



## Structural Analysis of North-Central Nigeria's Younger Granite Province Using Aeromagnetic Data

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### ABSTRACT

This study investigates the subsurface structural framework of North-Central Nigeria's Younger Granite Province, a geologically complex area known for Jurassic granitic intrusions and associated mineralization. High-resolution aeromagnetic data from eight sheets, specifically Sheet 125 (Dutsin wai), Sheet 126 (Ririwai), Sheet 146 (Geshere), Sheet 147 (Lere), Sheet 167 (Kafanchan), Sheet 168 (Naragatu), Sheet 188 (Jemaa), Sheet 189 (Kurra) were analyzed using advanced derivative filters, including First Vertical Derivative (FVD), Horizontal Gradient Magnitude (HGM), Tilt Derivative (TDR), and Analytic Signal (AS), to map structural lineaments, lithological contacts, and fault systems. The results reveal a complex structural architecture dominated by NE–SW, WNW–ESE, and NW–SE trending lineaments, reflecting influences from the Pan-African orogeny and Mesozoic tectonic reactivation linked to the Benue Trough. High analytic signal amplitudes (0.01-0.32 nT/m) delineate magnetic source boundaries and fault zones, particularly in the northern (Binchi, Zallaki) and southeastern (Sawi) regions, which are associated with potential hydrothermal mineralization (e.g., Pb-Zn, Au, Sn). The structural density map highlights high-density zones in the northeastern (Kakwonka) and southwestern (Nok) regions, indicative of intense tectonic activity conducive to both mineralization and geothermal fluid flow. These findings provide critical insights for mineral exploration, geothermal resource assessment, and regional tectonic studies, positioning the Younger Granite Province as a key target for Nigeria's resource development and energy transition strategies.

### Keywords:

Structural analysis,  
Younger Granite  
Province, lineaments,  
Geothermal potential,  
North-Central Nigeria

### INTRODUCTION

North-Central Nigeria's Younger Granite Province is a geologically significant region characterized by Jurassic (150–200 Ma) anorogenic granitic complexes formed during extensional tectonism following the Pan-African orogeny (Obaje, 2009). These complexes, comprising alkali granites, syenites, and volcanic rocks such as rhyolites and ignimbrites, are associated with economically significant mineralization, including tin (Sn), niobium (Nb), and potentially gold (Au) and lead-zinc (Pb-Zn) deposits (Kinnaird, 1985; Obaje, 2009). The region's tectonic history, marked by the Pan-African orogeny (ca. 600–550 Ma) and Mesozoic rifting associated with the Benue Trough, has produced a complex network of faults, fractures, and lithological contacts that control both mineralization and geothermal fluid circulation (Anudu *et al.*, 2020; Abraham *et al.*, 2014).

Structural analysis is critical for understanding the subsurface framework that governs resource distribution.

Faults and fractures act as conduits for hydrothermal fluids, facilitating the emplacement of ore deposits and geothermal reservoirs (Bons *et al.*, 2012). In the Younger Granite Province, these structural features are often associated with magnetite-rich intrusions, which produce distinct magnetic anomalies detectable through aeromagnetic surveys (Anudu *et al.*, 2020). High-resolution aeromagnetic data, with their ability to map subsurface magnetic variations, offer a non-invasive and cost-effective method for delineating structural lineaments and lithological boundaries over large areas (Airo, 2002; Emmanuel *et al.*, 2023).

Despite the region's potential, detailed structural studies remain limited compared to other African regions, such as the East African Rift, where structural mapping has advanced mineral and geothermal exploration (Simiyu and Keller, 2001). Previous studies in Nigeria, such as those by Anudu *et al.* (2020) and Mohammed *et al.* (2019), have highlighted the Younger Granite Province's structural complexity and its association with mineralization,

but comprehensive mapping using advanced derivative techniques is sparse. This study leverages high-resolution aeromagnetic data from eight sheets to map structural lineaments, identify lithological contacts, and assess their implications for mineral exploration and geothermal resource development. By applying derivative filters such as First Vertical Derivative (FVD), Horizontal Gradient Magnitude (HGM), Tilt Derivative (TDR), and Analytic Signal (AS), this study provides a detailed characterization of the subsurface structural framework, contributing to Nigeria's resource exploration and sustainable energy goals. The aim is to investigate the subsurface structural framework of North-Central Nigeria's Younger Granite Province using high-resolution aeromagnetic data, with the goal of delineating structural lineaments, lithological boundaries, and fault systems to support mineral exploration and geothermal resource assessment. The objectives are to; process high-resolution aeromagnetic data and produce Total Magnetic Intensity (TMI) and Reduction to Equator (RTE) maps to identify magnetic anomalies associated with structural features, apply derivative filters (FVD, HGM, TDR, and AS) to enhance shallow and deep structural lineaments and lithological contacts, extract and quantify structural lineaments using rose diagrams to determine dominant tectonic trends and their relationship to regional geological processes, generate a structural density map to

identify zones of high tectonic activity and their potential for hosting mineral deposits and geothermal reservoirs, correlate structural findings with the geological and tectonic framework of the Younger Granite Province to assess implications for resource exploration and recommend priority areas for further geophysical, geochemical, and drilling investigations to confirm the economic viability of mineral and geothermal resources.

**LOCATION, EXTENT AND TOPOGRAPHY OF THE STUDY AREA**

The study area is located within a region defined by the geographic coordinates of Latitude 9°N to 11°N and Longitude 8°E to 9°E (Figure 1). Settlements such as Binchi, Zallaki, Kударu, Sawi, Damau, Rimiwai, Buruku, Doka, Kutri, Richaha, Dan Alhaji, Zuku, Sabon Gida, and Kakwonka, are known to be in this region.

The study area spans approximately 1° of latitude (9°N to 11°N) and 1° of longitude (8°E to 9°E), forming a roughly square region.

The region features varied lithologies, including magnetite-rich younger granites, which suggest the presence of elevated or rugged terrain (Figure 2), such as hills or plateaus, commonly associated with granitic intrusions.

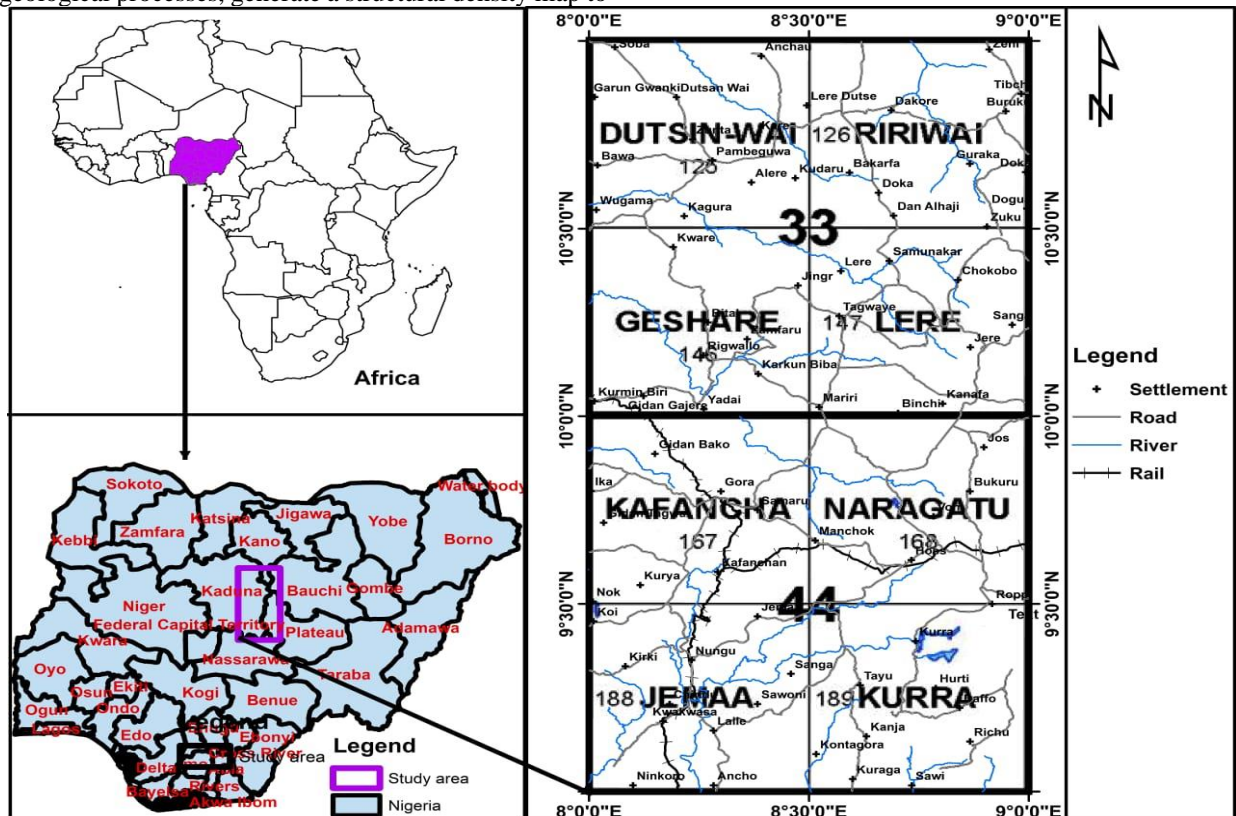
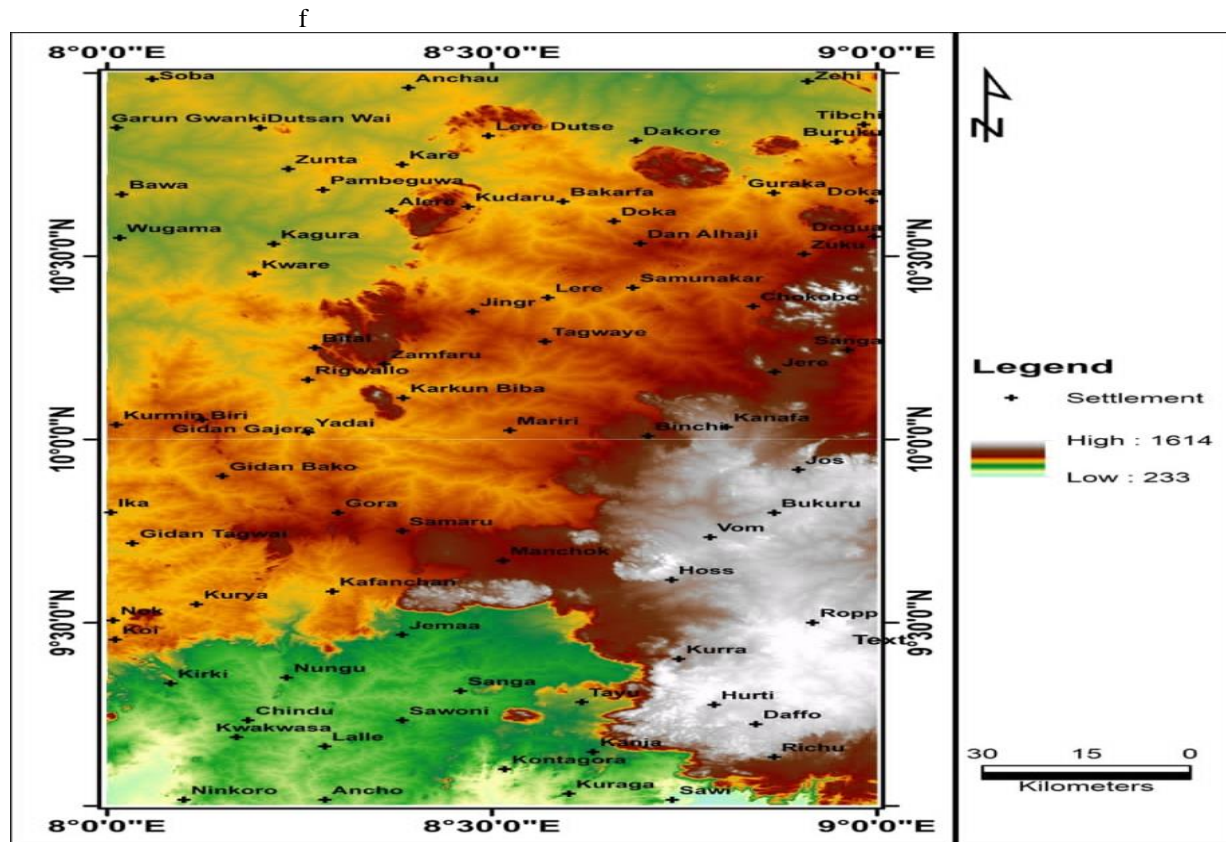


Figure 1: shows a Map of the Study Area. (NGSA 2006)



**Figure 2: Digital Elevation Map (DEM) of the Study Area (NGSA 2006)**

### Geology of the Study Area

The study area in North-Central Nigeria (latitude 9°N–11°N, longitude 8°E–9°E), lies within the Nigerian Basement Complex and encompasses significant portions of the Younger Granite Province (Figure 3). The Nigerian Basement Complex, part of the Pan-African orogenic belt, consists of Precambrian to early Paleozoic rocks, including migmatites, gneisses, schists, and granitic intrusions, shaped by multiple tectonic and metamorphic events (Obaje, 2009). The Younger Granite Province, a hallmark of the study area, is characterized by Jurassic (150–200 Ma) anorogenic granitic complexes formed during extensional tectonism following the Pan-African orogeny. These complexes, including the Ririwai, Dutsin Wai, and Kafanchan ring complexes, comprise alkali granites, syenites, and volcanic rocks such as rhyolites and ignimbrites, often associated with tin, niobium, and rare earth element (REE) mineralization (Kinnaird, 1985; Obaje, 2009).

The province's structural framework includes ring dykes, cone sheets, and fault systems that facilitated magma emplacement and hydrothermal activity. These structures are linked to Mesozoic extensional tectonics associated with the opening of the Benue Trough, a Cretaceous rift

basin that extends across the study area with sedimentary cover overlying basement rocks (Benkhelil, 1989). Major fault systems, trending NE–SW and NW–SE, enhance subsurface permeability and fluid circulation, creating pathways for hydrothermal fluids and geothermal reservoirs (Mohammed *et al.*, 2019). The presence of magnetite-rich granitic intrusions, as indicated by magnetic anomalies, suggests high magnetic susceptibility and potential for elevated heat flow due to radioactive decay of uranium, thorium, and potassium within the granites (Obaje, 2009).

The geological setting is analogous to other mineralized and geothermally active regions globally, such as the East African Rift, where tectonic activity and magmatism drive resource formation (Simiyu and Keller, 2001). Surface manifestations, such as warm springs in the nearby Ikogosi region, further support the potential for structurally controlled geothermal and mineral systems in the Younger Granite Province (Abraham *et al.*, 2014). The interplay of Jurassic intrusions, fault systems, and volcanic activity creates a favorable environment for both economic mineral deposits and geothermal energy exploration.



calculating the horizontal gradient of the magnetic field (Phillips, 2000).

The horizontal derivative of an anomaly field is considered as the Pythagorean sum of the gradient in the orthogonal direction. If  $M(x, y)$  is the magnetic field, then the horizontal derivatives are:

$$HGM(x, y) = \sqrt{\left(\frac{dm}{dx}\right)^2 + \left(\frac{dm}{dy}\right)^2} \quad (5)$$

- **Tilt Derivative (TDR):** Normalized magnetic anomalies to map both shallow and deep structures, with zero contours indicating structural boundaries (Miller and Singh, 1994).

One of the simplest and most effective ways to enhance features in aeromagnetic grids remains the tilt derivative of Miller and Singh (1994).

The tilt derivative (TD) as normally calculated is given by:

$$TD = \tan^{-1} \left[ \frac{dF_{dz}}{\sqrt{\left(\frac{dF}{dx}\right)^2 + \left(\frac{dF}{dy}\right)^2}} \right] \quad (6)$$

- **Analytic Signal (AS):** Identified magnetic source boundaries and sheet-like structures by combining horizontal and vertical gradients, independent of magnetization direction (Roest *et al.*, 1992).

**5. Structural Mapping:** Lineaments were extracted from derivative maps using automated edge detection and manual interpretation in ArcGIS. Automated extraction was performed using Edge Detection tools with a gradient magnitude threshold above 75<sup>th</sup> percentile; only features

longer than 500m were retained. Rose diagrams were generated to quantify azimuthal trends of lineaments.

**6. Validation of Result:** The interpreted lineaments and boundaries were validated by comparing them with NGS geological maps (2006), known ring complexes (Kinnaird, 1985; Obaje, 2009) and available field data from Riruwai, Dutsen Wai, and Kafanchan areas. Quantitative spatial correlation was also performed with known mineral occurrences and fault traces from previous studies (Anudu *et al.*, 2020; Mohammed *et al.*, 2019)

**7. Structural Density Analysis:** A density map was created by calculating the number of lineaments per unit area (55 km x 55 km grid), identifying zones of high tectonic activity.

## RESULTS AND DISCUSSION

The results of the structural analysis of North-Central Nigeria's Younger Granite Province using high-resolution aeromagnetic data from eight sheets (Sheet 125 Dutsin Wai, Sheet 126 Ririwai, Sheet 146 Geshere, Sheet 147 Lere, Sheet 167 Kafanchan, Sheet 168 Naragatu, Sheet 188 Jemaa, and Sheet 189 Kurra) are presented according to the study objectives.

The Total Magnetic Intensity (TMI) map (Figure 4) shows magnetic intensity values ranging from 32,873.21 nT to 33,123.37 nT. Prominent high magnetic anomalies are observed in the northern (Binchi, Zallaki) and southeastern (Sawi) regions. These anomalies are associated with magnetite-rich granitic intrusions characteristic of the Younger Granite Province.

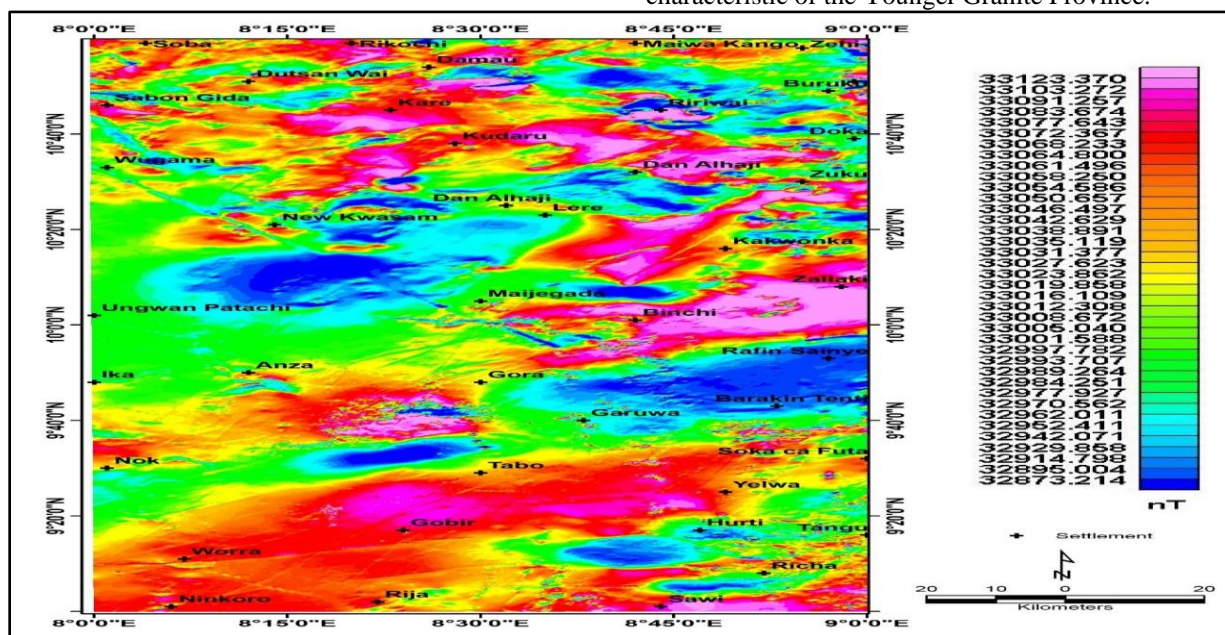


Figure 4: Total magnetic intensity map of the study area

The Reduction to Equator (RTE) map (Figure 5) effectively centered the magnetic anomalies and improved the clarity of lithological contacts and structural trends, particularly in low-latitude conditions. A total of

1,847 lineaments were extracted with lengths ranging from 0.5km to 28.4km, with mean length of 4.7km and cumulative total length of approximately 8,680km.

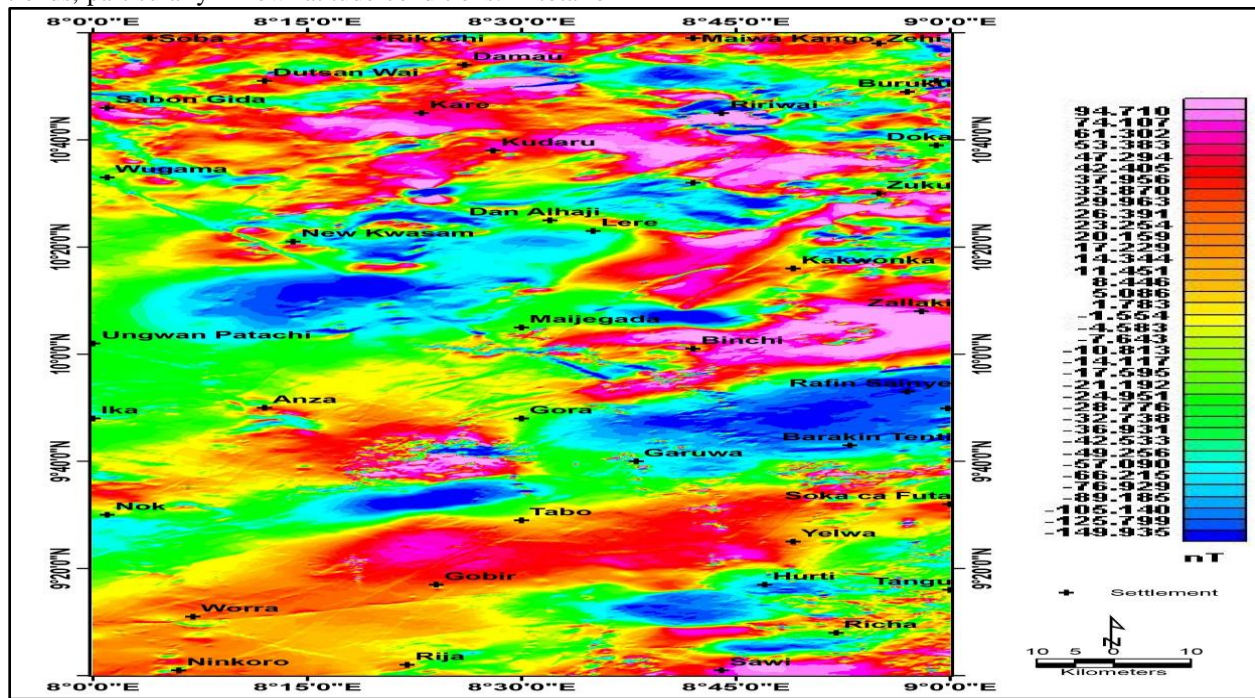


Figure 5: Residual magnetic intensity map reduced to the equator

The Analytic Signal (AS) map (Figure 6) reveals amplitudes ranging from 0.01 to 0.32 nT/m. High AS

amplitude zones are concentrated in the Damau–Rimiwai–Buruku–Doka and Kutri–Richaha–Sawi areas, indicating sharp lithological contacts and fault systems.

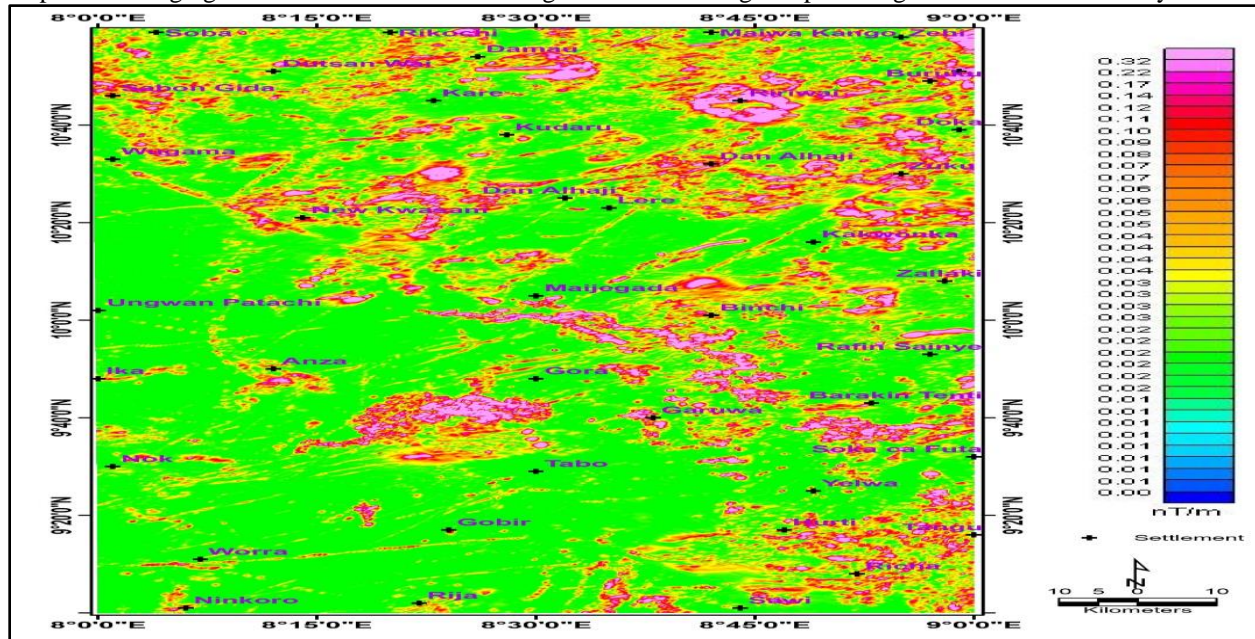


Figure 6: Analytic signal

The First Vertical Derivative (FVD) map (Figure 7) NE–SW, with secondary NNE–SSW and NW–SE enhanced shallow structural features and clearly delineated lineaments trending mainly WNW–ESE and

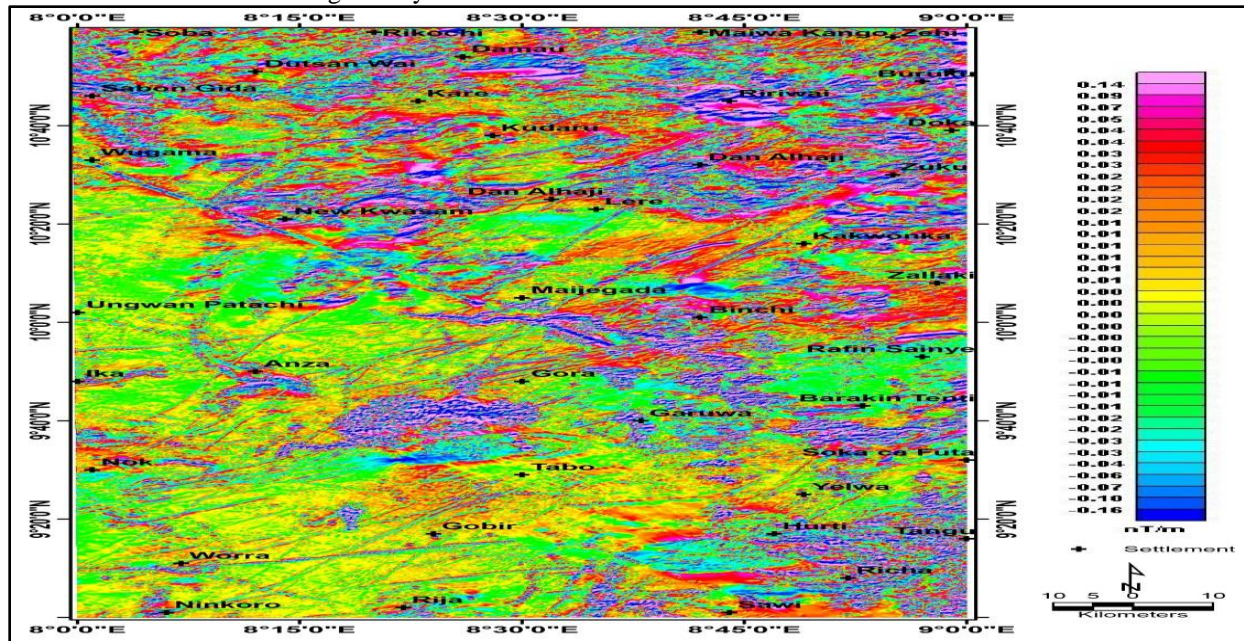


Figure 7: First vertical derivative map

The Horizontal Gradient Magnitude (HGM) map (Figure 8) highlighted magnetic contacts and fault zones, with prominent maxima observed near Dan Alhaji, Zuku, and Sabon Gida.

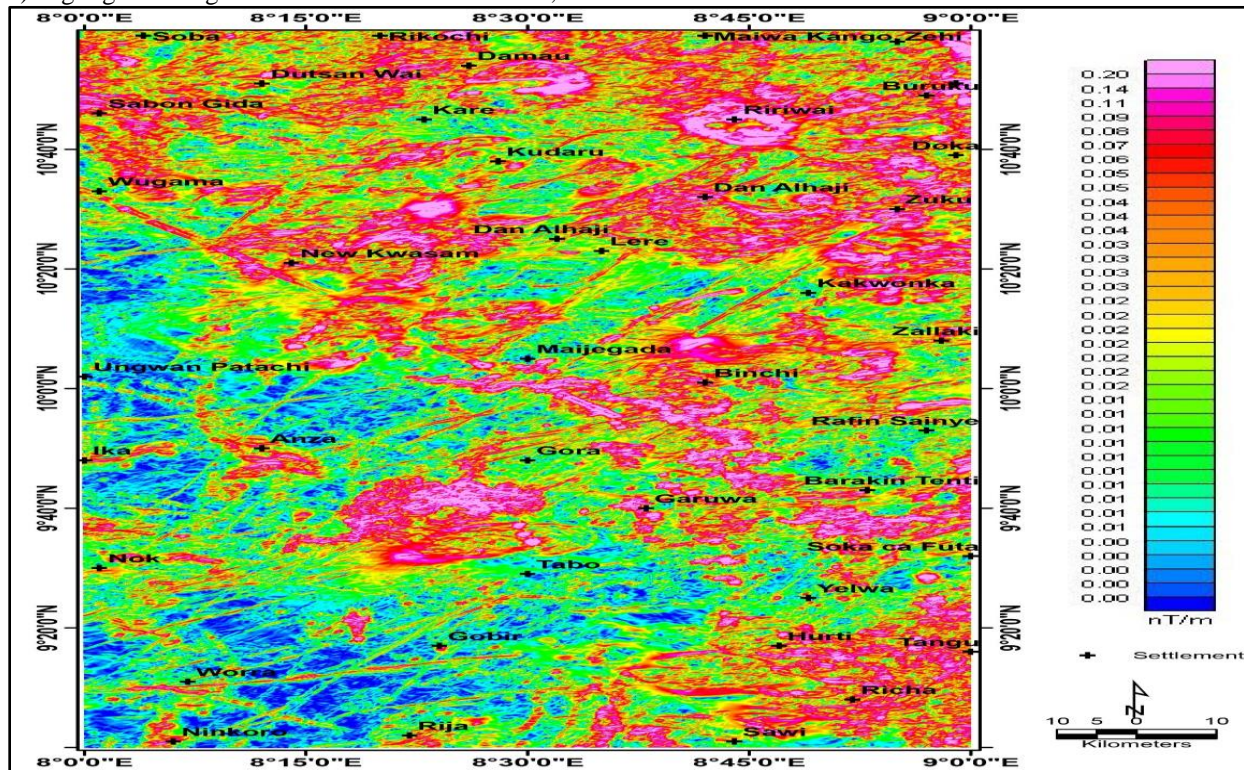
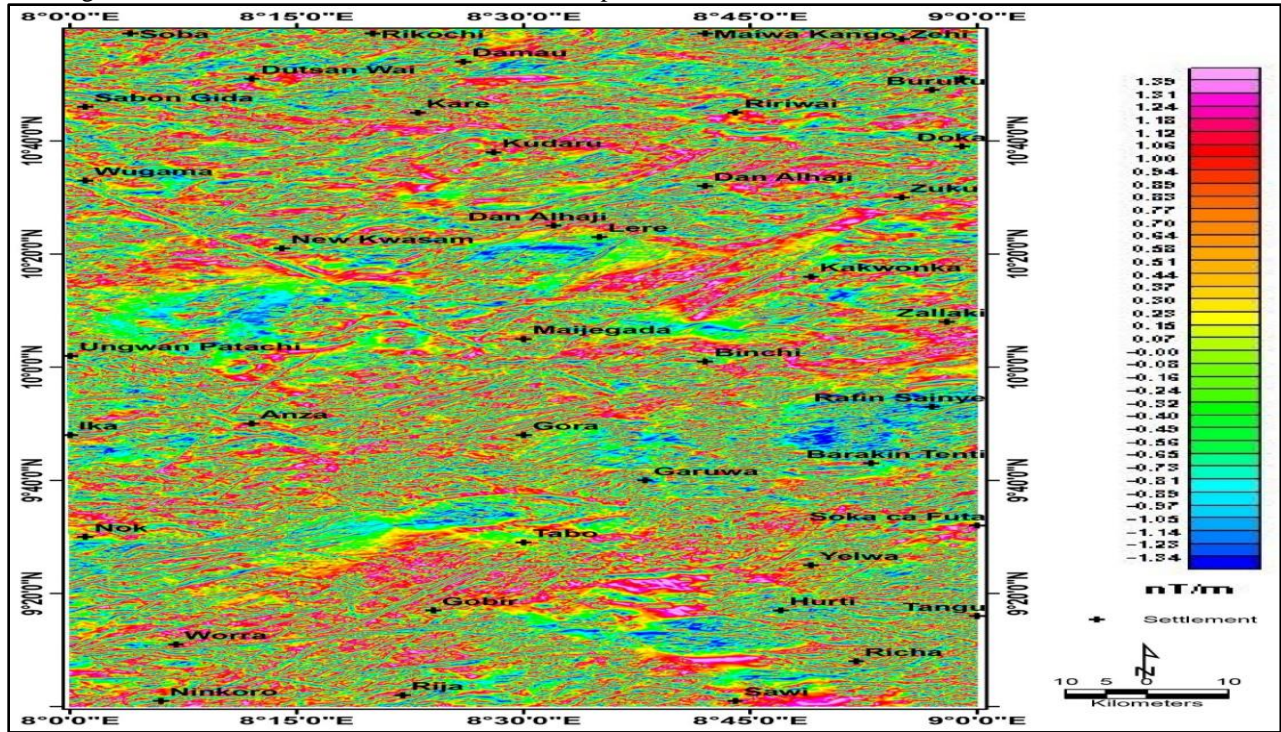


Figure 8: Horizontal gradient magnitude map of the area

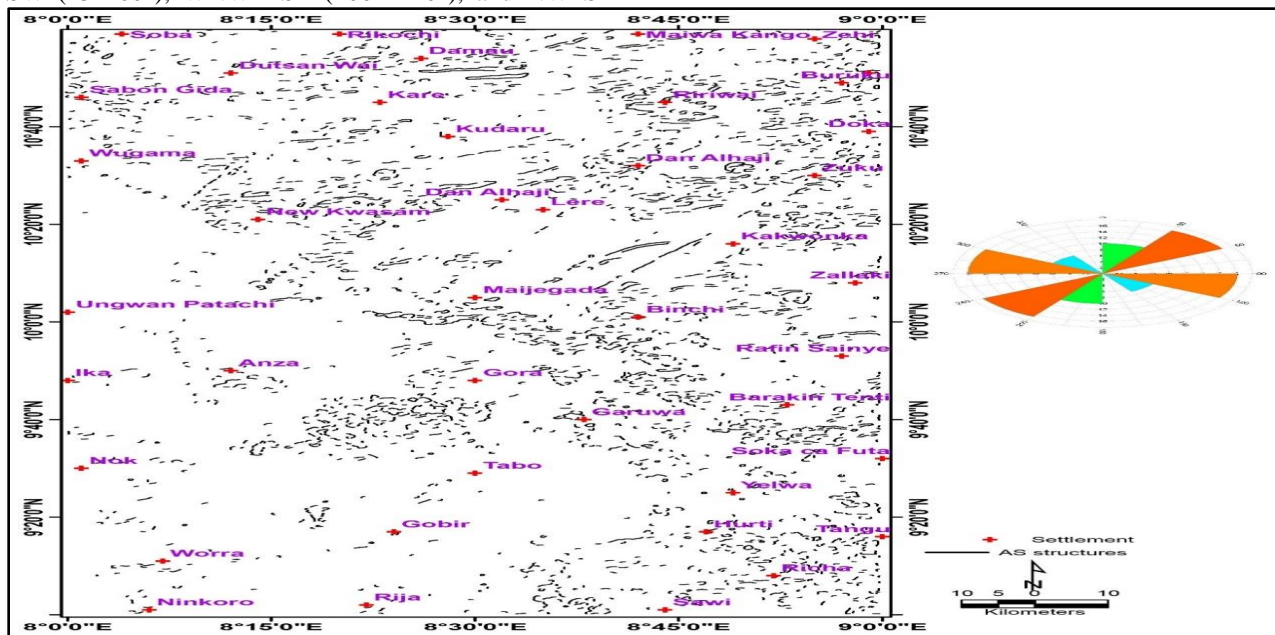
The Tilt Derivative (TDR) map (Figure 9) normalized the magnetic anomalies, with zero contours effectively marking structural boundaries. The TDR map

successfully enhanced both shallow and deeper structural features across the study area.



**Figure 9: Tilt derivative map of the area**  
 Lineaments were extracted from the derivative maps. The rose diagram (Figure 10) shows the azimuthal distribution of the lineaments, revealing dominant trends in the NE-SW (45°-60°), WNW-ESE (100°-120°), and NW-SE

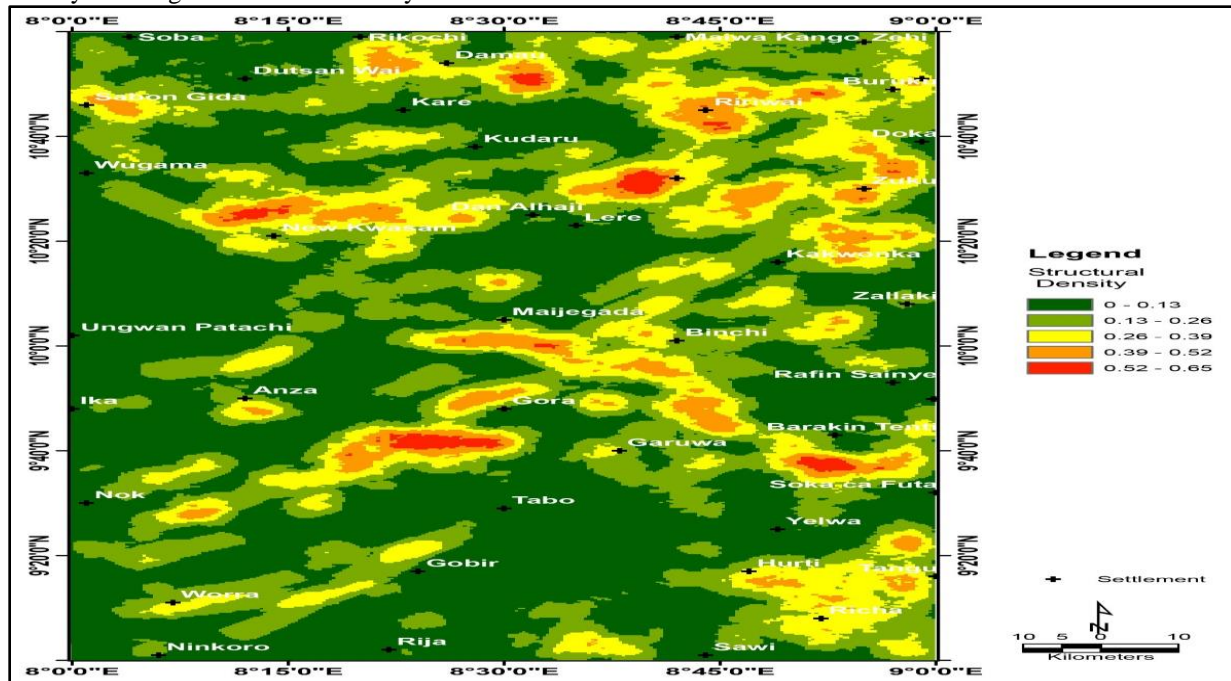
(120°-140°) directions, with minor NNE-SSW orientations. It reveals three dominant trends:  
 NW-SW (40°-60°) 38% of total lineaments  
 WNW-ESE (100°-120°) 27% of total lineaments  
 NW-SE (120°-140°) 21% of total lineaments



**Figure 10: Analytic signal structures with Rose diagram**

The structural density map (Figure 11), generated using a 55 km × 55 km grid, identifies zones of high lineament density. The highest structural density is observed in the

northeastern (Kakwonka) and southwestern (Nok) regions, indicating areas of intense tectonic deformation.



**Figure 11: Horizontal gradient magnitude structural map of the area**

High AS amplitudes and high structural density zones show strong spatial correlation with known granitic intrusions and fault systems within the Younger Granite Province. The high-density zones in Kakwonka and Nok coincide with areas of prominent magnetic anomalies and lineament intersections.

Based on the integrated results, the northeastern (Kakwonka), southwestern (Nok), and central zones (Damau–Rimiwai–Buruku–Doka and Kutri–Richaha–Sawi) are identified as high-priority areas due to their high structural density, strong AS amplitudes, and favorable lineament trends

The TMI map (Figure 4) effectively revealed magnetic anomalies linked to magnetite-rich granitic intrusions, particularly in the northern (Binchi, Zallaki) and southeastern (Sawi) regions. The RTE map (Figure 5) successfully reduced distortions associated with low magnetic latitude, thereby improving the definition of structural trends and lithological boundaries. The multi-filter approach proved highly effective. The Analytic Signal map (Figure 6) provided clear delineation of magnetic source boundaries and fault zones through high amplitudes (0.01–0.32 nT/m), especially in the Damau–Rimiwai–Buruku–Doka and Kutri–Richaha–Sawi zones. The First Vertical Derivative (Figure 7) and Horizontal Gradient Magnitude (Figure 8) enhanced shallow lineaments and magnetic contacts, while the Tilt Derivative (Figure 9) successfully mapped both shallow and deeper structures by normalizing anomaly polarity.

The consistency observed across these filters increases confidence in the mapped structures. The rose diagram (Figure 10) confirms the dominance of NE–SW, WNW–ESE, and NW–SE trending lineaments. These trends reflect the polyphase tectonic history of the region, with NE–SW directions linked to Pan-African compressional structures and WNW–ESE/NW–SE trends representing Mesozoic extensional reactivation associated with the Benue Trough rifting. The structural density map (Figure 11) highlights zones of intense tectonic activity, with the highest lineament density concentrated in the northeastern (Kakwonka) and southwestern (Nok) regions. These high-density zones likely represent areas of fault intersections and intense fracturing, which are favorable for fluid migration and resource concentration. The structural patterns show excellent correlation with the geology of the Younger Granite Province. High AS amplitudes and structural density zones align with Jurassic granitic ring complexes and associated fault systems. The lineament trends are consistent with the known tectonic evolution involving Pan-African orogeny and subsequent Mesozoic rifting. These structurally complex zones, particularly at lineament intersections, provide favorable pathways for hydrothermal fluids, supporting both mineralization (Sn, Nb, Pb–Zn, Au) and geothermal potential. The integrated interpretation identifies the northeastern (Kakwonka), southwestern (Nok), and central zones (Damau–Rimiwai–Buruku–Doka and Kutri–Richaha–Sawi) as

priority targets. These areas combine high structural density, strong analytic signal responses, and favorable lineament intersections, making them prospective for both hydrothermal mineralization and structurally controlled geothermal systems. These zones warrant detailed follow-up investigations including magnetotelluric surveys, geochemical sampling, and exploratory drilling.

Qualitative analysis shows that lineaments in the dominant NE-SW trend are generally longer (mean 5.6km) compared to the NW-SE set (mean 3.8km), suggesting greater continuity of Pan-African structures. High density zones (>3.5 lineament/km<sup>2</sup>) cover approximately 12% of the study area but account for over 45% of major lineament intersections, highlighting their importance for fluid flow and mineralization.

The multi-technique aeromagnetic approach has successfully revealed the complex structural architecture of the Younger Granite Province and its strong control on resource potential. The results are consistent with previous studies in the region and comparable mineralized granitic provinces worldwide.

## CONCLUSION

This study demonstrates the effectiveness of a multi-derivative aeromagnetic approach (FVD, HGM, TDR, and AS) for structural mapping in low-latitude crystalline basement terrains. By integrating these filters with hybrid automated-manual lineament extraction, the research provides a high-resolution subsurface framework of North-Central Nigeria's Younger Granite Province that was previously unavailable at this level of detail. The results reveal a structurally complex province dominated by NE-SW, WNW-ESE, and NW-SE lineaments, with high lineament density (>3.5 lineaments/km<sup>2</sup>) and elevated Analytic Signal amplitudes (0.01-0.32 nT/m) concentrated in specific zones. These features highlight favourable pathways for hydrothermal fluid flow and mineralisation.

Recommendations for follow-up work include: Detailed ground geophysical surveys (magnetotelluric and induced polarisation) targeting the Kakwonka (northeast), Nok (southwest), and Damau-Rimiwai-Buruku-Doka areas; Geochemical sampling and structural mapping along major lineament intersections in the Kutri-Richaha-Sawi zone; Shallow exploratory drilling (up to 500 m) at high-priority sites to confirm mineralisation and geothermal gradients; Integration of these findings with radiometric and remote sensing data for refined targeting.

## Declaration of competing interest

The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

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