, upward continuation, first vertical derivative, and reduction-to-pole

(RTP) maps (Figs 3–6) to identify structural features and magnetic source distributions within the study area. The total magnetic field intensity ranges from -114.3 to 183.5 nT, reflecting significant contrasts in magnetic susceptibility and variations in basement depth



across the study area (Fig. 3). The closely spaced, sub-parallel linear contours observed in the northern and southern sectors of the TMI map (Fig. 3) indicate structurally controlled zones interpreted as faults or fracture systems

that may influence subsurface lithological distribution. Most of the anomalous features trend in the East-West direction, while minor ones trend Northeast-Southwest. .

Table 1: Summary of modeling results.

Model	X(m)	Y(m)	Depth (m)	Types of body	Dip (deg.)	Plunge (deg.)	Strike (deg.)	K value	Possible cause of anomaly
1	256023	818283	-526	Sphere	0.0	0.0	-90.0	0.0003	Limestone
2	254198	799523	-461	Sphere	0.0	0.0	-90.0	0.0879	Diorite
3	228074	779201	-4347	Sphere	0.0	0.0	-90.0	0.0800	Andesite
4	322749	786982	-1751	Rect. prism	-35.4	-21.3	-44.3	0.0004	Sandstone
5	283633	804631	-6847	Ellipsoid	-	109.3	69.3	0.0700	Gabbro or Basalt

The first vertical derivative map (Fig. 5) enhances shallow magnetic sources and clearly delineates zones of high magnetic response concentrated in the north-central, western, and eastern regions, while relatively low responses dominate the southern area. The first vertical derivative map (Fig. 5) enhances shallow magnetic sources and clearly delineates zones of high magnetic response concentrated in the north-central, western, and eastern regions, while relatively low responses dominate the southern area. In comparison, the south region has a lower intensity (low signal). The reduction-to-pole (RTP) map (Fig. 6) reveals elliptical anomaly patterns centered directly above their causative bodies, facilitating improved localization of magnetic sources. The upward continuation map (Fig. 4) emphasizes deeper regional magnetic sources by smoothing short-wavelength anomalies associated with shallow structures, thereby highlighting basement-controlled features. Depth estimates derived from Source Parameter Imaging (SPI) and forward-inverse modelling show strong consistency, indicating reliable characterization of shallow and deep magnetic sources. The SPI grid image and colour legend (Fig. 7a) illustrate variations in magnetic source depth and susceptibility

contrasts, reflecting undulations in the basement surface and spatial variations in sedimentary thickness. The depth range of 431.5 m to 6494.3 m suggests heterogeneous basement topography, with deeper zones potentially representing structural depressions favorable for sediment accumulation. In the modeled profiles (Figs. 9a–9c), the blue curves represent observed magnetic responses, whereas the red curves correspond to calculated model responses obtained through iterative forward modeling and inversion. The modeled depth estimates closely agree with SPI-derived depths (Fig. 7a), thereby validating the robustness of the applied quantitative interpretation techniques.

The profiles, which represent three out of five models, were modeled with ellipsoid, sphere, and rectangular prism bodies at depths of 526 m, 461 m, 4347 m, 1751 m, and 6847 m, respectively, with corresponding susceptibility values of 0.0003, 0.0879, 0.0800, 0.0004, and 0.0700. The derived susceptibility values indicate the coexistence of intermediate and basic igneous rocks alongside sedimentary units such as sandstone and limestone, suggesting a complex basement architecture beneath the study area.



3.3 Comparison with Previous Studies in the Anambra Basin

The results obtained in this study were evaluated in relation to previous geophysical investigations conducted within different parts of the Anambra Basin to assess regional consistency. Although slightly higher than the depths estimated in the present study, the values reported by Adetona & Abu (2013) fall within comparable regional depth ranges, indicating similar basement configurations across the basin. Ankpa, and beneath Udegi, located in the central part of the basin. They also identified minimum depth estimates ranging from 188 to 452 m in areas underlain by basement rocks. These values are slightly higher than the depth estimates obtained in the present study.

Similarly, Igwesi & Umego (2013) proposed a two-layer magnetic source model, with depths to deeper magnetic sources ranging from 1.16 to 6.13 km (average of 3.03 km), and shallower sources ranging from 0.016 to 0.37 km (average of 0.22 km). Their results show reasonable agreement with the present study, particularly with respect to the deeper magnetic sources. These results show strong agreement with the present study, particularly regarding deeper magnetic sources interpreted as basement structures.

The lithological interpretations derived from susceptibility values reported by Obiora *et al.* (2016) closely align with those obtained in the present study, reinforcing the reliability of forward and inverse modeling in identifying subsurface rock types. Their susceptibility analysis indicated that Profile 1 (0.0175) corresponds to non-magnetic sedimentary deposits, Profile 2 (0.07) is characteristic of basic igneous rocks (e.g., gabbro and basalt), while Profiles 3, 4, and 5 (0.01–0.013) are indicative of intermediate igneous rocks such as diorite and andesite. These findings are consistent with the results of the present study, particularly regarding lithological

interpretations derived from forward and inverse modeling.

It is important to note, however, that these previous studies were conducted in other parts of the Anambra Basin and did not specifically cover Idah and Angba in Kogi State, which constitute the focus of the present investigation. It should be emphasized that earlier studies focused on other segments of the Anambra Basin, whereas the present investigation specifically targets the Idah and Angba areas of Kogi State. Consequently, this study provides new localized geophysical insights that contribute to improved understanding of basement configuration and lithological distribution within previously under-investigated portions of the basin.

3.4 Conclusion

This study investigated the magnetic anomalies of the Idah and Angba areas through qualitative and quantitative interpretation of aeromagnetic data. Source Parameter Imaging (SPI) together with forward and inverse modeling techniques were employed for quantitative analysis. The SPI results revealed depth estimates for anomalous sources ranging from 431.5 m to 6494.3 m. Forward and inverse modeling results (Table 1) yielded depth estimates of 526 m, 461 m, 4347 m, 1751 m, and 6847 m for Profiles 1–5, respectively, with corresponding susceptibility values of 0.0003, 0.0879, 0.0800, 0.0004, and 0.0700. Based on susceptibility classifications reported by Telford *et al.* (1990), Profiles 2, 3, and 5 are interpreted to correspond to intermediate and basic igneous rocks such as diorite, andesite, gabbro, and basalt. The depth estimates obtained in this study agree well with those reported by previous researchers (Adetona and Abu, 2013; Igwesi and Umego, 2013; Obiora *et al.*, 2015; Obiora *et al.*, 2016) within the Lower Benue Trough and Anambra Basin. Results from the SPI and modeling analyses indicate that the Idah and Angba areas possess sufficiently thick sedimentary sequences that may favor



hydrocarbon accumulation. Overall, the integrated application of SPI and modeling techniques enhances understanding of subsurface structural configuration and provides important implications for hydrocarbon exploration within the study area.

5.0 References

- Adeigbe, O. C., & Salufu, A. E. (2009). Geology and depositional environment of Campano–Maastrichtian sediments in the Anambra Basin, southeastern Nigeria: Evidence from field relationship and sedimentological study. *Earth Science Research Journal*, 13(2), 58–75. <https://revistas.unal.edu.co/index.php/esrj/article/view/13664>
- Adetona, A. A., & Abu, M. (2013). Estimating the thickness of sedimentation within Lower Benue Basin and Upper Anambra Basin, Nigeria, using both spectral depth determination and source parameter imaging. *Geophysics*, 1–10. <https://doi.org/10.1190/geo2012-0149.1>
- Anyanwu, G., & Mama, L. (2013). Structural interpretation of Abakaliki–Ugep using airborne magnetic and Landsat Thematic Mapper (TM) data. *Journal of Natural Sciences Research*, 3(13), 137–148. <https://www.iiste.org/Journals/index.php/JNSR/article/view/8457>
- Ekwueme, O. U. (2025). Structural mapping of the Idah and Angba regions, North-Central Nigeria, using aeromagnetic data analysis. *Journal of Science, Technology and Innovation Research*, 1(2), 84–94. <https://doi.org/10.51459/jostir.2025.1.2.022>
- Igwesi, I. D., & Umego, N. M. (2013). Interpretation of aeromagnetic anomalies over some parts of Lower Benue Trough using spectral analysis techniques. *International Journal of Scientific and Technology Research*, 2(8), 153–165. <http://www.ijstr.org/final-print/aug2013/Interpretation-Of-Aeromagnetic-Anomalies.pdf>
- Nwajide, C. S., & Reijers, T. J. A. (1995). Sedimentology and sequence stratigraphy of selected outcrops in the Upper Cretaceous to Lower Tertiary of the Anambra Basin. *SPDC Exploration Report*, XPMW 96007, 21–37.
- Nwosu, O. B. (2015). Qualitative interpretation of aeromagnetic data over parts of Middle Benue Trough, Nigeria using HRAM. *Standard Scientific Research and Essays*, 3(2), 026–032.
- Obaje, N. G. (2009). *Geology and mineral resources of Nigeria* (Lecture Notes in Earth Sciences, Vol. 120). Springer-Verlag. <https://doi.org/10.1007/978-3-540-92685-6>
- Obiora, D. N., Ossai, M. N., & Okwoli, E. (2015). A case study of aeromagnetic data interpretation of Nsukka area, Enugu State, Nigeria, for hydrocarbon exploration. *International Journal of Physical Sciences*, 10(17), 503–519. <https://doi.org/10.5897/IJPS2015.4311>
- Obiora, D. N., Yakubu, J. N., Okeke, F. N., Chukwudebelu, J. U., & Oha, A. I. (2016). Interpretation of aeromagnetic data of the Idah area in North Central Nigeria using combined methods. *Journal of the Geological Society of India*, 88(1), 98–106. <https://doi.org/10.1007/s12594-016-0442-1>
- Odumoso, S. E., Oloto, I. N., & Omoboriowo, A. O. (2013). Sedimentological and depositional environment of the Mid-Maastrichtian Ajali Sandstone, Anambra Basin, Southern Nigeria. *International Journal of Science and Technology*, 3(1), 26–33.
- Okiwelu, A. A., Okwueze, E. E., Akpan, P. O., & Ude, I. A. (2015). Basin framework and basement structuring of Lower Benue Trough, West Africa based on regional magnetic field data: Tectonic and hydrocarbon implications. *Earth Science*



- Research*, 4(1), 1–20. <https://doi.org/10.5539/esr.v4n1p1>
- Onuba, L. N., Anuba, G. K., Chiaghanam, O. I., & Anakwuba, E. K. (2011). Evaluation of aeromagnetic anomalies over Okigwe area, southeastern Nigeria. *Research Journal of Environmental and Earth Sciences*, 3(5), 498–507.
- Onwe, I. M., Odoh, B. I., & Onwe, R. M. (2015). Estimation of sedimentary thickness in eastern Anambra Basin by qualitative and quantitative interpretation of aeromagnetic data. *Advances in Applied Science Research*, 6(10), 1–6.
- Onwumemesi, A. G. (1995). *Interpretation of magnetic anomalies from the Anambra Basin of southeastern Nigeria* (Unpublished doctoral dissertation). Nnamdi Azikiwe University, Awka, Nigeria.
- Oweh, B. N., Ideozu, R. U., & Emudianughe, J. E. (2015). Aeromagnetic studies of sheets 248, 249, 268 and 269, Lower Benue Trough, Nigeria. *International Journal of Science Inventions Today*, 4(5), 451–462.
- Reeves, C. (2005). *Aeromagnetic surveys: Principles, practice and interpretation*. Geosoft.
- Selley, R. C. (1998). *Elements of petroleum geology* (2nd ed.). Academic Press. <https://doi.org/10.1016/B978-012636370-8/50002-5>
- Telford, W. M., Geldart, L. P., & Sheriff, R. E. (1990). *Applied geophysics* (2nd ed.). Cambridge University Press. <https://doi.org/10.1017/CBO9781139167932>
- Thurston, J. B., & Smith, R. S. (1997). Automatic conversion of magnetic data to depth, dip and susceptibility contrast using the SPI method. *Geophysics*, 62, 807–813. <https://doi.org/10.1190/1.1444190>
- Ugwu, G. Z., Ezema, P. O., & Ezech, C. C. (2013). Interpretation of aeromagnetic data over Okigwe and Afikpo areas of the Lower Benue Trough, Nigeria. *International Research Journal of Geology and Mining*, 3, 1–8.

Declaration

Competing Statement: Financial Interests Statement:

There are no competing financial interests in this research work.

Ethical considerations

Not applicable

Data availability

The microcontroller source code and any other information can be obtained from the corresponding author via email.

Funding sources

The authors declared no source of funding

Authors' Contribution

Oliver U. Ekwueme conceptualized the study, supervised the research, performed data interpretation, and prepared the manuscript draft. Samuel E. Edu carried out data processing, applied qualitative and quantitative aeromagnetic analyses, conducted modeling and visualization, and contributed to result validation and manuscript revision. Both authors discussed the findings, approved the final version, and agreed to be accountable for the work.

