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# Edge detection and depth estimation of subsurface structural architecture and its implications for mineral exploration, groundwater, hydrocarbon prospecting, and tectonic investigation

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# Edge detection and depth estimation of subsurface structural architecture and its implications for mineral exploration, groundwater, hydrocarbon prospecting, and tectonic investigation.

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## Abstract

Edge detection techniques is an effective approach for delineating subsurface structural features and estimating their depths in crystalline basement terrains. In this research, high resolution aeromagnetic data was processed by derivative filters: First Vertical Derivative (FVD), Tilt Derivative (TDR), Total Horizontal Gradient (THG), Analytical Signal (AS) and Centre for Exploration Targeting (CET) algorithm to enhance and extract magnetic lineaments associated with geological boundaries. Integrated application of the above filters resulted in the identification of faults, fractures, intrusive bodies, lithological contacts, and shear zones which delineated the structural framework of the research region. The depth of the magnetic causative sources was constrained by using the Radial Average Power Spectrum and Source Parameter Imaging techniques. The regional average depths provided by RAPS were used for shallow and deep magnetic ensembles, while the high-resolution source-top depths provided by SPI were used to mapped structural edges. Rose diagram analysis of magnetic linear and frequency density was used to determine the prevailing orientations of magnetic lineaments and magnetic trends, and CET analysis was used to quantify the distribution and continuity of magnetic lineaments. The integrated interpretation shows a structurally complex basement with zones of high deformation and of differing source depths. These results improve the understanding of subsurface tectonic architecture and provide valuable information for mineral exploration, groundwater investigations, hydrocarbon prospecting and geothermal resource assessment.

**Keywords: Environmental Implications, Exploration, Basement architecture, Lineation.**

## 1 Introduction

Aeromagnetic survey is still one of the most widely used geophysical techniques for investigating subsurface geological features as it allows rapid coverage of large areas and the delineation of lithological contacts, faults, fractures, dykes and intrusive bodies in relation to variation in magnetic susceptibility. The recorded magnetic anomalies are believed to be due to variations in the magnetic properties of the

underlying rocks and have wide applications in mineral exploration, hydrocarbon prospecting, groundwater investigations and regional tectonic study (Ibraheem et al., 2023; Adetona et al., 2021).

However, aeromagnetic interpretation is frequently complicated due to overlapping anomalies produced by sources at different depths, geometry and intensity of magnetization. The visibility of subtle structural signatures will therefore have to be emphasized by enhancement techniques, and the boundaries of causative bodies will have to be well defined. Edge detection methods have thus become essential in the interpretation of potential fields, with the aim of highlighting areas of sharp differences in magnetic susceptibility, which are related to contacts between geological units and discontinuities. The techniques used in these methods help to identify faults, shear zones, fracture systems, lithological boundaries, and mineralized zones (Ibraheem et al., 2019; Ibraheem et al., 2023).

A number of derivative filters have been created for magnetic edge enhancement, such as the First Vertical Derivative (FVD), Total Horizontal Derivative (THD), Analytical Signal (AS), Tilt Derivative (TDR), Theta Map, and modified versions of these filters (Ismael et al., 2023). They differ in their ability to respond to depth of the sources and resolution of adjacent anomalies, and in noise sensitivity. The recent advances have been aimed at better delineation of the boundaries, less ambiguity in interpretation and at the same time imaging shallow and deep magnetic sources (Ibraheem et al., 2023; Yusuf et al., 2026; Yakubu et al., 2025).

In this research, the AS, TDR, TH_TDR and FVD techniques were used to map subsurface geological structures and locate magnetic source boundaries that may be important for future mineral prospecting. The agreement among the different edge detection techniques was also assessed. Also, Source Parameter Imaging (SPI) and spectral analysis were employed to estimate basement depths and compare the consistency of their estimates. The depth to magnetic basement model is valuable for understanding the basement rock configuration beneath the overlaying non-magnetic rock and helps to establish a framework for mineral exploration planning.

## 2 Study Area Description & Geology

Geographically, the study area (Figure 1) is situated in Kogi State cutting across Kabba, Okene and Ode Ape local government in north-central Nigeria, between latitudinal range of 7°36′–7°48′N and longitudinal range of 6°06′–6°15′E. The study area covers two major geological terrains; the sedimentary rocks of the eastern flank of the Anambra Basin and the rocks of the Nigeria Basement Complex (Figure 2). The Basement Complex, which underlies the Precambrian rocks, includes migmatites, gneisses, granite gneisses, schist belts and Older Granites from the Pan African Orogenic period which have been extensively deformed and metamorphosed forming the regional structural architecture. Crystalline rocks contain valuable minerals such as iron ore, gemstones, quartz and feldspar. The sedimentary terrain on the other hand is made up of Cretaceous to Recent deposits comprising the Nkporo, Mamu, Ajali and Nsukka Formations among others that are responsible for the distribution of coal, kaolin, clay and other industrial minerals (Ayomide et al., 2025).

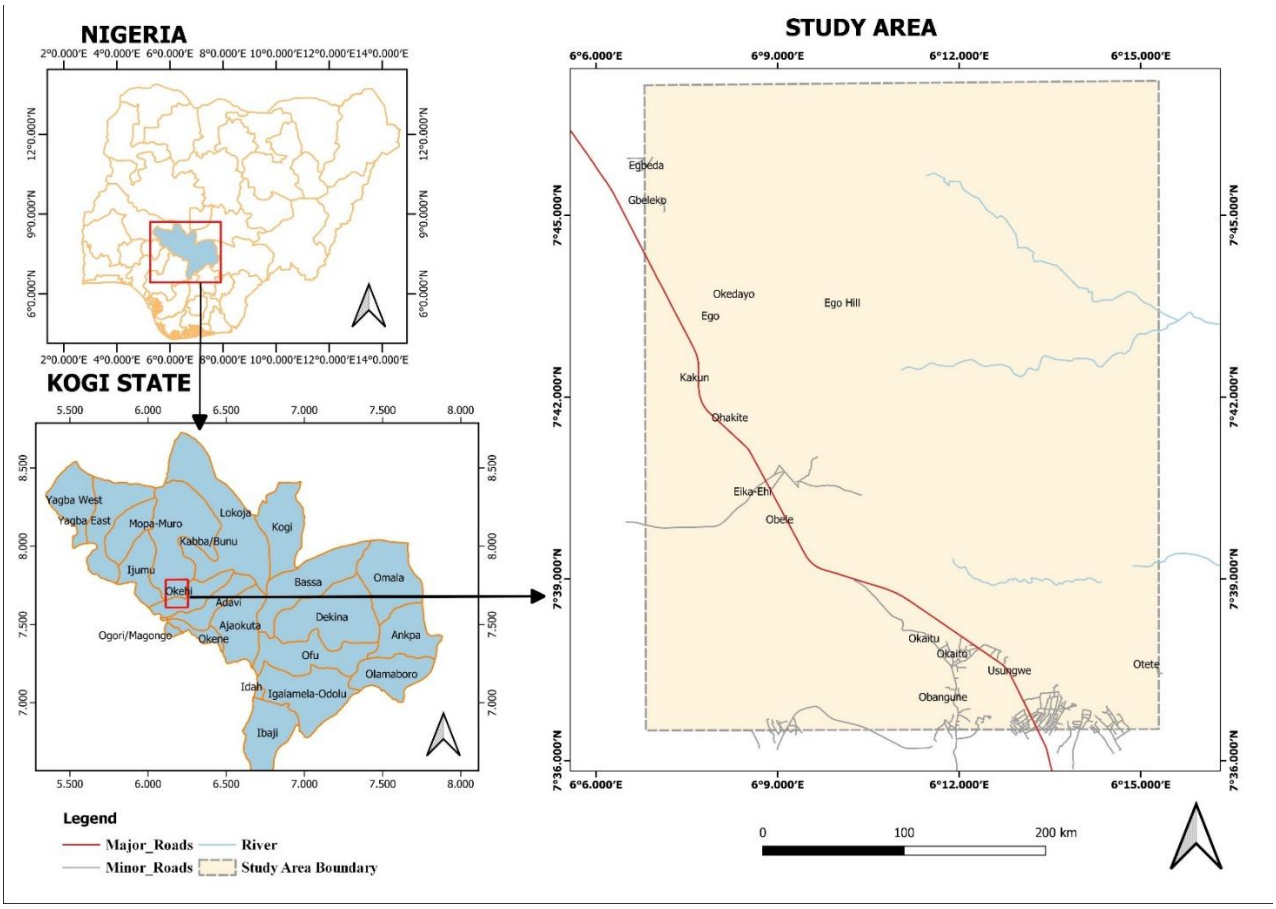



Figure 1: Research region

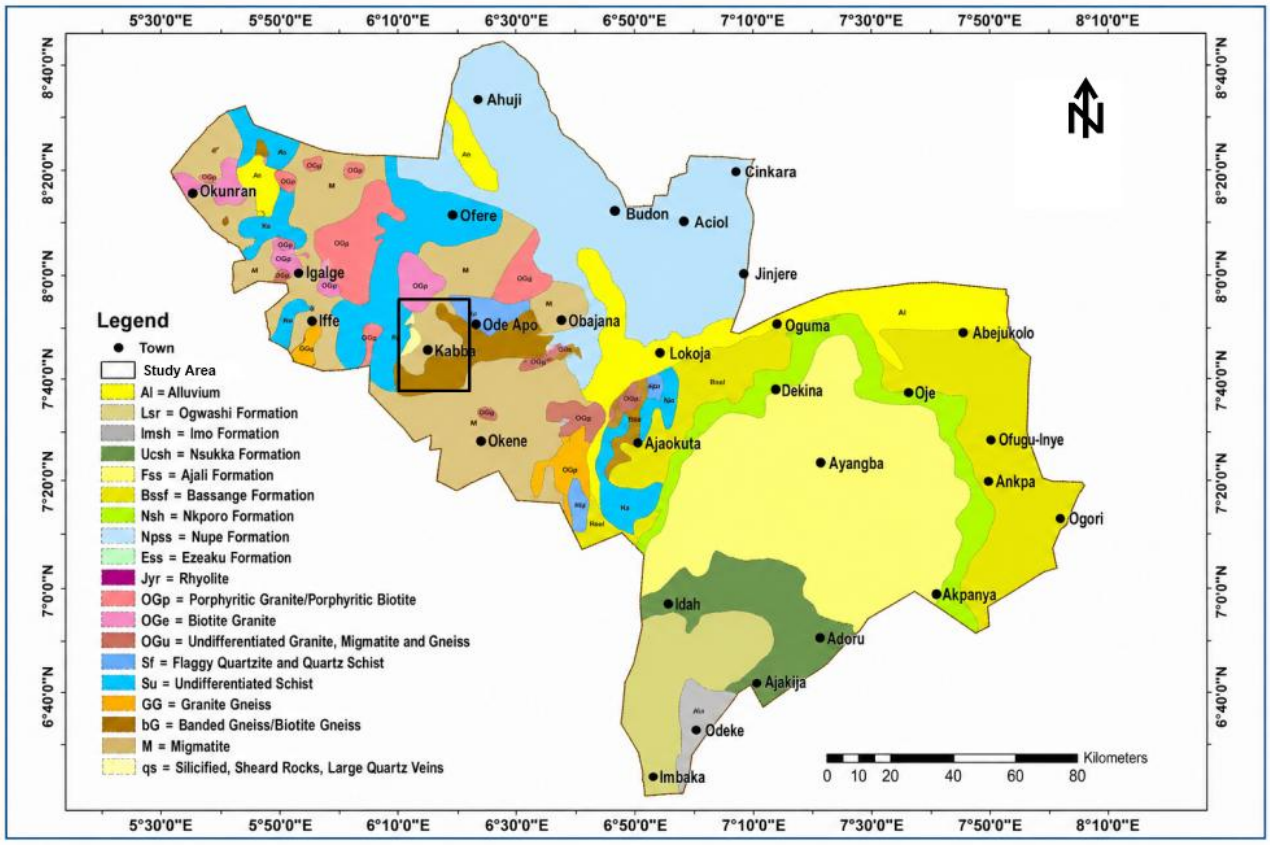



Figure 2: Research region Geological Map

## 3 Data Analysis & interpretation techniques

The aeromagnetic data processed in this study was obtained from the Nigerian Geological Survey Agency (NGSA) from Fugro Airborne Surveys. Regional–residual separation on the Total Magnetic Intensity (TMI) data was done using Fast Fourier Transform (FFT). The residual was reduced to the magnetic equator (RTE) after IGRF calculation in order to remove the asymmetry in magnetic anomalies at low latitudes and ensure that the anomalies are symmetrically centered over their causative sources.

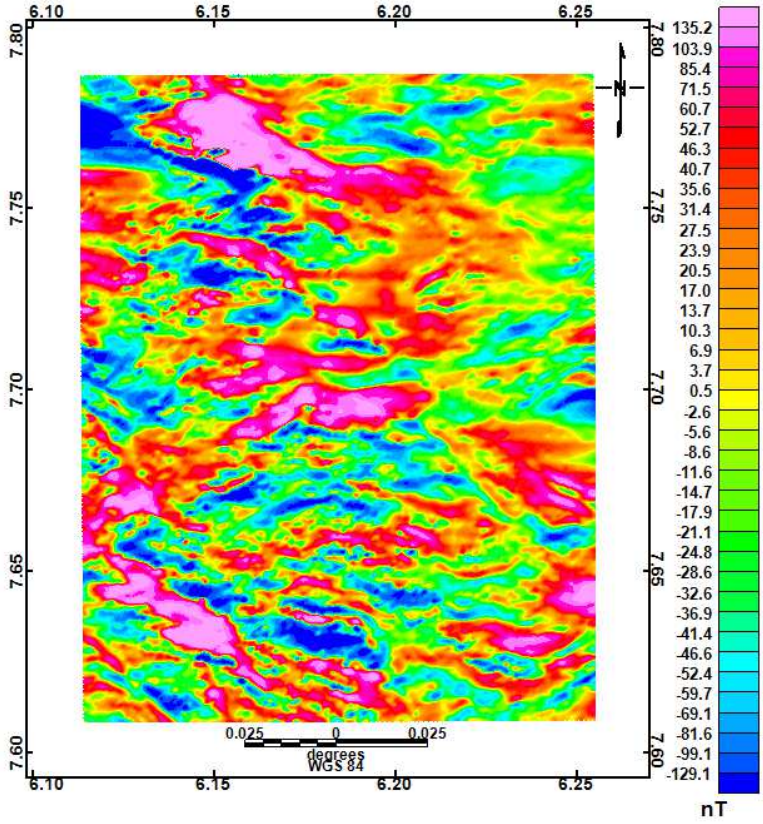



Figure 3: Residual Map RTE

## Edge Detection Methods

The edge enhancement techniques are of basic importance in aeromagnetic interpretation since they highlight the small gradients of lithological contacts and structural discontinuities such as faults, fractures, dykes and intrusive masses. The recent progress has been in noise suppression and the enhancement of the boundary resolution together with the retention of responses from sources of differing depths. The following methods were used in this study: First Vertical Derivative (FVD), Analytical Signal (AS), Tilt Derivative (TDR) and Total Horizontal Gradient Magnitude of the Tilt Derivative (TH_TDR)(Saada, 2016). The lineaments derived from these maps were further analyzed to obtain rose diagram analysis which helps to identify the predominant tectonic orientations in the study area.

### Total Horizontal Gradient Magnitude of the Tilt Derivative (TH_TDR)

TH_TDR enhances the horizontal gradients of the tilt angle and produces sharp maxima over structural boundaries. High TH_TDR readings usually represent a sharp change in magnetic susceptibility that is characteristic of faults, shear zones, dyke margins, fracture networks, and intrusive contacts. Subsequent linear highs can provide regional tectonic trends and structural fabrics that control fluid flow and mineralization. In complex situations like those with overlapping anomalies and in structurally complex environments, TH_TDR offers enhanced boundary definition compared to conventional TDR. The TH_TDR responses can be concentrated, which can also indicate fractured or intensely deformed areas with increased permeability. The Total Horizontal Derivative (THDR) of a potential field is represented by Equation (1) and the amplitude peaks of the THDR mark the edges of magnetic and gravity source bodies (Cordell & Grauch, 1985; Naheem et al., 2019).

$$THDR = \sqrt{\left(\frac{\partial P}{\partial x}\right)^2 + \left(\frac{\partial P}{\partial y}\right)^2} \qquad (1)$$

where P is the measured potential field and $\left(\frac{\partial P}{\partial x}\right)$ and $\left(\frac{\partial P}{\partial y}\right)$ are its derivatives in x and y directions. Moreover, the amplitude of the analytical signal (AS) is calculated using the following formulation (Roest et al., 1992):

$$|AS(x,y)| = \sqrt{\left(\frac{\partial P}{\partial x}\right)^2 + \left(\frac{\partial P}{\partial y}\right)^2 + \left(\frac{\partial P}{\partial z}\right)^2} \qquad (2)$$

where $\frac{\partial P}{\partial y}$ is the derivative of the field P in z direction. The causative body is defined by the AS maxima where The Analytical Signal (AS) often displays anomaly peaks that are bell-shaped above magnetic sources. Its reaction is, on the other hand, more influenced by shallow and high amplitude anomalies where there are several causative bodies (Arısoy & Dikmen, 2013). Besides, the limits of the mapped units might be more diffuse and extensive than their actual geologic extent (Nasuti et al., 2019). Like AS the Total Horizontal Derivative (THDR) is independent of the magnetization direction. The differences to AS are that THDR produces sharper responses, and better-defined maxima, directly over source edges, unlike AS. This property is useful for separation of bodies that have induced and/or remanent magnetization or both (Rahman & Ullah, 2013).

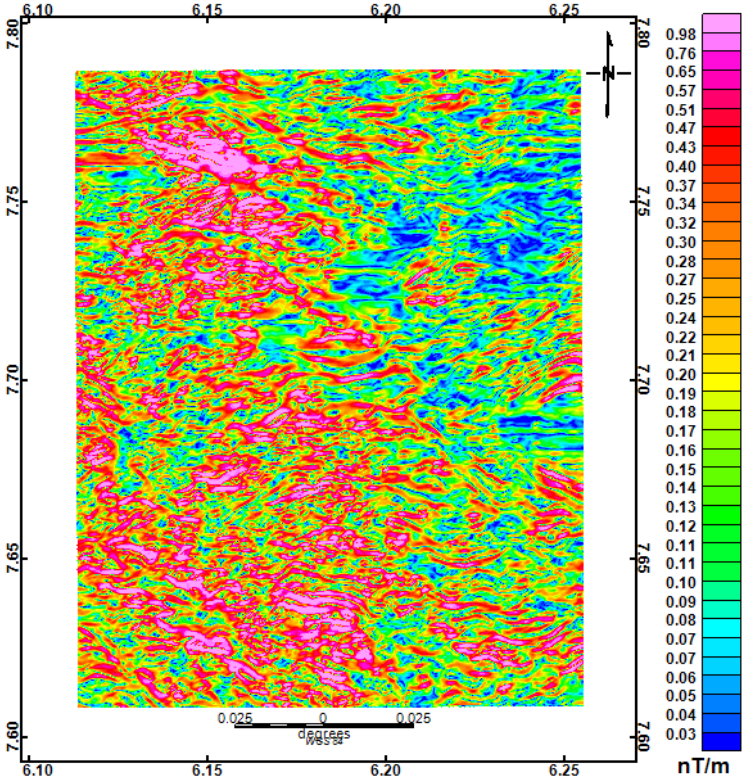



Figure 4: **Total Horizontal Gradient Magnitude of the Tilt Derivative** MAP

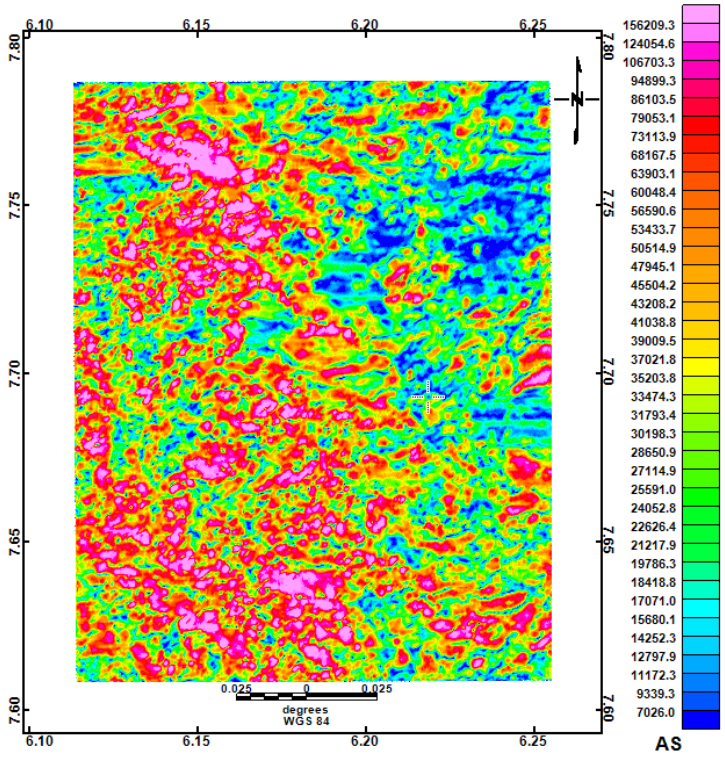



Figure 5: Analytical Signal

Tilt Derivative (TDR) applied to Edge Detection.

The Tilt Derivative (equation 3 & 4) is a technique that is often used for magnetic edge detection because it improves the visibility of shallow and deep magnetic sources and minimizes the influence of strong magnetic anomalies. It normalizes responses to produce better identification of lithological contacts, faults, fractures and intrusive boundaries regardless of the amplitude of the anomalies. The method, which was first published by Miller and Singh (1994), is simply the arctangent of the ratio between the first vertical derivative and the total horizontal derivative of the magnetic field. Later on, Salem et al., (2007-2008) and Fairhead et al., (2008) extended its use, and its simplicity of computation made it popular in potential field interpretation (Hinze et al., 2013). The TDR can be mathematically written as:

$$TDR = \tan^{-1}\left(\frac{VDR}{TH_TDR}\right) \qquad (3)$$

where VDR is the vertical derivative and TH_TDR is the total horizontal derivatives/HGM.

$$TDR = \tan^{-1}\left(\frac{\partial P/\partial z}{\sqrt{\left(\frac{\partial P}{\partial x}\right)^2 + \left(\frac{\partial P}{\partial y}\right)^2}}\right) \qquad (4)$$

The magnetic field is represented by P, whereas the first-order derivatives of the magnetic field in the x, y and z directions are represented by $\partial P/\partial x$, $\partial P/\partial y$ and $\partial P/\partial z$ respectively. The range of the Tilt Derivative (TDR) values is independent of the magnitude of the vertical derivative, and of the total horizontal gradient (Salem et al., 2008), with limits ranging from $-90°$ to $+90°$ (or from $-\pi/2$ to $+\pi/2$ radians). An important property of TDR is that at, or near, source edges the value of TDR approaches zero, and is used for the delineation of source edges (Miller & Singh, 1994). Positive tilt values typically lie above the bodies causing the tilt, while negative values lie outside of their margins.

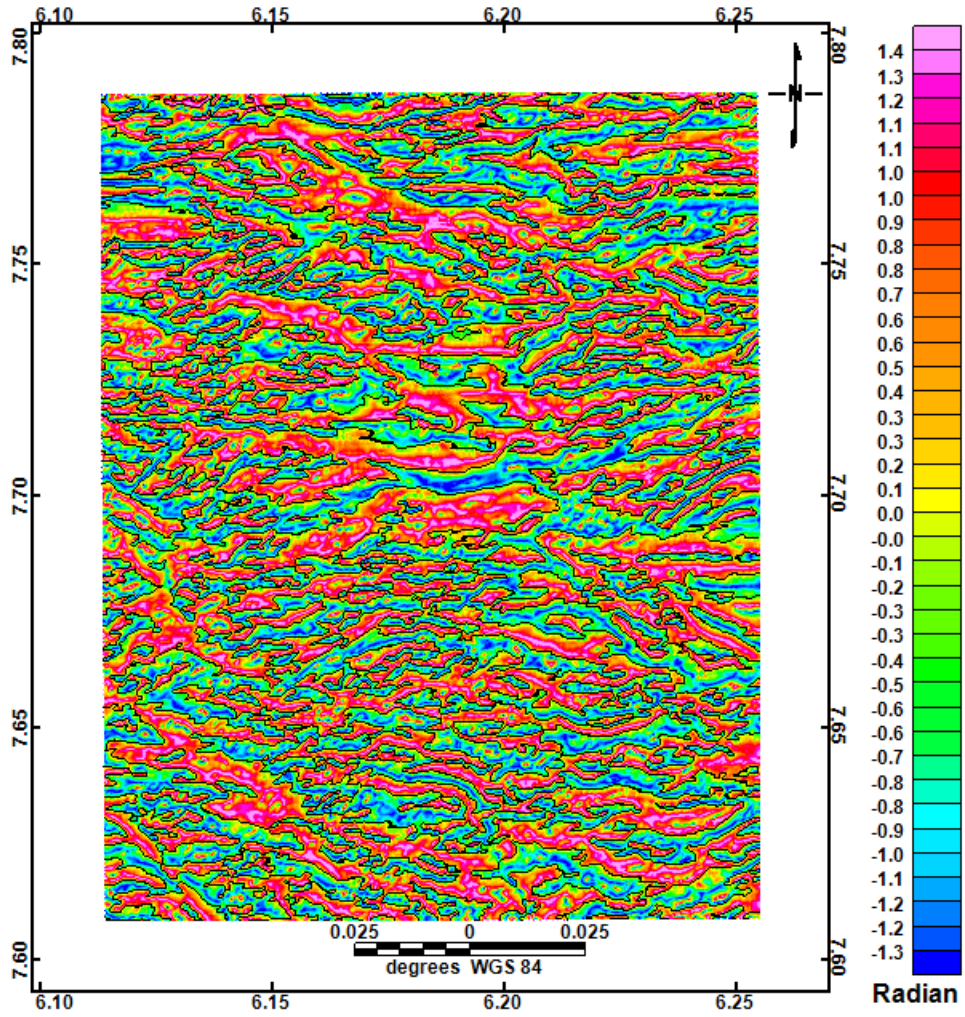



Figure 6: TDR MAP

**First Vertical Derivative (FVD).**

The First Vertical Derivative (FVD) measures the rate of change in the magnetic field in the vertical direction. It improves the high frequency components and the near surface geological details by reducing the long wavelength regional components. It is especially suited for shallow fault, contact and structural lineament mapping. However, the depth-dependency of the attenuation behavior can result in FVD being able to interfere with deeper magnetic responses (Cooper et al., 2008), and it is highly sensitive to noise. It is therefore typically combined with other normalized filters to amplify the confidence in its interpretation. Mathematically, the FVD is given by:

$$FVD = -\frac{\partial P}{\partial x} \quad (5)$$

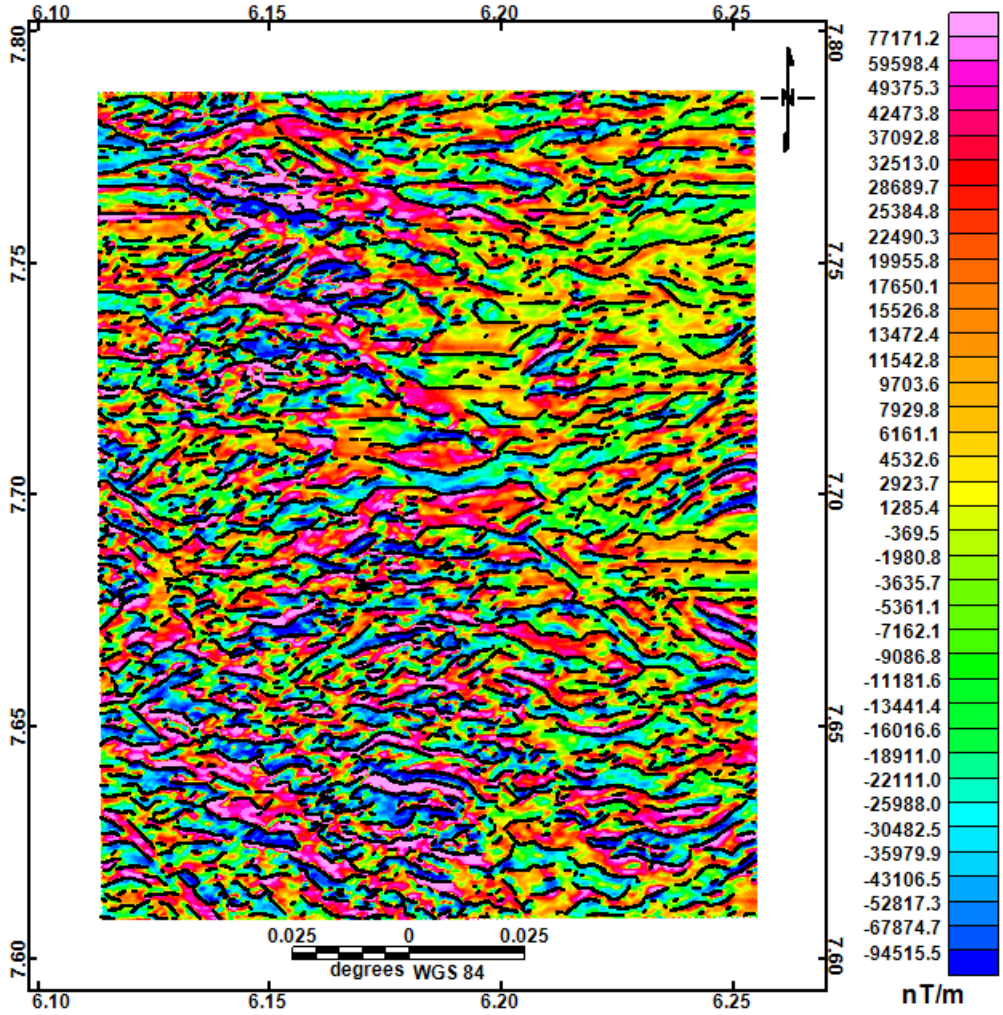



Figure 7: Lineament Superimposed on First Vertical Derivative (FVD) Map

## Depth to basement Estimation

Power Spectrum

To estimate the depth of shallow and deep magnetic source ensembles, the power spectrum analysis was performed, and the Fast Fourier Transform (FFT) was used. The method is based on the separation of signals by their frequency content using cut-off frequencies which allow the passage or rejection of the different wavelength bands. The radially averaged power spectrum technique is widely applied to the estimation of depths to basement, volcanic intrusions and other subsurface structures (Bhattacharyya, 1966; Spector & Grant, 1970). It is based on Fourier transformation of magnetic data in both the x and y directions following the conditioning of the gridded data to make it periodic on its boundaries. Lee (1960) described the Fourier transform $\emptyset(x, y)$ of the periodic function $\phi(k_x, k_y)$ as:

$$\emptyset(x, y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \phi(k_x, k_y) e^{i(k_x x + k_y y)} \, dxdy \quad (6)$$

where $(k_x)$ and $(k_y)$ are the spatial coordinates in the x and y directions respectively. $(k_x)$ and $(k_y)$ are the angular frequencies in the x and y directions respectively.

This study employed the software package, Geosoft® Oasis Montaj™, to calculate the radially averaged power spectrum of the aeromagnetic data, and to approximate average depths of magnetic source assemblages. Spectral power values were plotted versus the wavenumber to obtain the power spectrum, which provided information about the distribution of short and long wavelengths in the data. The resulting spectrum was then divided into linear sections, reflecting the contribution of each of the source groups at the same depth. The gradient of each segment is proportional to source depth and this can be used to estimate depth of magnetic bodies and the basement surface (Bhattacharyya, 1966; Spector & Grant, 1970). The averaged power spectrum is thus a function of wavenumber and is called the radially averaged power spectrum.

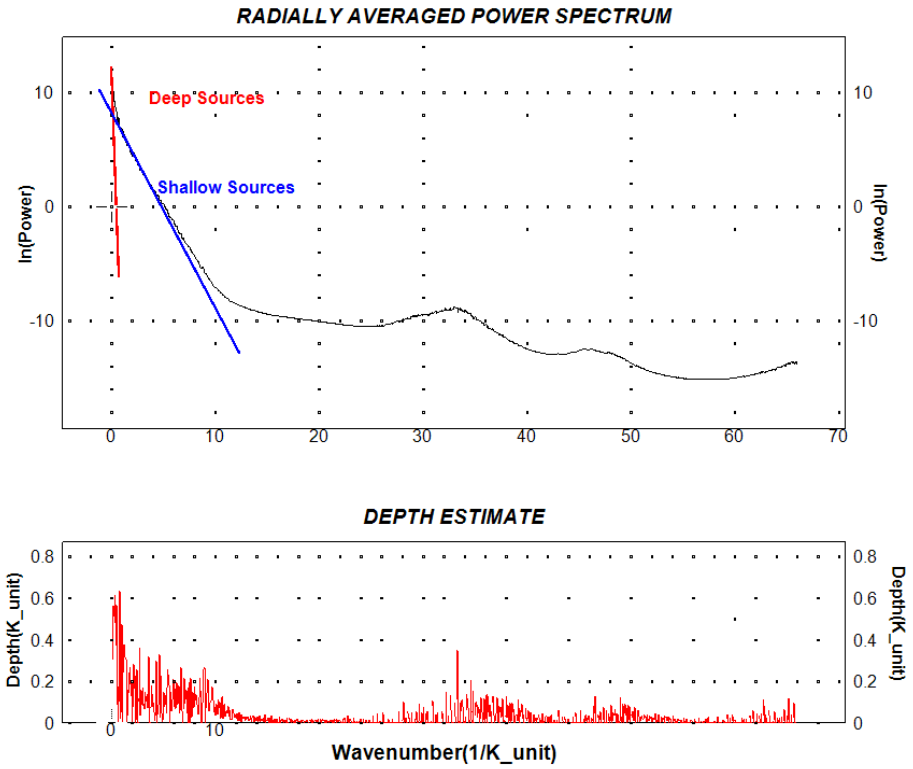



Figure 8: Radially Average Power Spectrum

## Source Parameter Imaging (SPI)

The Source Parameter Imaging (SPI) is a depth estimation method which uses the local wavenumber and spatial derivatives of the magnetic field to estimate the depths to the top boundaries of magnetic sources automatically. SPI can be used on edge enhanced aeromagnetic data to give estimates of depth at each anomaly, without making any assumption about the direction of the magnetization or the source geometry (Samson et al., 2026.

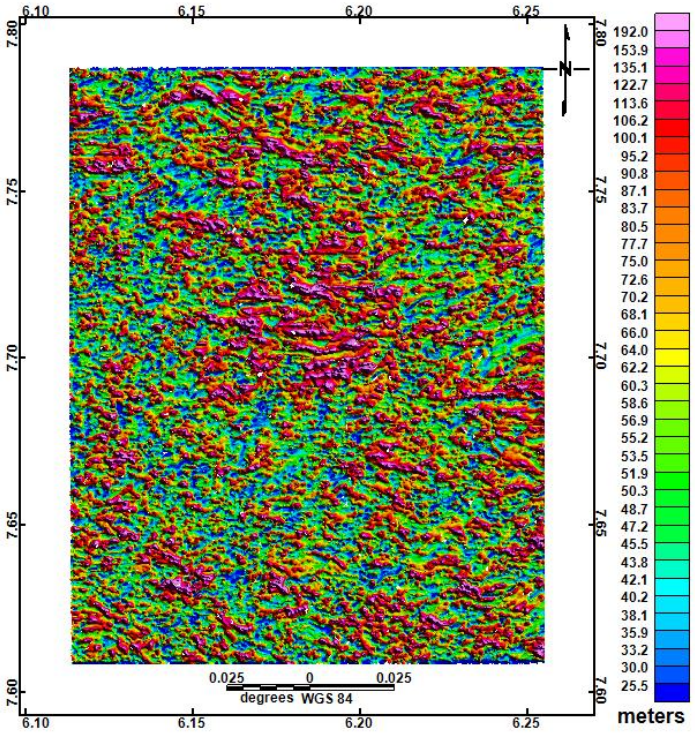



Figure 9: Source Parameter Imaging of the research region

## The Centre for Exploration Targeting (CET)

The Centre for Exploration Targeting (CET) is a collection of image processing methods that are used to assess the complexity of the structure, detect lineaments, analyze the texture, and vectorize the geological features. It combines the texture analysis, edge enhancement, thresholding, lineament extraction and structurally complex domain delineation (Kovesi, 1991; Lam et al., 1992; Kovesi, 1997). Phase symmetry is more preferred than phase congruence in the context of CET analysis as it is more useful for the detection of symmetric features such as faults and lineaments that are essential for structural interpretation. Other advantages of phase symmetry include increased noise and contrast insensitivity, and clearer definition of structural boundaries, while phase congruence is more sensitive to noise than edges and contrast responses (Holden et al., 2008).

Lineaments extracted from the aeromagnetic dataset were used to create the rose diagram (Figure 11) which summarizes the orientations and frequencies of the extracted lineaments, and thus reveals the dominant structural trends interpreted from the edge-enhanced aeromagnetic dataset.

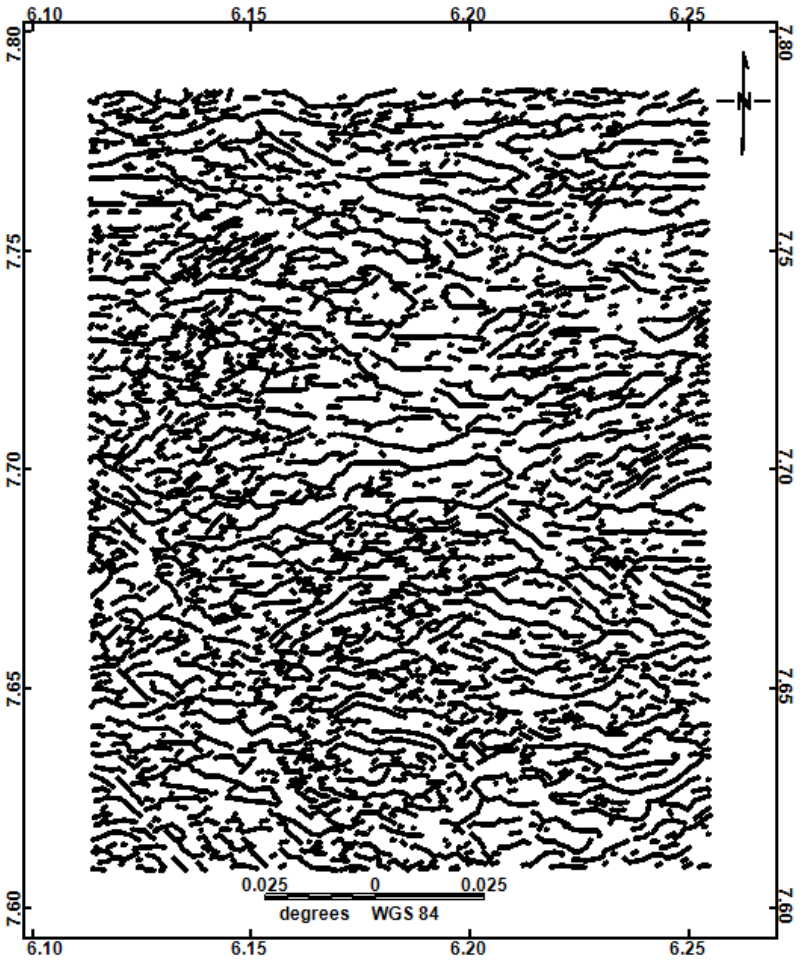



Figure 10: CET Structural Map

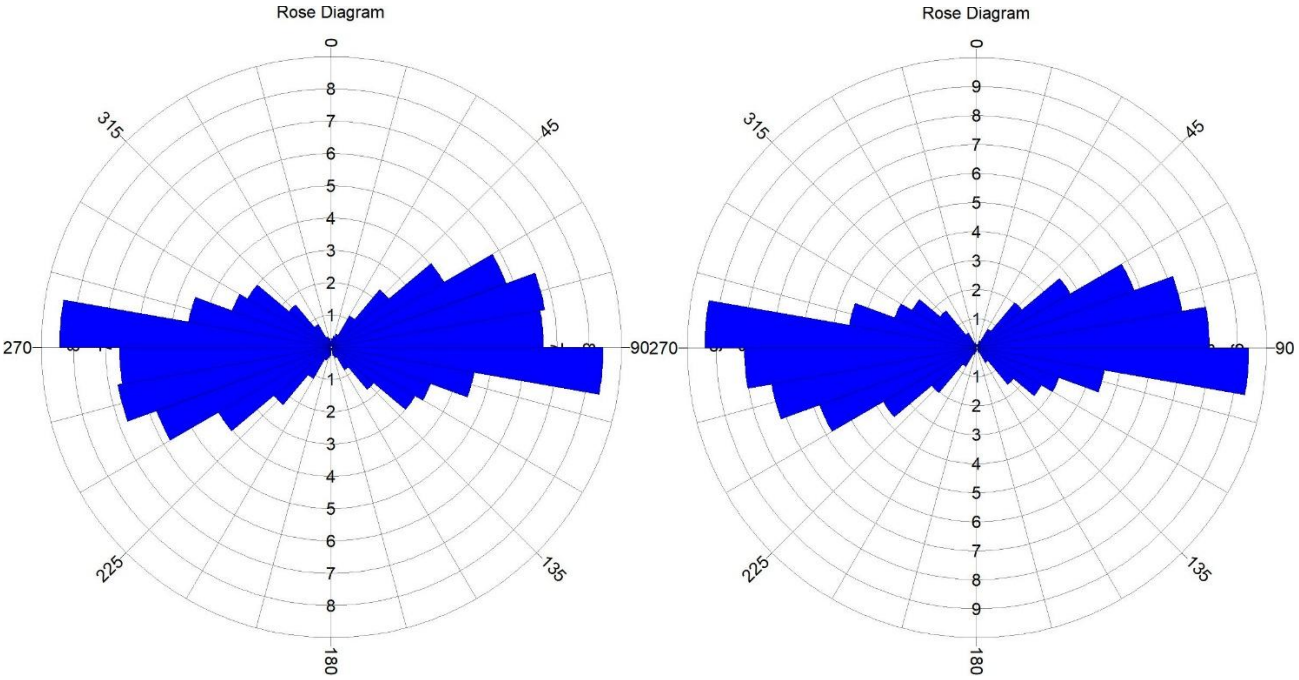



Figure 11: (a) Rose diagram using Frequency density (b) Rose diagram using Linear density

## 4 Discussion & Interpretations

The lineaments shown on the FVD map (Figure 7) were delineated based on the distribution of the derivative maxima and high frequency magnetic response. Shallow geologic contacts are represented by strong positive (pink) and negative (blue) amplitudes. Linear derivative anomalies are associated with faults, fractures, dyke intrusions and shear zones in the upper crust. The anomalies are close to each other indicating structurally complex, intensely deformed terrains, while the subdued FVD responses indicate relatively homogeneous lithologies and/or deeper magnetic sources. The extracted lineaments are considered to be near surface structures as their presence is amplified by FVD, and thus could play a role in groundwater flow, in mineralization and in the local tectonic deformation.

The spatial distribution of the positive and negative values and zero contour make up the basis for interpreting the TDR map (see Figure 6). Positive tilt values are typically found over magnetic sources and negative values are found away from magnetic sources. The zero contour (light yellow) represents the boundary between the adjacent colour zones and is expected to approximate the boundaries of causative bodies and is related to lithological contacts, basement offsets, intrusive margins and fault traces. Major regional structures are shown by continuous zero contours, and segmented fault systems are shown by discontinuous zero contours. The TDR of the reduced-to-equator data shows mainly E–W structural trends, to allow simultaneous imaging of shallow and deep sources and to interpret the regional tectonics.

Given the map TH_TDR (Figure 4), structural boundaries are sharpened by enhancing horizontal gradients of the tilt angle. The high amplitude ridges (red and pink) are associated with regions of high lateral susceptibility contrast, such as fracture corridors, dyke margins, lithological contacts, shear zones and faults. The main structural grain in the area is set by their orientation. The intersecting lineaments and the clustered maxima may indicate favorable pathways for hydrothermal fluid flow and mineral deposition, respectively, and may indicate high deformation intensity and repeated tectonic reactivation. Because of its excellent edge localization, TH_TDR offers one of the best definitions of subsurface structures.

The Analytical Signal (AS) map (Figure 5) highlights the overall magnetic gradient and generates peaks directly above the boundaries of the sources, independent of the direction of magnetization. The high amplitude responses (red to pink) represent strongly magnetized rocks such as mafic intrusions, iron rich units, basement uplifts and basaltic bodies. The broad anomalies can be associated with a large intrusive complex, while the narrow peaks are typical of dykes or areas of mineralization. The direction independence of AS makes it very reliable for low magnetic latitude areas. The confidence in the subsurface contacts interpretation is enhanced when there is agreement between the AS maxima and the edge(s) defined by the TDR and TH_TDR.

High density of CET lineaments (Figure 10) is considered to be the zones of greater structural complexity and deformation which have experienced multiple tectonic activity in the past and allow a higher permeability of the crust. These areas can be conducive to hydrothermal fluids, accumulation of groundwater, mineralization and geothermal fluids circulation. Finally, low-density areas are probably areas of structurally stable basement blocks or relatively uniform lithologies. Therefore, the use of CET analysis is an objective method for determining prospective targets in aeromagnetic data that have structural features.

The main tectonic orientations that controlled the development of the structure in the study area are indicated by the dominant peaks (9) in the rose diagram (Figure 11). The predominance of NE–SW and E–W trending faults, fractures and basement fabrics suggest preferred directions of faulting, fracturing and basement fabric development related to regional stress fields and tectonic reactivation. The areas of groundwater occurrence, fluid migration and mineral deposition are favored by zones of increased lineament density which indicate areas of

structural intersections, which can increase secondary porosity and permeability. Incorporation of CET and rose diagram analysis thus enhances the understanding of the tectonic controls and enhances geological interpretation from edge enhanced magnetic data.

The Radially Averaged Power Spectrum (RAPS) (Figure 8) and Source Parameter Imaging (SPI) (Figure 9) methods were used to estimate depths to magnetic sources within the study area. Edge detection filters differentiate shallow (~115 m) from deep (~239 m) spectral depths, which are interpreted as near surface contacts, faults, dykes and fracture zones, and regional basement structures and major tectonic discontinuities, respectively. RAPS therefore offers average depth estimates which are consistent with the structural framework developed based on the derivative analysis. SPI results provide greater depth resolution than RAPS. Shallow solutions (<50 m) are frequently associated with faults, intrusive contacts and other structures in the near surface that can be resolved using TDR, FVD and TH_TDR; deeper solutions (>100 m) are associated with offsets in the basement and crustal discontinuities. Traditionally, SPI is used to determine the geometry and continuity of individual magnetic features, as opposed to the regional depth averages given by RAPS. The use of SPI in conjunction with edge detection is thus useful for better interpretation of the structures and better characterization of subsurface tectonic architecture.

## 5 Conclusion

The results indicate that there is no universal best edge enhancement technique. FVD can be used to image shallow structures, while TDR and TH_TDR offer better edge continuity and depth responses. The other advantage of AS is that it is not directionally sensitive. Geological lineaments that are consistently identified on FVD, TDR, TH_TDR and AS maps are considered to be reliable and highly confident. They are oriented to show the major tectonic patterns which controlled the development of the study area. Lineament intersections are good sites to consider for mineral prospecting as they are frequently associated with migration of hydrothermal fluids. Groundwater accumulation may also be related to the fractured basement areas that also appear to be coincident with magnetic anomalies. Thus, the use of these derivative techniques can give a more complete picture of the subsurface structural architecture and its implications for the mineral exploration, groundwater evaluation and regional tectonic studies.

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The authors did not receive any specific funding for this research.

### Ethics, Consent to Participate, and Consent to Publish declarations

Not applicable.

### Declarations:

### Competing interests

The authors declare no competing interests.

### Conflict of Interest

There is no conflict of interest among the authors.

## Clinical Trial

Not applicable, this study is not a clinical trial.

## Credit authorship contribution statement

S.O.A.; writing—original draft preparation, methodology, interpretation and software, S.O.A, & M.A.S data curation and Visualization, M.A.S, U.M.Z. & J.I.T; writing—review and editing. All authors actively discussed, reviewed and approved the final version of the manuscript.

## Data Availability

The data for this research will be made available by the corresponding author upon request.

## Reference


Adetona, A.A., Hammed, O.S., & Adepelumi, A.A. (2021). Structural interpretation of high-resolution aeromagnetic data over the Dahomey Basin, Nigeria: Implications for hydrocarbon prospectivity. *Journal of Petroleum Exploration and Production Technology, 11*, 1955–1973. https://doi.org/10.1007/s13202-021-01138-w.

Ayomide, A.A., Ojo, O.F., Blessing, A.M., (2025). Determination of Depth to Magnetic Source from Aeromagnetic Data of Idah, Kogi State Using Euler Deconvolution Technique. International Journal of Earth Sciences Knowledge and Applications 7 (2), 223-231. https://doi.org/10.5281/zenodo.17021283.

Bhattacharyya, B. k. (1966). Continuous spectrum of the total-magnetic-field anomaly due to a rectangular prismatic body: Geophysics, 31, 97–121, doi: https://doi.org/10.1190/1.1439767

Cooper G.R.J., Cowan D.R. (2008). Edge enhancement of potential-field data using normalized statistics. Geophysics 73(3):H1–H

Cordell, L., & Grauch, V. J. S. (1985). Mapping basement magnetization zones from aeromagnetic data in the San Juan Basin, New Mexico. The Utility of Regional Gravity and Magnetic Anomaly Maps. Society of Exploration Geophysicists, pp 181–197, https://doi.org/10.1190/1.0931830346.ch16

Fairhead, J.D., Salem, A., Williams, S., Samson, E. (2008) Magnetic interpretation made easy: The tilt-depth-dip-Dk method. In: 2008 annual international meeting expanded abstracts. Society of Exploration Geophysicists, pp 779–783

Hinze W.J., Von Frese RRB, Saad A.H. (2013). Gravity and magnetic exploration principles, practices, and applications. Cambridge University Press, New York

Holden, E. J., Dentith, M. C., Kovesi, P., (2008). Towards the automatic analysis of regional aeromagnetic data to identify regions prospective for gold deposits. Computers & Geosciences, 34(11), 1505–1513.

Ibraheem, I. M., Haggag, M., & Tezkan, B. (2019). Edge detectors as structural imaging tools using aeromagnetic data: a case study of Sohag area. Egypt. Geosciences, 9(5), 211. https://doi.org/10.3390/geosciences9050211

Ibraheem, I.M., Tezkan, B., Ghazala, H., & Othman, A.A. (2023). A new edge enhancement filter for the interpretation of magnetic field data. *Pure and Applied Geophysics, 180*(6), 2223–2240. https://doi.org/10.1007/s00024-023-03249-3.

Ismael, M., Ibraheem, B.U., Lent, T., Hosni G., Amal, A. O. (2023). A New Edge Enhancement Filter for the Interpretation of Magnetic Field Data. Pure and Applied Geophysics. 180 (2023), 2223–2240. https://doi.org/10.1007/s00024-023-03249-3

Kovesi, K., (1991). Image features from phase congruency. Videre: Journal of Computer Vision Research, Summer, 1(3), The MIT Press.

Kovesi, P., (1997). Symmetry and asymmetry from local phase. AI'97, Tenth Australian Joint Conference on Artificial Intelligence. 2 – 4.

Lam, L., Lee S.-W., Suen, C. Y., (1992). Thinning methodologies-A comprehensive survey. IEEE Transactions on Pattern Analysis and Machine Intelligence, 14(9), 879.

Lee, Y. W. (1960). Statistical theory of communication. John Wiley & Sons.

Miller, H. G., & Singh, V. (1994). Potential field tilt—a new concept for location of potential field sources. Journal of Applied Geophysics, 32, 213–217. https://doi.org/10.1016/0926-9851(94)90022-1

Nasuti, Y., Nasuti, A., & Moghadas, D. (2019). STDR: a novel approach for enhancing and edge detection of potential field data. Pure and Applied Geophysics, 176, 827–841. https://doi.org/10.1007/s00024-018-2016-5

Naheem, B.S., Saminu, O., Leke, S.A., Nurudeen K.O., Silas S.D., (2019). Edge detection and magnetic basement depth of Danko area, northwestern Nigeria, from low-latitude aeromagnetic anomaly data. SN Applied Sciences 1:1056 | https://doi.org/10.1007/s42452-019-1090-3

Rahman M, Ullah SE (2013) Constrained interpretation of aeromagnetic data using tilt-angle derivatives from northwestern part of Bangladesh. Glob Adv Res J Eng Technol Innov 2:196–204

Roest, W. R., Verhoef, J., & Pilkington, M. (1992). Magnetic interpretation using the 3-D analytic signal. Geophysics, 57(1), 116–125. https://doi.org/10.1190/1.1443174

Saada A. Saada. (2016). Edge detection and depth estimation of Galala El Bahariya, Plateau, Eastern Desert-Egypt, from aeromagnetic data. Geomech. Geophys. Geo-energ. Geo-resour. 2:25–41 DOI 10.1007/s40948-015-0019-6

Salem, A., S. Williams, J. D. Fairhead, D. Ravat, and R. Smith. (2007) Tilt depth method: A simple depth estimation method using first-order magnetic derivatives: The Leading Edge, 26, 1502–1505, doi: 10.1190/1.2821934.

Samson O.A., Musa A.T., Jeffrey, I. (2026). Euler Homogeneity Equation in Source Parameter Imaging (SPI) and Deconvolution for Depth to Basement Estimation of Ground Magnetic Survey Data (Unpublished).

Spector A., Grant FS (1970) Statistical models for interpreting aeromagnetic data. Geophysics 35:293–302

Yakubu, O., et al. (2025). Data driven frequency ratio modeling for iron-ore exploration using ASTER and aeromagnetic datasets in parts of Nasarawa, Northcentral Nigeria. *Discover Geoscience, 3*. https://doi.org/10.1007/s44288-025-00202-w.

Yusuf, J., Théophile, N.M., & De Pesquidoux, T.T.I. (2026). Multiscale analysis and 3D inversion modelling of aeromagnetic data for mapping BIF-hosted iron deposits in the Djadom-Eta area, Southeastern Cameroon. *Discover Geoscience, 4*, 74. https://doi.org/10.1007/s44288-026-00415-7.