



Targeting Mineralization Zones Using Aeromagnetic data over Gusau and its Environs, Northwestern Nigeria

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Received on: August, 2025 Revised and Accepted on: September, 2025

Published on: October, 2025

ABSTRACT

This study area is bounded by Latitude 12° 00" N to 12° 30" N and longitude 6°30" E to 7° 00" E with an estimated area of 55 square km². The region is predominantly underlain by the Migmatite–Gneiss Complex, with associated **intrusive granites** that complicate structural interpretation and mineral targeting. The present research used aeromagnetic interpretation to delineate potential mineralization zones in the area. High-resolution aeromagnetic data of the study area were processed using OASIS Montaj software version 8.4 to produce magnetic intensity maps, along with other edge detection techniques: tilt derivative, total horizontal gradient and lineament map. The result shows that the magnetic anomalies across the study area ranges from –43.0 nT to 74.0 nT. These edge detection filters identified structural features such as faults, fractures, dikes and sills which could save as pathways for mineralizing fluids. These structurally controlled zones can be indicative of promising deposits of gold, banded iron formations (BIF), chromite, chamovite, and kaolin which are found mostly by artisanal miners in the area. The study demonstrates application of aeromagnetic data in as a mapping technique that provides a reliable and cost-effective framework for targeting mineralization zones and guiding future exploration in Damba and its surrounding areas.

Keywords: Geophysical mapping, Subsurface structure, Mineralization zones, Delineation, Migmatite–Gneiss Complex.

1.0 INTRODUCTION

Mineral exploration in crystalline basement terrains often presents significant challenges due to complex subsurface geology and limited surface exposures. In such regions, geophysical methods particularly aeromagnetic surveys serve as effective tools for mapping concealed structures and delineating zones of mineralization. Aeromagnetic interpretation provides valuable insights into subsurface lithological variations, fault systems, and structural trends that control mineral deposition (Abraham *et al.*, 2024). One of the major challenges in the region is that the complex geology complicates structural interpretations, making the delineation of mineralization zones difficult. This has limited advanced mineral exploration and resource estimation efforts, resulting in the reliance on uncoordinated artisanal mining that yields low productivity and environmental concerns (Abraham *et al.*, 2025).

Although several authors, including (Usman *et al.*, 2025a) have analysed and interpreted aeromagnetic data to evaluate potential field responses, most of these studies primarily focused on estimating the depth to the magnetic basement. However, Many studies stop at derivatives and edge detectors (TDR, THG, analytic signal). Advances like depth-constrained 3D inversion, Source Parameter Imaging (SPI) and rigorous

uncertainty estimates provide much better depth/volume constraints for drill targeting (Abraham, *et al.*, 2024). Recent papers call for wider adoption of these methods.

Aeromagnetic interpretation, offers a cost-effective and reliable approach for resolving these complexities and identifying subsurface structural features that control mineralization. By processing high-resolution aeromagnetic data and applying edge detection filters such as the tilt derivative (TD), total horizontal (THG), and lineament mapping, key structural elements like faults, fractures, dikes, and sills were delineated (Usman *et al.*, 2025b). These structures often act as pathways for mineralizing fluids, making them prime targets for exploration (Ndikum *et al.*, 2024).

This study, therefore, aims to integrate aeromagnetic data processing to delineate potential mineralization zones in the study area. The findings are expected to enhance the understanding of the subsurface framework, guide future exploration activities, and support sustainable development of the region's mineral resources.

1.1 The Study Area

The area is 55 km² limited by latitudes 12° 00" N to

12° 30" N and longitudes 6° 30" E to 7° 00" E as illustrated in figure 1.1 (Charles *et al.*, 2019)

2.0 GEOLOGY OF THE STUDY AREA

The studied location is geologically located among the Pan-African granodiorite and Wonaka schist belt basement rocks, as well as a likely earlier gabbrogranite-pegmatite complex (Umar, 2024; Bolarinwa, 2024). The following rock types were found in the research region by field studies: granite gneiss, biotite-muscovite schist, greenstone, granodiorite, hornfels, and granite as main rocks, while pegmatite and banded iron formation exist as minor rocks figure 1.1 shows the location of the study area (Adetunla and Oshin, 2024; Okpoli *et al.*, 2025).



Figure 1.1: Location Map of the Study Area

Table: 1

Map / Filter	Purpose	Mathematical Basis	Key Interpretation
Total Magnetic Field (TMI)	Displays total magnetic response	$(T = F + \Delta T)$	Overall magnetic distribution
Regional Map	Shows broad, deep-seated anomalies	Polynomial or low-pass filter	Deep geological structures
Residual Map	Isolates shallow anomalies	$(r = T - R)$	Shallow or near-surface sources
THG / THD	Highlights lateral changes	$(\sqrt{(\partial M/\partial x)^2 + (\partial M/\partial y)^2})$	Structural edges or contacts
TDM	Enhances edges and estimates depth	$(\tan^{-1}((\partial M/\partial z)/THD))$	Source boundaries and depths

(Miller and Singh, 1994; Harper *et al.*, 1973)

3.0 MATERIAL AND METHODS

The (NGSA) provided the aeromagnetic data sheets 54 of Gusau. The OASIS MONTAJ software version 8.4 was utilized in this study to create the regional residual separation, and total magnetic field intensity map (TMI). To enhance the maps and highlight previously indistinct features, both the regional and residual components were processed using a range of filtering techniques. The total magnetic field map was reduced to regional and residual maps in order to separate the high and low frequency anomalies. The residual map was then reduced to equator, and TMI was

3.1 Data Acquisition and Processing

Aeromagnetic data for Sheet 54 (Gusau) were obtained from the Nigerian Geological Survey Agency (NGSA). The survey was conducted by fugro airborne services at a nominal flight altitude of 100 m, with flight lines

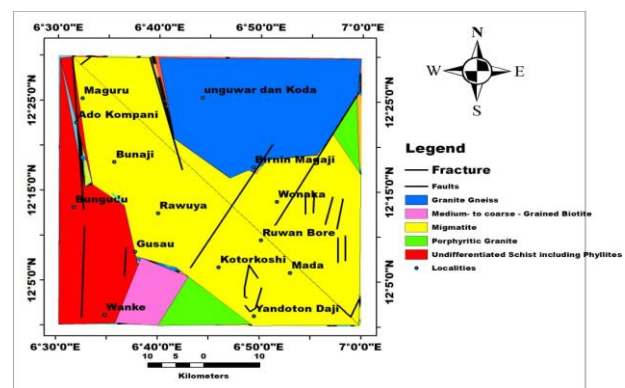


Figure 2.1: Geological Setting of the Study Area Adopted from Nigerian Geological Survey Agency (NGSA). (2023).

subjected to total horizontal gradient (THG), total horizontal derivative (THD) and tilt derivative map (TDM). The total horizontal gradient was later superimposed on tilt derivative map and finally, the high frequency anomalous zones of THG in (figure 4.5), and low frequency anomalous zones of tilt derivative (figure 4.4) respectively, indicate the lineament. This is done in order to enhance shallow geological features which were then, compared with geologic map of the study area which help to elucidate the geologic setting and mineralization of the area.

spaced 500 m apart along the north–south direction at an average speed of approximately 2 km/s. The acquired data were subsequently compiled into half-degree aeromagnetic maps at a scale of 1:100,000, with magnetic readings plotted at 10 nT intervals. A standard reduction of 33,000 nT was applied to the observed

magnetic values before contour plotting. These maps were digitized using a grid-based visual interpolation method following (Faruk *et al.*, 2025; Ogah and

4.0 RESULTS AND DISCUSSION

4.1 Total Magnetic Intensity Map

The research area's total magnetic intensity map shows both positive as well as negative anomalies, with values varying from -43.0 nT to 74.0 nT. While the low magnetic signature, which also covers a portion of the northeast and southeast of the study region, correlates to Wonaka and Mada, The research area's northwestern and south-eastern regions, which include portions of Kotorkoshi Mareri and Birnin Magaji, have a high magnetic signature that stretches from west to east (Usman and Ibrahim 2017).

On the other hand, Wonaka and Mada are represented by the low magnetic signature that also covers a portion of the research area's northeast and southeast. While the difference in color from pink to red may indicate older granite that intrudes into the gneiss-migmatite (Dahomeyan), the greenish portion of the study area may indicate the migmatite-gneiss complex, which is composed of gneisses and migmatites with entrained supracrustal relics whose metamorphism is generally in the amphibolites facies grade. Large masses of granite, granodiorite, and diorite rocks that reach up to 2100 meters above sea level and nearly delineate the western edge of the Wonaka schist belt, which includes

4.2 Residual Map Reduced to Magnetic Equator

The study area is a basement complex as can be seen from with the presence of mostly high and low values of magnetic susceptibility scattered all over the area. Broader magnetic highs and lows are associated with granites and granodiorite (Okpoli *et al.*, 2024; Lukman *et al.*, 2024). In broad, Paleo granites of 0.1% to 5% by volume of magnetite correspond to magnetic lows. The positive anomalies seem to mostly correlate with granodiorites, but in many places, granites do not have a consistent magnetic signature (some parts are highs, others lows). The part of Wonaka Schist belt in the study area occupies areas of Wonaka, and Mada whose major rock type include biotite gneiss, biotite humblende granite, quartz, and mica schist which occur on a regional scale due to the high grade metamorphism. These areas may hold an important promising solid minerals of economic potentials like, gold, banded iron ore (BIF), chromate and kaolin. While older granite occupies part of Kwatarkoshi, Mareri, rocks which include diorite, granodiorite, migmatite migmatite granite which overlie and intrude

4.3 Total Horizontal Derivative Map

Dikes, sills, and other major were identified as the sources of narrow linear positive magnetic anomalies based on the area's total horizontal map. Edges of migmatite sills and intrusions with high frequency

Abubakar, 2024), allowing for the conversion of analogue maps into digital datasets.

the Kotorkoshi and Mareri rocks, may be indicated by pink to red colouring as also reported by (Usman and Ibrahim 2017).

The geographic coordinates of this rocks measured by the GPS also agree with the coordinate of total magnetic intensity map TMI in figure 4.1 below.

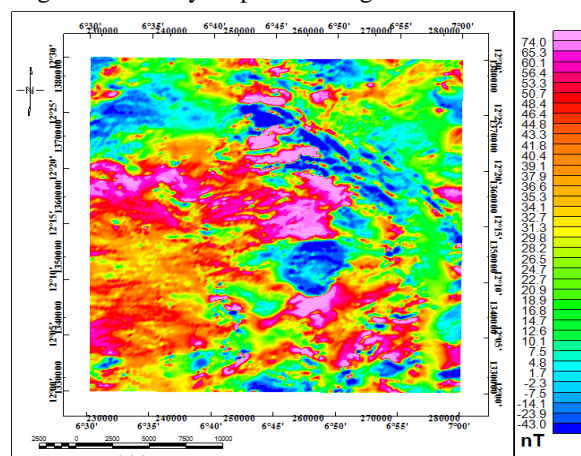


Figure 4.1: Total Magnetic Intensity Map

the basement gneisses, metasediments and granitic rocks may also host important industrial minerals like, granite, copper, zink and quartz as cited by (Usman & Ibrahim, 2017; Abdulmalik, *et al.*, 2024).

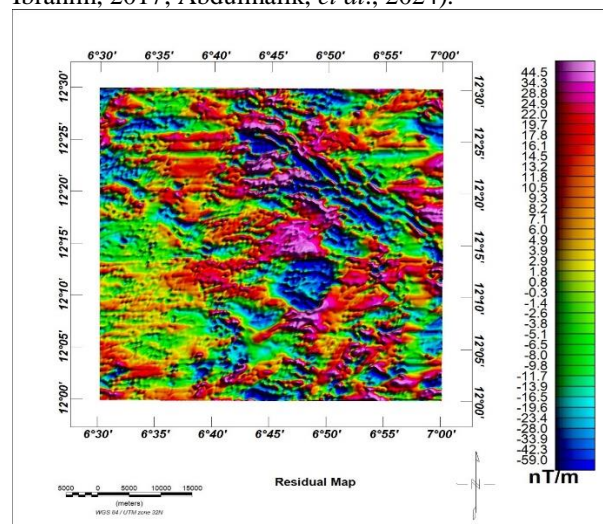


Figure 4.2: The Residual Map

anomalies may relate to ultramafic rocks or mafic rocks trapped in mixture (figure 4.3), while edges of dikes and sills which cut across different layers of rocks may serve as mineralization zones, since minerals are structurally controlled as cited by (Babu *et al.*, 2023;

Adewumi and Salako, 2018). High frequency magnetic lows are associated occasionally with dikes and sills, and it can also correspond to dike intrusion in dolerite or granite indicating that they are reversely-magnetized.

4.4 Tilt Derivative Map (TDR)

Interpreting a tilt derivative (TDR) map (figure 4.4), in aeromagnetic data analysis helps in identifying and tracing geological structures such as faults, contacts and lithological boundaries that may control mineralization. Positive values denoted by red to yellow color which ranges between (0.143 – 1.370 radiance), usually indicate the center or high side of the anomaly, often close to the magnetic source while Negative values denoted by green to blue colors (-1.327 – 0.004 radiance). Often represent areas away from the source or the outer zones of the structure and finally zero contour (green/yellow) marks the edges or boundaries of magnetic sources these are the most critical features of the map and serve as linear trends such as faults, fractures, dikes, or lithological contacts. TDR was used due to complex geology or overlapping anomalies and potential pathways for mineralizing fluids (Telford *et al.* 1990; Bagare *et al.*, 2018).

4.5 Total Horizontal Gradient Superimposed on Tilt Derivative map

The black lines represent lineament contours or intensity lines on the Total Horizontal Gradient (THG) map (Figure 4.5) and are observed within areas of high magnetic intensity, shown in pink to red shades, which may signify zones of sharp magnetic contrast. These areas trend mostly North West of the study area and their values were superimposed on tilt derivative map in (figure 4.6) The results also demonstrate that THG approach is less sensitive to variations in the depth of the sources and provides a more accurate indication of the position of the margins of causative bodies when compared to other methods, especially in cases where there are abnormalities caused by many interfering

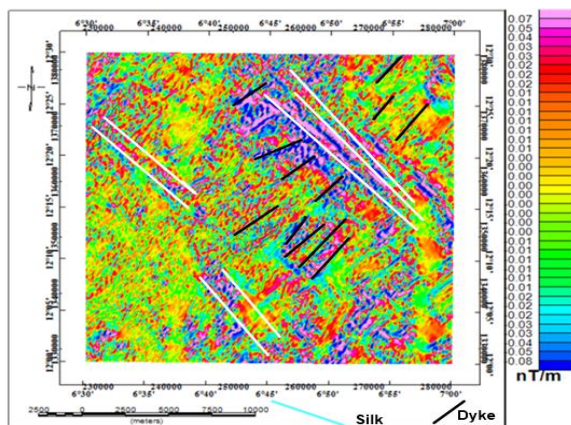


Figure 4.3: Total Horizontal Derivative Map

sources. On the other hand, the tilt derivative map (figure 4.4) shows its lineament in the areas of low magnetic intensity values depicted in blue to green colours. Similarly, the lineament of the tilt derivative agrees with that of the total horizontal derivative and trend in mostly North West of the study area. Where THG maxima coincide with TDR zero-contours, these lines mark true geologic edges or fault planes, while continuous alignments of THG peaks along zero-tilt zones represent faults, shear zones, or lithological contacts as reported by (Ekwok *et al.*, 2021). Areas where multiple THG lineaments intersect suggest structural intersections, often favorable for mineralization.

4.6 Lineament map

The high frequency anomalous zones of THG in (figure 4.5), and low frequency anomalous zones of tilt derivative (figure 4.4) respectively, indicate their lineament and were superimposed in (figure 4.7). In other words the superimposed THG and TDR intersections were used to produce the lineament map figure (figure 4.7). The lineaments map figure (4.7) can be divided into two high frequency magnetic zones, moderate and low frequency magnetic zones. High frequency amplitude can be associated occasionally to dikes and silk intrusion in dolerite or granite which may also indicate that they are reversely-magnetized. This collaborated well with the work of (Nzeuga *et al.*, 2022; Pham *et al.*, 2020). Low frequency magnetic zones may also be associated with other structures such as fractures and faults (Prasad *et al.*, 2022). These structures can be from shallow crustal depth where pegmatites tend to be intruded along anisotropies. The lineament map is well jointed mostly in N-E NW.

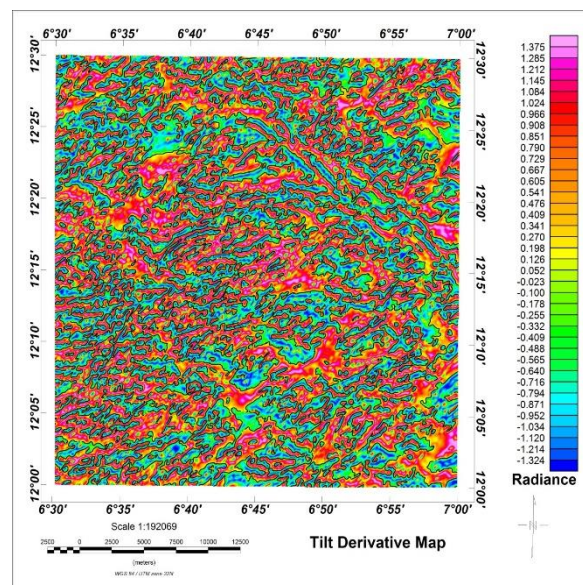


Figure 4.4: Tilt Derivative Map

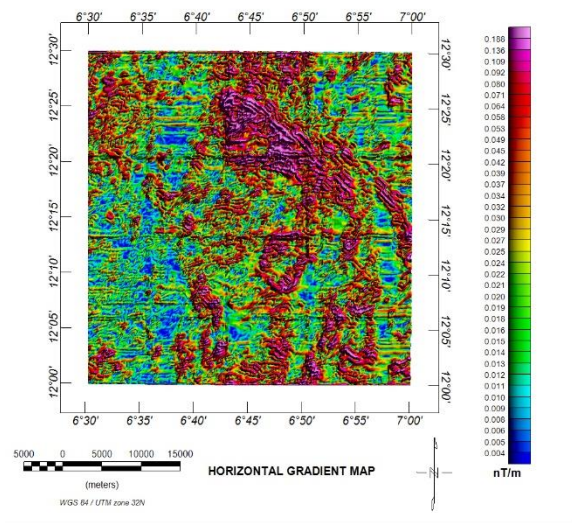


Figure 4.5: Total Horizontal Gradient Map

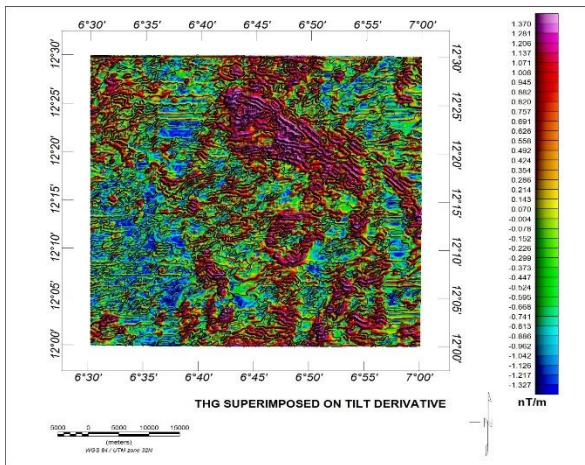
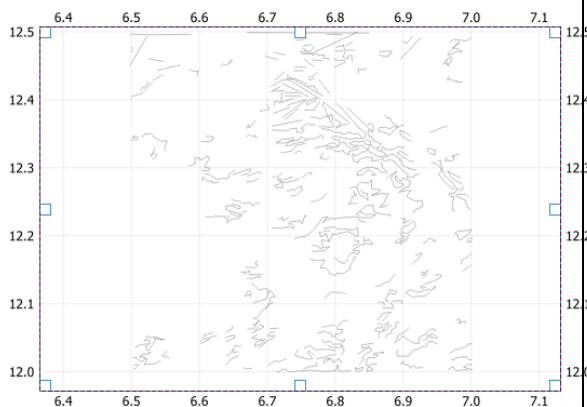


Figure 4.6: Total Horizontal Gradient Superimposed on Tilt Derivative Map



Lineament map of the study area
Figure 4.7: Lineament Map of the Study Area

5.0 CONCLUSION

This study demonstrates the effectiveness of aeromagnetic interpretation in delineating structurally

controlled mineralization zones within Gusau (sheet 54) in north northwestern Nigeria. High-resolution processing of aeromagnetic data, including regional-residual separation, total horizontal derivative, and tilt derivative filters, revealed key structural features such as faults, fractures, dikes, and sills that likely serve as pathways for mineralizing fluids. These features correlate strongly with known artisanal mining zones and indicate the potential for economic deposits of gold, banded iron formations (BIF), chromite, chamovite, kaolin, and other industrial minerals.

The findings highlight the region's underexplored potential and the limitations of artisanal mining practices, emphasizing the need for more advanced, systematic exploration programs. By providing a cost-effective and reliable framework, this approach can significantly improve resource estimation, exploration planning, and sustainable mineral development in the area.

Future work should integrate geochemical surveys, detailed field validation, and drilling programs to confirm and quantify the mineral resources indicated by this study.

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