# STRUCTURAL MAPPING OF THE IDAH AND ANGBA REGIONS, NORTH-CENTRAL NIGERIA, USING AEROMAGNETIC DATA ANALYSIS

**Ekwueme, O. U.**

**ABSTRACT**

The structural identity of some parts of north-central Nigeria has been mapped. The total magnetic intensity map of the study area ranges from -180 nT to 220 nT, exhibiting distinct high and low magnetic signatures. The residual magnetic data were contoured into a 2D map, revealing two prominent magnetic anomaly intensities. Higher residual intensity values, ranged from 20 nT to 180 nT as observed in the north-central and eastern regions, suggest the presence of near-surface bodies in areas with shallower sediments. Conversely, lower residual intensities values, at -220 nT to -20 nT in the southern region indicate deeper-lying bodies, likely corresponding to the magnetic basement depth due to thicker sediment accumulation. The regional magnetic field data delineate major tectonic elements that influence the structural framework of the area. The first-order polynomial analysis map of the aeromagnetic data highlights a dominant regional SW-NE trend, showing closely spaced, sub-parallel contour orientations in the northern and southern sections which suggest the presence of faults. Most magnetic anomalies exhibit an East-West trend, with minor trends oriented toward Northeast-Southwest. The study further reveals that the overall orientation of magnetic contour closures and magnetic lineaments aligns predominantly with the SW-NE trend, characteristic of the Pan-African Orogeny.

**Keywords:** Aeromagnetic data, regional-residual separation, Reduction to pole, magnetic lineament structure

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*Department of Physics, Federal University of Technology, Akure, Ondo State, Nigeria*

**Correspondence**
ouekwueme@futa.edu.ng

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## 1 | Introduction

Magnetic surveys are an essential geophysical technique for investigating subsurface structures by analyzing Earth's magnetic field changes (Kuang et al., 2022). These surveys can be conducted on land, at sea, or from the air (aeromagnetic surveys). Fundamentally, magnetic surveys operate on principles similar to gravity surveys. Aeromagnetic surveys, in particular, help delineate major basement surface structures, highlighting promising exploration areas that can be further examined using seismic geophysical method (Grauch & Kelson, 2004). The Earth's magnetic field interacts with magnetic minerals in the crust, inducing a secondary field that reflects their distribution. The primary magnetic field varies gradually over large areas, whereas the crustal field—caused by magnetism induced by the main field—exhibits more localized and rapid variations (Betts *et al.*, 2024; Shah and Crain, 2018, & Grauch, 1999).

The search for hydrocarbons and other minerals has posed a significant challenge in Nigeria since the 1960s. Before the discovery of oil, Nigeria's economy was predominantly driven by the solid minerals and agricultural sectors. However, today, the oil and gas industry accounts for over 80% of the country's revenue through exports and domestic sales. As the hydrocarbon reserves of the prolific Niger Delta become increasingly depleted due to continuous exploitation, there is a pressing need to explore other sedimentary basins. The Anambra Basin—particularly the Idah and Angba regions—is believed to hold significant hydrocarbon potential and concentrations of other economically valuable mineral deposits (Omietimi et al., 2025; Mallo, 2012; Maju-oyovwikowhe and Malomi, 2019, & Abubakar, 2014).

Several studies have been conducted on the Anambra Basin using aeromagnetic data interpretations and various analytical methods (Ekwueme *et al*., 2018; Onuba *et al*., 2011; Anyanwu and Mamah, 2013; Adetona and Abu, 2013; Ugwu *et al*., 2013; Obiora *et al*., 2015; Okiwelu *et al*., 2015; Onwe *et al*., 2015; Nwosu, 2015, & Obiora *et al*., 2016). These studies primarily focus on determining basement depths and magnetic source bodies within the basin. Onuba *et al*. (2011), analyzed aeromagnetic anomalies in the Okigwe area, southeastern Nigeria, using regional-residual separation and slope methods. Their findings indicate a 2.0 km to 4.99 km magnetic source depth. Anyanwu & Mamah (2023) conducted a structural interpretation of the Abakaliki–Ugep region using airborne magnetic data, revealing 0.035 km to 1.285 km as shallow magnetic bodies in the study area and obtain range of values of 1.585 km to 4.136 km indicating deeper bodies in the area.

Similarly, Obiora *et al*. (2015) evaluated the thickness of the sedimentary and basement of Nsukka regions by applying aeromagnetic data. Onwe *et al*. (2015) estimated the thickness of the sedimentary in the Anambra Basin applying aeromagnetic data interpretation, employing band-pass filtering to enhance anomalies related to faults and structural discontinuities. More recently, Igbokwe (2023) analyzed aeromagnetic data to study the structural and tectonic framework of Nkalagu and its surroundings, identifying dominant NW-SE trending lineaments.

This study aims to qualitatively interpret the aeromagnetic data of the Idah and Angba areas in north-central Nigeria. The primary objectives are to identify the structural trends within the study area and establish the magnetic signatures that characterize the region. Through this analysis, the study will contribute valuable insights into the area's geological framework, supporting further exploration efforts for hydrocarbons and other mineral resources.

## 2 | Location

This study focuses on the region encompassing Idah and Angba in Kogi State, located in north-central Nigeria. Geographically, the area lies within latitudes 7°00'N to 7°30'N and longitudes 6°30'E to 7°30'E, covering approximately 6,050 square kilometers. The study area falls within the Anambra Basin and is represented by aeromagnetic map sheets 267 and 268. Figure 1presents the study area.

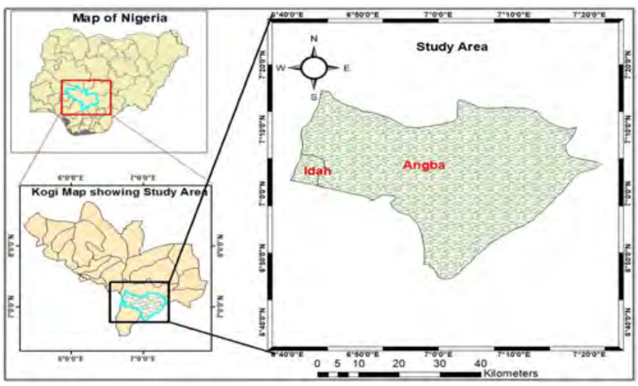


**Figure 1** | The map of the study area

## 3 | Geologic Area

The geological characteristics of Idah in Kogi State, Nigeria, are well-documented in various studies. The region is part of the Anambra Basin, a sedimentary basin that developed during the Late Cretaceous period. This area features formations such as the Mamu Formation and Ajali Sandstone, which were deposited during a phase of marine regression (*Ekwueme et al.*, 2018). The Mamu Formation comprises shale, sandstone, and coal deposits, indicating a transition between marine and deltaic environments. In contrast, the Ajali Sandstone consists of well-sorted, friable sandstones, signifying a fluvial depositional setting. These formations suggest that the region once experienced shallow marine, deltaic, and marshy conditions, influencing sediment accumulation. Additionally, the organic-rich shales present in the basin have the potential to generate hydrocarbons under suitable conditions. The geological framework of Idah significantly contributes to its mineral resources and affects its topography and hydrogeology (Oparaku and Iwar, 2018, & Reeves, 2005). Figure 2 displays the geologic map of the area.

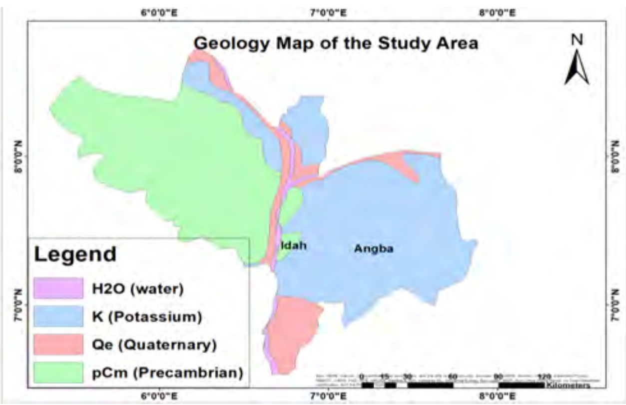


**Figure 2** | Geologic map of the study area

## 4 | Source of Data

The Nigerian Geological Survey Agency provided the two dataset sheets, covering portions of north-central Nigeria, specifically the Idah and Angba regions. The aeromagnetic data was recorded in three dimensions—latitude, longitude, and magnetic intensity—using a 3x Scintrex CS3 cesium vapor magnetometer.

## 5 | Methods and Analysis of Data

This study utilized qualitative interpretation techniques, starting with an analysis of the total magnetic intensity (TMI) grid of the study area. The reduction to the pole, upward continuation, first vertical derivative, and horizontal derivative, were carried out on the magnetic data qualitatively. These filters were instrumental in enhancing anomalies of interest and extracting key information related to source location and magnetization.

The upward continuation method was applied to attenuate near-surface anomalies by mathematically projecting them to a higher elevation above the original datum. Reduction to the pole was performed on gridded TMI, transforming magnetic anomalies into simplified, positive features directly above their sources. Additionally, the first vertical derivative filter was used to sharpen anomaly boundaries and emphasize shallow subsurface structures.

To differentiate regional anomalies from residual anomalies, a first-order polynomial was fitted to the data using the least squares method. After evaluating various polynomial orders, the first-order polynomial proved to be the most effective in representing the geological characteristics of the area. The algorithm for regional anomaly removal in Equation (1) was based on the approach outlined by Ugwu et al. (2013),

$$r = a_0 + a_1(X - X_{ref)} + a_2(Y - Y_{ref}) \quad (1)$$

where r represent the regional field, $X_{ref}$ ,$Y_{ref}$, X and Y are dataset geographical Coordinates. Subscripts

$a_0$, $a_1$ and $a_2$ are the polynomial coefficients.

### 5.1 | Reduction To Pole (RTP)

Reduction to the pole was used to transform magnetic anomalies as if they were measured at the magnetic pole, where the induced magnetization and Earth's magnetic field are both vertical. This process simplifies anomaly interpretation by centering anomalies directly over their sources. Mathematically, the RTP filter is expressed in the Fourier domain is expressed in Eqn.(2)

$$RTP(K_x, K_y) = \frac{P(K_x,K_y)}{T(K_x,K_y)} \quad (2)$$

where $P(K_x, K_y)$ It is the Fourier transform of the observed magnetic field.
$T(K_x, K_y)$ Is the transformation function given in Eqn(3):

$$T(K_x, K_y) = \frac{cosI + isinIsinD}{cos^2I + sin^2Isin^2D} \quad (3)$$

where *I* Is the magnetic inclination, and D is the magnetic declination.

### 5.2 | First Vertical Derivative (FVD)

The first vertical derivative applied enhances shallow anomalies by emphasizing rapid changes in the field, improving the resolution of near-surface structures. In the Fourier domain, the FVD operator applied in this research work is presented in Eqn. 4)

$$FVD(K_x, K_y) = \sqrt{K_x^2 + K_y^2}.F(K_x, K_y) \quad (4)$$

where $F(K_x, K_y)$ Is the Fourier transform of the potential field data.

## 6 | Result

The qualitative interpretation of the aeromagnetic data began with generating a TMI map (Figure 3a), which presents the study area in a color aggregate. This map was derived and processed using Surfer 10, Oasis Montaj, and WinGlink software. The magnetic intensity across the region ranges from -180 nT to 220 nT, reflecting high and low magnetic signature (Onuba *et al*. 2011). These variations are suspected to be magnetic susceptibility, depth variations, structural orientation, and lithological difference (Obiora *et al.* 2016).

The northern and southern parts of the map show closely spaced, sub-parallel linear contours, which suggest the presence of faults or local fractured zone (Telford *et al.* 1990). The dominant orientation of anomalous features follows an East-West trend, with minor anomalies trending Northeast-Southwest. Additionally, elliptical contour closures observed in the region indicate the presence of magnetic bodies. The analysis further reveals that the primary lineament trends are East-West, with a few extending in a Northeast-Southwest direction. Figure 3(b) delineates rock boundaries, represented by drawn lines, which likely differentiate the basement and sedimentary sections of the study area. The figure also highlights two distinct magnetic signatures within the zone, characterized by contour truncations and lineaments, further indicating structural complexities within the region.

### 6.1 | Residual Magnetic Map

The residual magnetic map was derived using Surfer 10 and WinGlink software. The resulting residual map, presented in Figure 4(a), reveals a magnetic value ranging from -220 nT to 180 nT. Areas with negative residual values indicate regions of low magnetization, whereas positive residual anomalies correspond to zones of higher magnetization (Obiora *et al*. 2016).

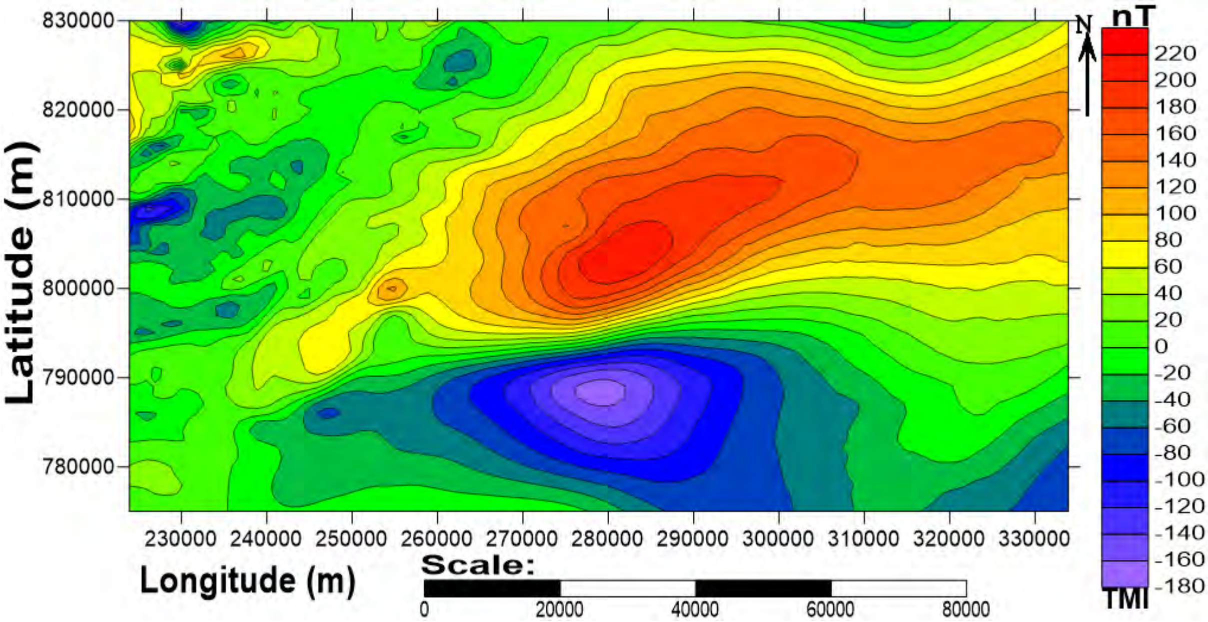


**Figure 3(a)** | TMI map

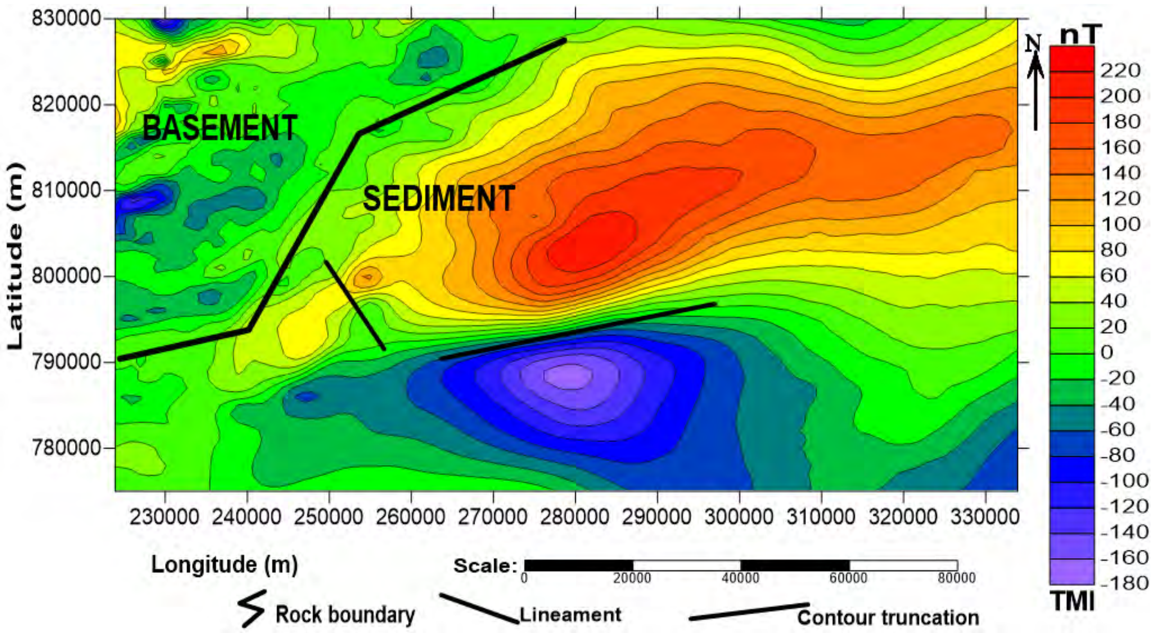


**Figure 3(b)** | TMI map showing major magnetic signatures

### 6.2 | Regional Magnetic Map

Figure 4(b) presents a map of the regional magnetic field intensity, which varies from a minimum of -45 nT to a maximum of 85 nT, extending from the eastern to the western direction. The regional field component was extracted from the total magnetic field intensity data using a first-order polynomial fit, implemented through the Polifit program in Surfer 10 and WinGlink software. A first-order polynomial was selected due to the distribution of data points and the study area's characterization as an inclined plane surface. The regional magnetic

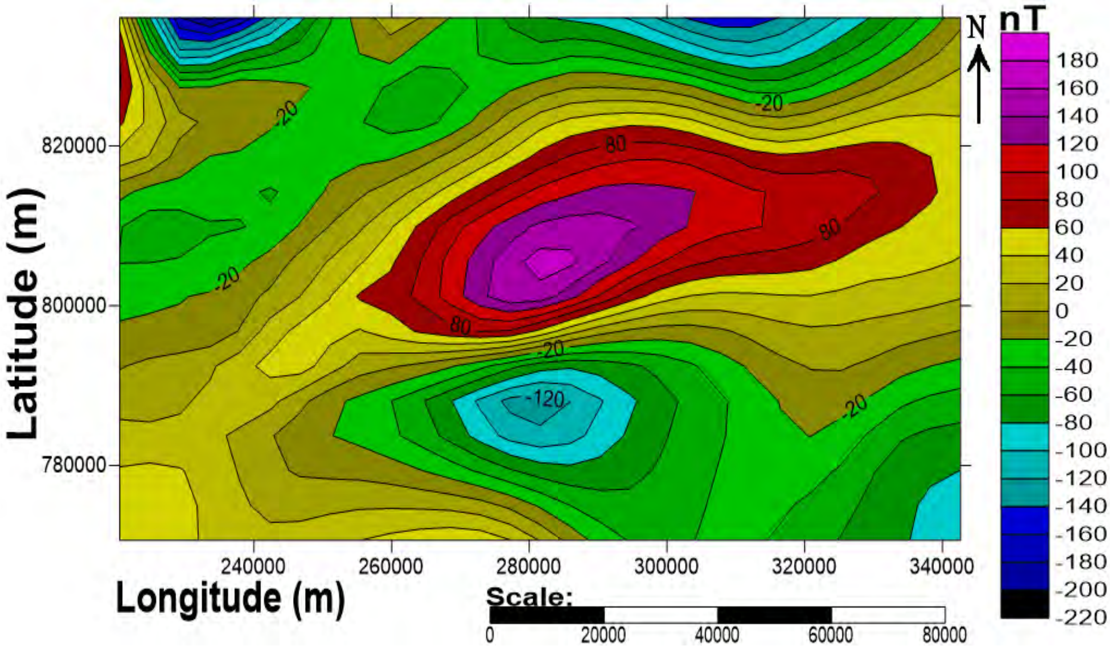


**Figure 4(a)** Residual magnetic map.

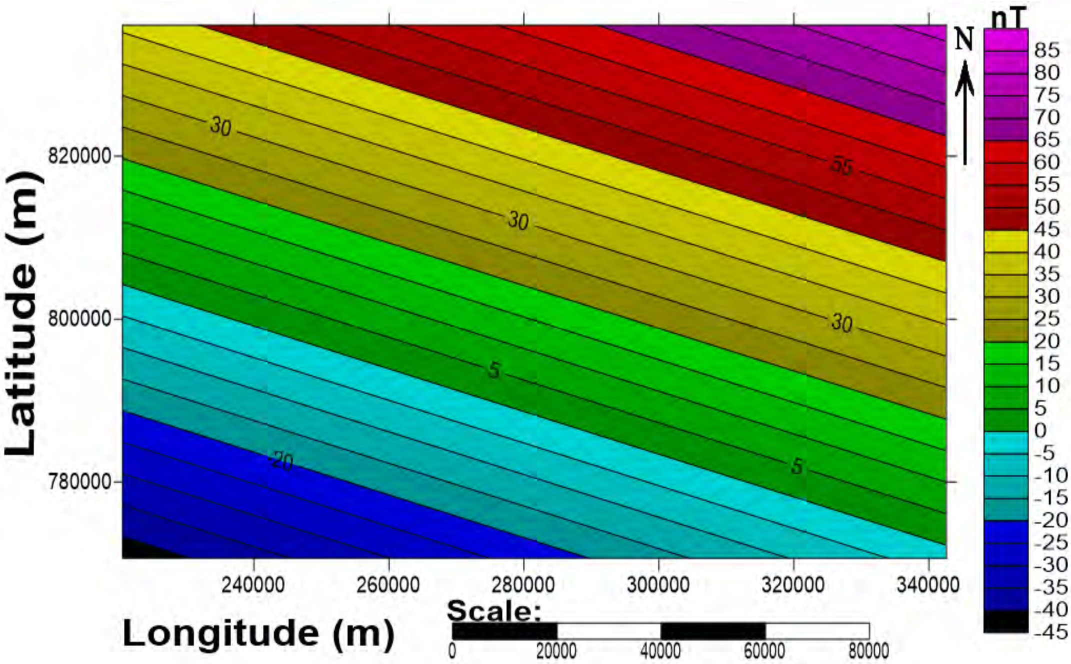


**Figure 4(b)** Regional magnetic map.

field highlights major tectonic elements of significant depth and regional influence, which shape the structural framework of the area. Furthermore, the analysis of aeromagnetic data reveals a dominant SE-NW regional trend.

### 6.3 | First Vertical Derivative

The first vertical derivative applied to the study area's data effectively enhanced shallow sources while suppressing the influence of deeper ones, thereby revealing near-surface anomalies. This filter calculates the vertical rate of change in the magnetic field, improving spatial resolution by amplifying high-frequency components associated with shallow sources. Figure 5 illustrates the filter's characteristics and the resulting first derivative map. Additionally, the shape of a magnetic anomaly is influenced by the inclination and declination of Earth's main magnetic field, meaning that identical magnetic bodies can produce anomalies of varying shapes depending on their orientation and position.

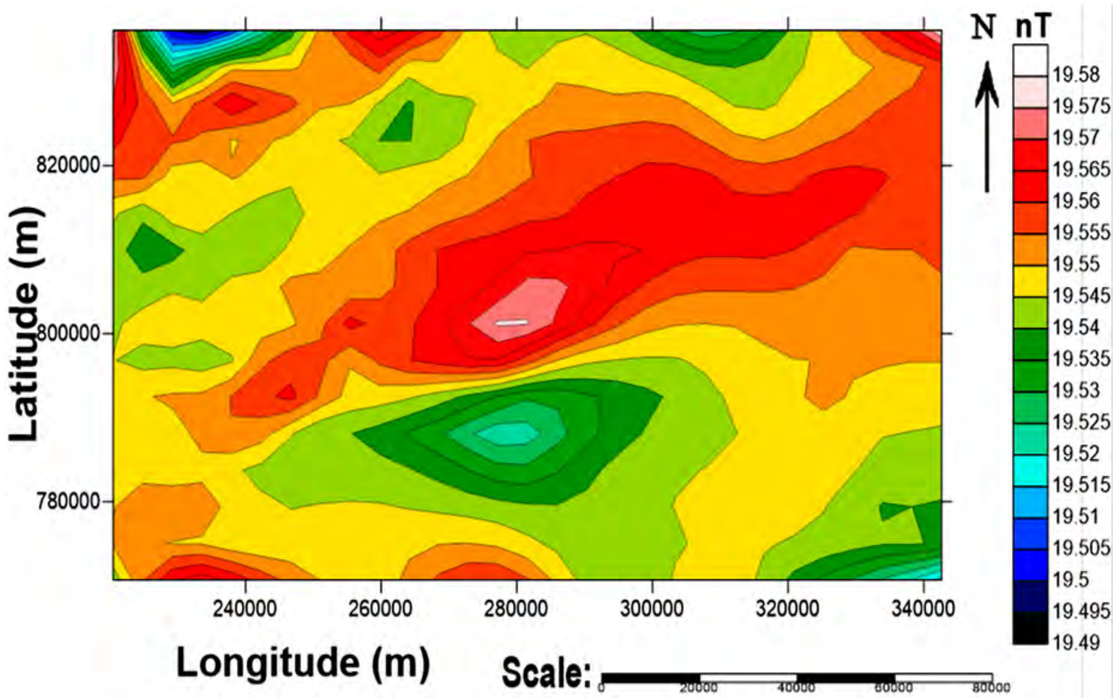


**Figure 5** | First vertical derivative map.

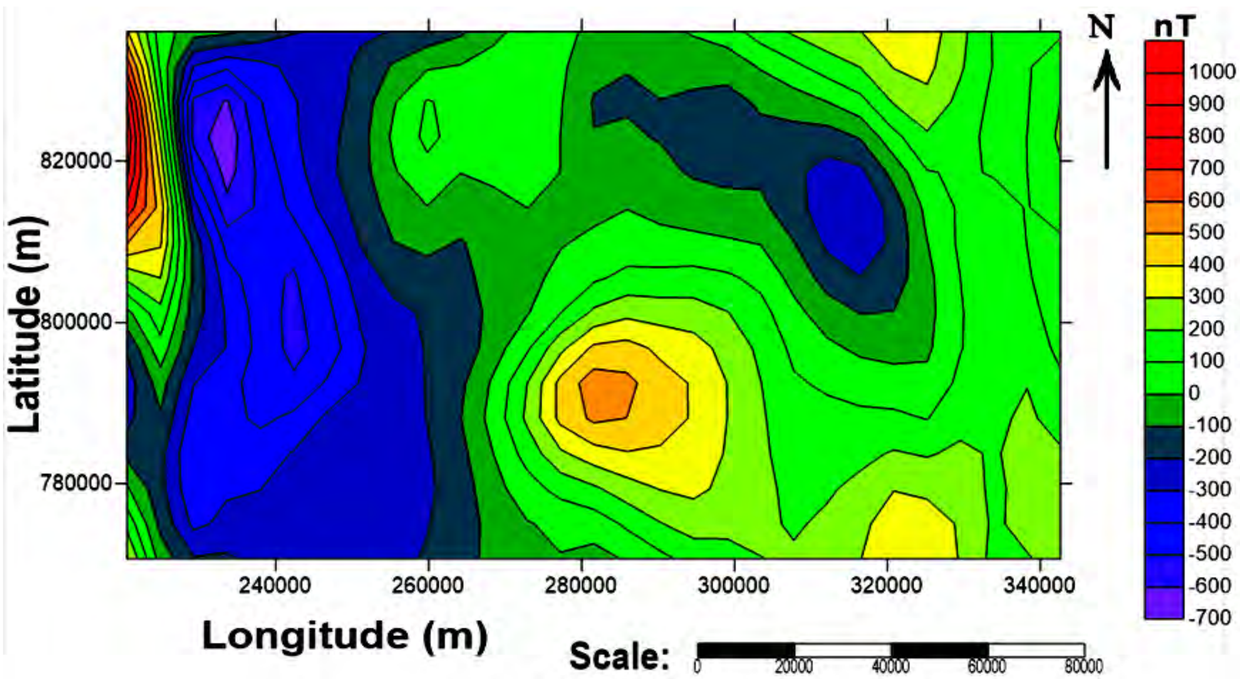


**Figure 6** | Reduction to Pole map

### 6.4 | Reduction to the pole

By applying reduction to the pole filters to the residual magnetic intensity grid, the interpretation of magnetic anomalies becomes more straightforward. Vertical bodies generate induced magnetic anomalies that are symmetrically centered over the source, simplifying their identification. As a result, the anomalies appear as positive features directly above the expected magnetized bodies at the magnetic poles, as illustrated in Figure 6.

### 6.5 | Magnetic Lineament Map

The structural features observed on the aeromagnetic map are typically represented by thin elliptical closures and nosing, with their positions delineated by lines parallel to their elongation and passing through the center of the anomalies. Figure 7 presents the structural trend map, illustrating the orientation of major faults within the study area. The predominant magnetic lineaments follow a southwest-northeast (SW-NE) trend, with a secondary east-west (E-W) orientation. These magnetic lineaments may serve as indicators of potential hydrocarbon migration pathways, if present, and could also reflect the prevailing structural fractures within the study area.

## 7. | Discussion

A qualitative analysis was performed by visually examining various geophysical maps, such as the

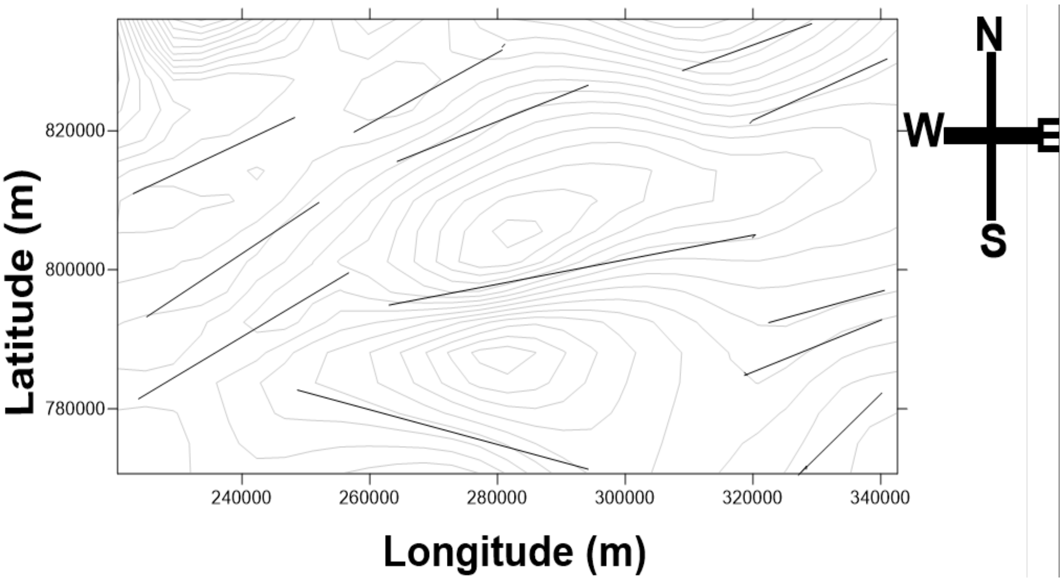


**Figure 7** | Lineament map

total magnetic intensity map, regional magnetic map, upward continuation, first vertical derivative, and reduction to the pole. The total magnetic field intensity in the study area varies between -180 nT and 220 nT (Figure 3a). Higher intensity values are observed in the north-central and eastern regions, indicating the presence of near-surface magnetic bodies where sediments are relatively shallow. Conversely, lower intensity values in the southern region suggest deeper-lying magnetic bodies, possibly corresponding to the magnetic basement depth.

A quantitative interpretation of this area using spectral analysis or other depth-estimation techniques could provide further insights into the thickness of the magnetic basement. Preliminary assessments suggest that this thickness may exceed 2.3 km, a depth considered significant for hydrocarbon accumulation under favorable geological conditions. According to Wright et al. (1985), if other conditions for hydrocarbon formation are met—such as an average geothermal gradient of 1°C per 30 m, similar to that observed in the oil-rich Niger Delta—a sediment thickness of at least 2.3 km is required to reach the threshold temperature of 115°C for hydrocarbon maturation. Therefore, this study area warrants further investigation and exploration due to its potentially favorable geologic characteristics.

The northern and southern regions of the study area display closely spaced, sub-parallel linear contour patterns, indicating possible fault lines or localized fracture zones. The majority of the detected anomalies follow an East-West orientation, while some minor features align in a Northeast-Southwest direction. Fracture zones often exhibit variations in magnetic susceptibility, which can result from processes such as the oxidation of magnetite to hematite or the intrusion of dike-like structures with distinct magnetic properties. These geological formations typically appear as thin elliptical closures or nosing on aeromagnetic maps. In this study, the identified elliptical contour closures suggest the presence of magnetic bodies.

Furthermore, the total magnetic map (Figure 3b) delineates rock boundaries, potentially distinguishing between basement and sedimentary sections of the study area. Additionally, two dominant magnetic signatures are observed, characterized by contour truncations and lineaments.

The residual magnetic field map (Figure 4a) reveals magnetic residual values ranging from -220 nT to 180 nT. Negative residual anomalies correspond to zones of low magnetization, whereas positive residual anomalies indicate areas of high magnetization. Meanwhile, the regional magnetic field intensity (Figure 4b) ranges from -45 nT to 85 nT, displaying a gradient from the eastern to the western part of the study area. These regional magnetic variations reflect major tectonic elements with deeper regional influence, which shape the structural framework of the region. A first-order polynomial regional anomaly analysis of the aeromagnetic data indicates a dominant Southwest-Northeast (SW-NE) structural trend.

The first vertical derivative map (Figure 5) highlights areas of high magnetic intensity in the north-central, western, and eastern parts of the study area, whereas the southern region exhibits lower intensity values. Additionally, the reduction-to-pole map (Figure 6) reveals several elliptical anomalies symmetrically centered over their respective magnetic sources. Finally, the general orientation of magnetic contour closures and lineaments (Figure 7) predominantly follows a Southwest-Northeast (SW-NE) trend, aligning with the structural patterns associated with the Pan-African Orogeny.

## 8. | Conclusion

The mapping of aeromagnetic data from the Idah and Angba areas has provided valuable insights into the region's subsurface structure. Higher total magnetic intensity values in the north-central and eastern parts indicate the presence of near-surface bodies, while lower values in the southern region suggest deeper-lying bodies with thicker sedimentary cover, potentially marking the magnetic basement depth. The closely spaced, sub-parallel contour orientations in the northern and southern areas suggest possible faulting or localized fractured zones. The dominant East-West and minor Northeast-Southwest trends of anomalous features align with the broader structural framework of the region. Additionally, the first-order polynomial regional anomalies highlight a prevailing SW-NE trend consistent with major tectonic influences. Overall, this study confirms that the general orientation of magnetic contour closures and lineament structures predominantly follows the SW-NE direction, a characteristic feature of the Pan-African Orogeny.

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