FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 10 No. 5, March, 2026, pp 323 – 330
DOI: https://doi.org/10.33003/fjs-2026-1005-5004

INVESTIGATION OF MINERAL DEPOSIT SUSING AEROMAGNETIC DATA IN PART OF NORTH CENTRAL NIGERIA

***[1]Ugwu Augustine Nnabuike, [1]Ayanninnuola Samuel Olatunji and [2]Okenu Chigozie Stella**

[1]Department of Physics, Nasarawa State University, Keffi, Nasarawa State, Nigeria.
[2]Physics Advanced Research Centre, Sheda Science and Technology Complex (SHETSCO), Nigeria.

*Corresponding authors' email: ugwuaugustine60@gmail.com

ABSTRACT

Karu and its surroundings are located in North Central Nigeria, within the middle belt of the Benue trough. This study analyzes high-resolution aeromagnetic data to provide insights into magnetic sources, structures, and potential mineralization zones in the area. The Total Magnetic Intensity data was examined using both qualitative and quantitative techniques, including reduced to equator, residual regional separation, First Vertical Derivative, Horizontal Derivative, Analytical Signal, and Source Parameter Imaging (SPI). Findings from the First Vertical Derivative and Analytical Signal maps indicate various structures with pronounced NE-SW trends, attributed to mega faults near Udeni, NE Brumburum, and NW Gofa. These areas display high structural intensity within sedimentary formations (sandstone, shale) and deep SPI depths, suggesting potential for base metals like lead and zinc, along with iron oxides.Depth estimations through SPI reveal that deep magnetic sources range from -46.352 to 90.252 nT, while shallow sources vary from -59.883 to 89.580 nT. The band pass analysis and integrated data from source parameter imaging and structural density delineate litho-structural controls on mineralization.High-priority zones identified include Uke, Gudi, Magayaikai, Keffi, Akwanga, Nasarawa, Garaku, and Bagaji, with Uke showing significant structural intensity, shallow SPI depths (~85.432 m), and notable geophysical anomalies.

Keywords: Basement, Structures, Spectral, Airborne Magnetics, Lineaments

INTRODUCTION

The earth and its content have always been of great concern to man. In the quest to understand the makeup of the earth, man has delved into diverse kinds of studies and research, one of which is geophysics. The study of earth's magnetism is the oldest branch of the subject of geophysics. Sir William Gilbert (1540 – 1603), made the first scientific investigation of the terrestrial magnetism when he showed that the earth's magnetic field was equivalent to that of a permanent magnet, lying in a general north-south direction, near the earth's rotational axis (Telford *et al.,* 1976).

The continued expansion in the demand for metals of all kinds and the enormous increase in the search for oil and natural gas during the past fifty years have led to the development of many geophysical techniques of ever-increasing sensitivity for the detection and mapping of unseen deposits and structures in the earth interior. Since majority of mineral deposits are beneath the earth's surface, their detection depends upon those characteristics that differentiate them from the surrounding media (Agbata *et al*., 1989). Methods based upon variations in the elastic properties of rocks have been developed for determining structures associated with oil and gas, such as faults, anticlines and synclines, though these are often thousands of meters below the earth's surface. The variations in the electrical conductivity and natural currents in the earth, local changes in gravity, magnetism and radioactivity provide information to the geophysicist about the nature of the structures below the earth's surface, thus permitting him to determine the most favorable places for locating the mineral deposits (Adetona *et al*., 2007).

MATERIALS AND METHODS

Location and Geology of the Study Area

The study area is made up of Cretaceous sedimentary succession; (Ofoegbu and Onuoha, 1991). It comprises of Cretaceous sediments formations. The North Central Area Cretaceous sediment in the Benue Trough, consists of shale and limestone with intercalations of sandstone. It is bounded by latitude$7^0$00'N and $11^0$00'N of the equator and longitude $4^0$00'E and $11^0$00'E of the Greenwich meridian covering an area of 242,425 km^2 and average elevation of 1,300m above sea level. The formation is made up of shale and limestone of Coniacian age. Koroduma formations are mainly shales and mudstones, while New Karu formations consist of sandstones and ironstones; but the Lower substructure formations consist of Sandstones and shales, as indicated in the Geological (Chemin *et al*., 2006) map in Figure 2.2

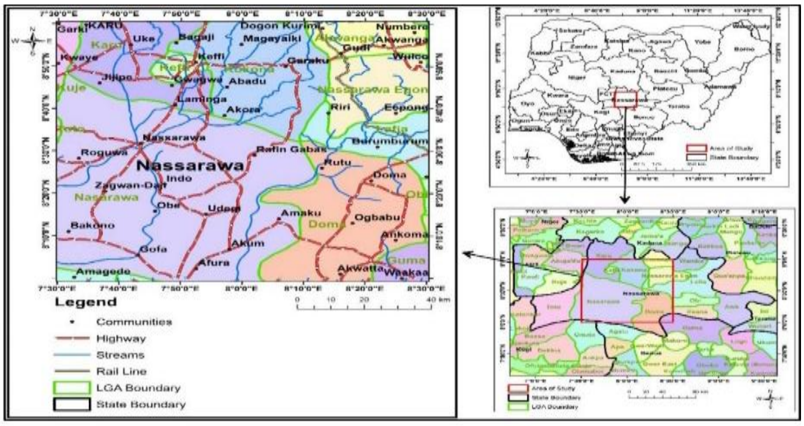

Figure 1: Map of Nasarawa State showing Location of Minerals (Kogbe, 1981)

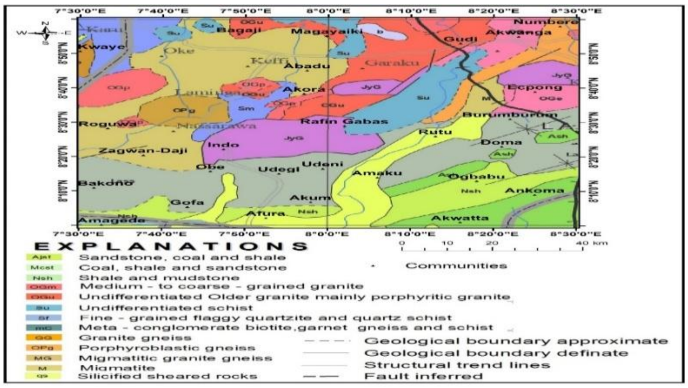

Figure 2: Geological Map

Method of Data Collection

The study area North Central cut across Keffi (Sheet 208), Akwanga (Sheet 209), Udegi (Sheet 229), and Doma (Sheet 230) area, was covered by an aeromagnetic survey conducted by Nigerian Geological Survey Agency (NGSA) in 2009. Fugro Airborne Survey carried out the airborne geophysical work. The data was collected in digitized form (X Y Z) data. The X and Y represent the longitude (easting) and latitude (northing) respectively in meters, the Z represents the magnetic intensity measured in nano Tesla (nT).

The specification of the data and parameters used for data collection are specified below after (Nigerian Geological Survey Agency);

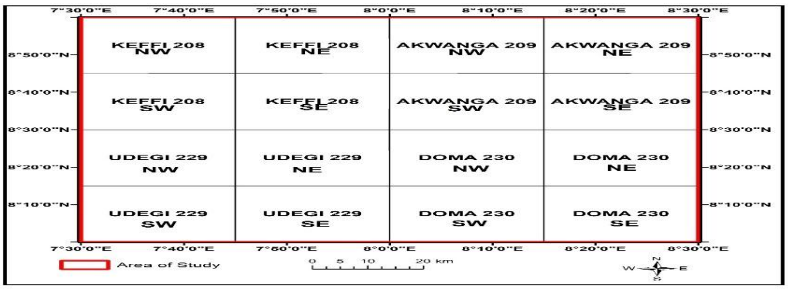

Table 1: Data Sheet

Method of Data Analysis

Interpretation of Aeromagnetic Data

Analysis and interpretation of aeromagnetic data are done in two phases; the qualitative interpretation and the quantitative interpretation.

Qualitative Interpretation

Qualitative interpretation involves the description of the survey results and the explanation of the major features revealed by a survey in terms of the types of likely geological formations and structures that give rise to the evident anomalies. Typically, some geological information is available from outcrop evidence within the survey area (or nearby) and very often the role of the geophysical data is to extend this geological knowledge into areas where there is no outcrop information (i.e. extrapolation from the known to the unknown) or to extend mapped units into the depth dimension. Qualitative interpretation is largely map-based and dominates the early stages of aeromagnetic study. The resultant preliminary structural element map is the cornerstone of the interpretation. Qualitative interpretationinvolves recognition of:

i. The nature of discrete anomalous bodies including intrusions, faults and lenticular intrasedimentary bodies - often aided by reference to characteristic magnetic response charts and perhaps performing simple test models
ii. Disruptive cross-cutting features such as strike-slip faults
iii. Effects of mutual interference
iv. Relative ages of intersecting faults
v. Structural styles
vi. Unifying tectonic features/events that integrate seemingly unrelated interpreted features

Quantitative Interpretation

Quantitative interpretation involves making numerical estimates of the depth and dimensions of the sources of anomalies and it often takes the form of modelling of sources which could, in theory, replicate the anomalies recorded in the survey. In other words, conceptual models of the subsurface are created and their anomalies calculated in order to see whether the earth-model is consistent with what has been observed, i.e. given a model that is a suitable physical approximation to the unknown geology, the theoretical anomaly of the model is calculated (forward modelling) and compared with the observed anomaly. The model parameters are then adjusted in order to obtain a better agreement between observed and calculated anomalies (Reeves, 2005).

RESULTS AND DISCUSSION

Total Magnetic Intensity Map (TMI)

Total Magnetic Intensity (TMI) refers to the overall strength of the Earth Magnetic field at a specific location, encompassing both the Earth's main magnetic field and any local variations caused by magnetic minerals in the Earth's crust.

This intensity is typically measured in nanoteslas(nT). At the Earth's surface, TMI values generally range from approximately 22,000nT to 67,000nT, depending on geographic location and local geological conditions (Telford *et al.*, 1976).

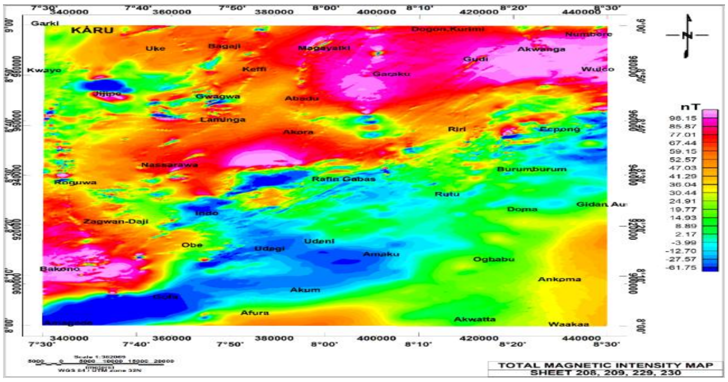

Figure 3: The Total Magnetic Intensity Map (TMI) Over the Study Area

Total Magnetic Map Reduced to Magnetic Equator (RTE)

The total magnetic intensity map of the study area, reduced to the magnetic equator (RTE), reveals significant variations in magnetic intensity and susceptibility, reflecting the underlying lithological and structural characteristics. The RTE map, as depicted in Figure 4.2, displays magnetic intensity values ranging from -61.710 nT to 89.72 nT, with an inverse relationship between magnetic intensity and susceptibility: regions of high magnetic intensity correspond to low magnetic susceptibility, and vice versa. This relationship arises because rocks with low susceptibility, such as sedimentary units like sandstones and shales, produce weaker magnetic responses, while basement rocks (igneous and metamorphic) with high susceptibility generate stronger anomalies. The absence of core effects in the data, as removed by NGSA, ensures that the observed magnetic intensities reflect local geological features rather than global geomagnetic influences. These findings align with geophysical principles governing aeromagnetic surveys, where RTE processing enhances the resolution of anomalies in low-latitude regions like Nigeria (Telford *et al*., 1976; Nabighian *et al*., 2005).

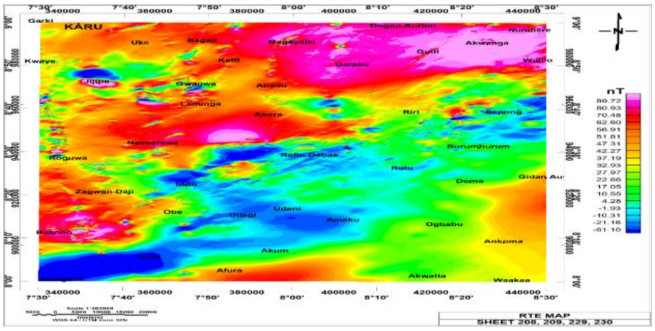

Figure 4: The Total Magnetic Intensity Map Reduced To the Magnetic Equator (RTE) Over the Study Area

The Residual Magnetic Anomaly Map

The first-order residual magnetic intensity map of the study area, that was processed, exhibits magnetic intensity values ranging from -40.81 nT to 21.07 nT, highlighting localized remnant magnetization after the removal of regional and core magnetic field effects. These amplified residual anomalies reflect variations in the magnetic susceptibility of subsurface lithological units, driven by their ferromagnetic mineral content, such as magnetite. High-intensity, short-wavelength anomalies indicate shallow basement rocks, typically igneous or metamorphic, with high magnetic susceptibility, while low-intensity, long-wavelength anomalies suggest deeper magnetic sources or sedimentary cover with minimal magnetic response, such as sandstones and shales (Adamu. *et al* 2026). The sharp gradations in magnetic intensity across the study area delineate boundaries between high-susceptibility basement rocks and low-susceptibility sedimentary units, enabling the delineation of distinct lithological zones. This pattern is consistent with aeromagnetic survey principles, where residual maps enhance the resolution of local geological features in low-latitude regions like Nigeria (Telford *et al*., 1976; Nabighian *et al.,* 2005).

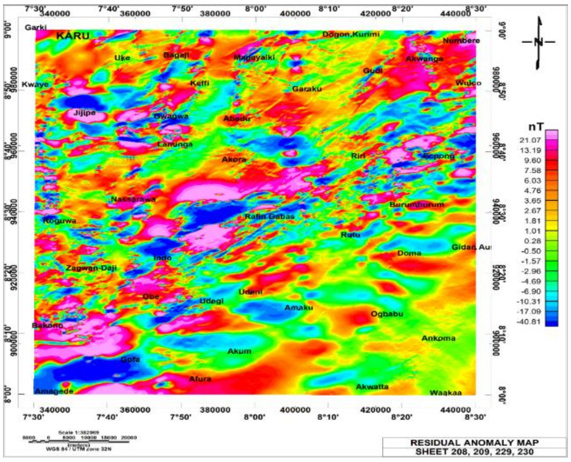

Figure 5: The Residual Anomaly Map of the Study Area

First and Second Vertical Derivatives

Vertical derivatives, computed in either the space or frequency domains, are essential geophysical tools for mineral exploration, as they enhance high-frequency, shallow magnetic anomalies critical for identifying near-surface mineralized zones and structural features. These operators amplify magnetic field gradients associated with shallow sources, though they also intensify high-frequency noise, which is mitigated through techniques such as frequency response tapering or low-pass filtering to ensure clear anomaly resolution. In the study area, vertical derivatives applied to the processed secondary raw Total Magnetic Intensity (TMI) data, reduced to the magnetic equator (RTE), highlight shallow magnetic sources and structural lineaments across the Keffi (Sheet 208), Akwanga (Sheet 209), Udegi (Sheet 229), and Doma (Sheet 230) regions. The significance of vertical derivatives lies in their ability to delineate edges of magnetic bodies and resolve subtle structures, such as faults or intrusions, which often serve as conduits for mineralizing fluids. This approach has proven effective in Nigeria's Basement Complex, where aeromagnetic studies, including those over Keffi and Akwanga, have used vertical derivatives to map mineralized intrusions and structural controls (Steven *et al.,* 2018; Telford *et al*., 1976).

The first vertical derivative (1VD) map (Figure 4.4) of the study area reveals shallow magnetic anomalies, likely resulting from near-surface granitic or mafic intrusions or shallow basement depths, characterized by high-frequency signals that delineate the edges of magnetic bodies. These anomalies are prominent in the northwestern (e.g., Karu, BagajiUke, Gwagwa, Lamunga), northeastern (e.g., Akwanga, Numbere, Gudi), and southwest-to-northeast zones (e.g., Bakoko, ZagwanDaji, Nasarawa, Rutu, Obe, Udegi, Indo, RafinGabas, Riri, Ecpong), indicating rocks with high magnetic susceptibility. The second vertical derivative (2VD) map (Figure 4.5) enhances these near-surface structures, resolving finer details of lineaments and features closer to the surface compared to the 1VD map. A structural map derived from the 1VD, supported by a rose diagram, identifies two dominant structural trends: north-south (N-S) and east-west (E-W), with minor northeast-southwest (NE-SW) trends, reflecting tectonic deformation likely associated with faults or fractures. These trends align with findings from aeromagnetic studies in Keffi (Sheet 208), where Steven *et al.* (2018) reported NE-SW trending structures hosting pegmatite mineralization, and in Akwanga (Sheet 209), where Salako (2023) identified NE-trending structures linked to tin and columbite deposits. Similar shallow anomalies and structural patterns in Udegi (Sheet 229) and Doma (Sheet 230) suggest comparable geological settings, potentially hosting economic minerals (Clark, 1997, Olashinde, 2009).

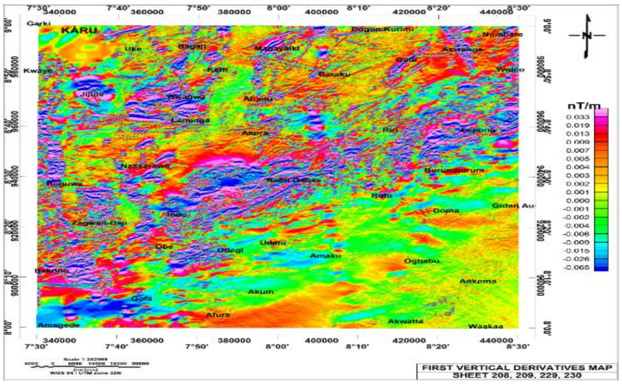

Figure 6: First Vertical Derivative (Z Direction) Map of the Study Area

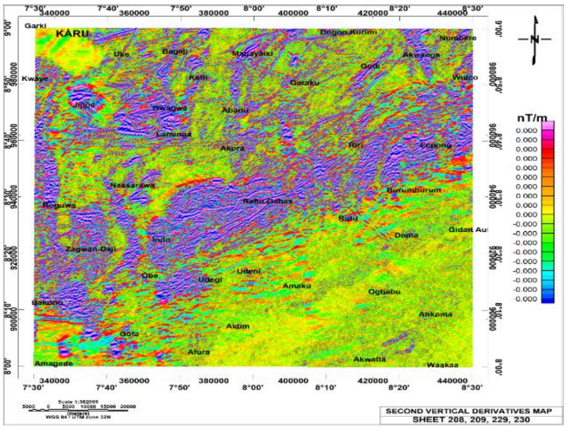

Figure 7: Second Vertical Derivative (Z Direction) Map of the Study Area

Horizontal Derivatives of the Tilt Derivatives (HD_TDR)
The Horizontal Derivative of the Tilt Derivative (HD_TDR), computed from the processed secondary raw Total Magnetic Intensity (TMI) data reduced to the magnetic equator (RTE), is a geophysical enhancement technique that amplifies high-frequency magnetic anomalies associated with shallow geological structures and potential mineralized zones. HD_TDR combines the tilt derivative, which normalizes the magnetic field to highlight structural edges, with its horizontal gradient to emphasize lateral changes in magnetic susceptibility, making it particularly effective for delineating near-surface features such as faults, fractures, and intrusive bodies that may host mineral deposits. In the study area, encompassing Keffi (Sheet 208), Akwanga (Sheet 209), Udegi (Sheet 229), and Doma (Sheet 230), the HD_TDR map (Figure 4.6) enhances shallow magnetic sources and structural lineaments, aiding in the identification of potential mineralization zones. The technique's sensitivity to lateral gradients makes it a valuable tool for mineral exploration, as positive responses (marked by pinkish coloration) often correlate with high magnetic susceptibility rocks, such as granitic or mafic intrusions, which are known to host economic minerals like tin, columbite, or base metals in Nigeria's Basement Complex (Blakely, 1995; Telford *et al*., 1976). This aligns with aeromagnetic studies in the Keffi area, where similar enhancement techniques have mapped mineralized pegmatites (Steven *et al*., 2018).

The HD_TDR map (Figure 4.6) exhibits significant similarities to the first vertical derivative (1VD) map (Figure 4.5), particularly in areas with high structural complexity and localized high magnetic signals, such as the northwestern (e.g., Karu, BagajiUke, Gwagwa, Lamunga), northeastern (e.g., Akwanga, Numbere, Gudi), and southwest-to-northeast zones (e.g., Bakoko, ZagwanDaji, Nasarawa, Rutu, Obe, Udegi, Indo, RafinGabas, Riri, Ecpong). These regions, characterized by pinkish coloration on the HD_TDR map, show positive responses that align with the 1VD's high-frequency anomalies, indicating shallow basement rocks or near-surface intrusions with elevated magnetic susceptibility, likely granitic or mafic in composition

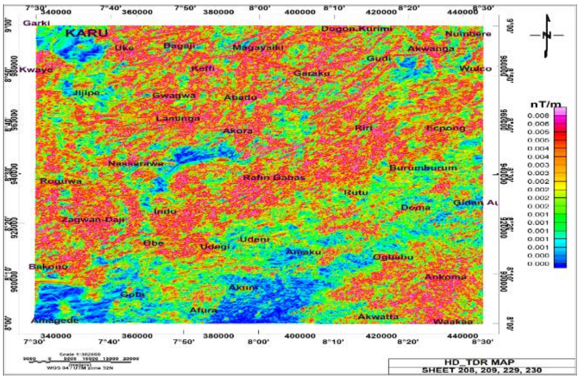

Figure 8: The Horizontal Derivative of the Tilt Derivative (HD_TDR) Map of the Study Area

Tilt Derivatives Map (TDR)

The Tilt Derivative (TDR), computed from the processed secondary raw Total Magnetic Intensity (TMI) data reduced to the magnetic equator (RTE), is a geophysical enhancement technique that normalizes the magnetic field to emphasize structural edges and delineate subsurface magnetic sources, making it a valuable tool for mineral exploration. By calculating the ratio of the vertical derivative to the total horizontal derivative, TDR produces values typically ranging from -90° to +90°, with high positive values (approaching +90°) indicating the centers of magnetic sources and negative values marking their edges. In the study area, encompassing Keffi (Sheet 208), Akwanga (Sheet 209), Udegi (Sheet 229), and Doma (Sheet 230), the TDR map (assumed Figure 4.9, pending confirmation) highlights both shallow and deeper magnetic anomalies, aiding in the identification of structural features and potential mineralized zones. The TDR's ability to enhance broad and localized anomalies, particularly in areas with high tilt values, complements other derivative methods like the Horizontal Derivative of the Tilt Derivative (HD_TDR) and is particularly effective in Nigeria's Basement Complex, where structural controls on mineralization, such as faults and intrusions, are critical (Blakely, 1986;). Aeromagnetic studies in Keffi have similarly utilized TDR to map pegmatite-hosted mineralization (Steven *et al*., 2018).

The TDR map exhibits similarities with the HD_TDR map (Figure 4.8) in areas with high magnetic responses, such as the northwestern (e.g., Karu, BagajiUke, Gwagwa, Lamunga), northeastern (e.g., Akwanga, Numbere, Gudi), and southwest-to-northeast zones (e.g., Bakoko, ZagwanDaji, Nasarawa, Rutu, Obe, Udegi, Indo, RafinGabas, Riri, Ecpong), where both methods highlight shallow basement rocks or near-surface intrusions with high magnetic susceptibility, likely granitic or mafic, as seen in the first vertical derivative (1VD) map (Figure 4.4). However, areas with low HD_TDR responses, such as the south and west of Karu and the southwestern to northeastern sedimentary regions (e.g., Amagede, Gofa, Udegi, Udeni, Amaku, Rutu, Brumburum, Ecpong, RafinGabas, Indo), display broad magnetic anomalies with pinkish coloration on the TDR map, indicating high tilt values. This suggests that TDR is more sensitive to deeper or broader magnetic sources in these regions, possibly due to thick sedimentary cover or deeper basement rocks, which produce residual anomalous zones.

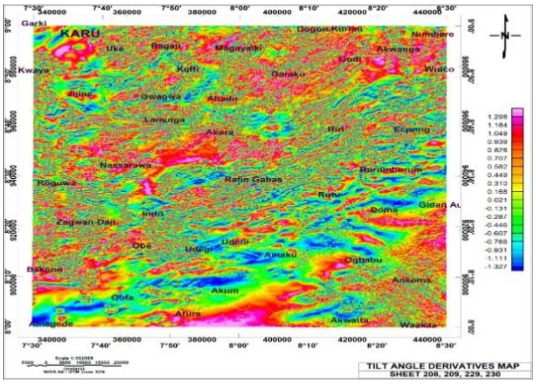

Figure 9: Tilt Derivatives (TDR) Map of the Study Area

Analytical Signal

The anomaly maps are resolved by the analytic signal, which is defined as the anomaly square root of the sum of squares of the horizontal (x and Y) and vertical derivatives (Z) along the orthogonal axes of the anomaly. Furthermore, the analytical signal of total magnetic intensity (Campbell *et al*., 2000), is vertically independent of the magnetic inclination of magnetization (Spector,, 1994) and is a better control tool for interpretation of magnetic anomalies in the middle and low altitudes than reduction to pole, and it more precisely locates the causative bodies.

The Analytical Signal (AS), computed from the processed secondary raw Total Magnetic Intensity (TMI) data reduced to the magnetic equator (RTE), is a geophysical enhancement technique that calculates the amplitude of the magnetic field's gradient, providing a robust method for identifying magnetic source locations and their depths, particularly in mineral exploration. Defined as the square root of the sum of the squared vertical and horizontal derivatives of the magnetic field, AS is independent of magnetization direction, making it ideal for mapping magnetic anomalies in low-latitude regions like Nigeria, where RTE processing is applied. In the study area, covering Keffi (Sheet 208), Akwanga (Sheet 209), Udegi (Sheet 229), and Doma (Sheet 230), the AS map (Figure 4.6) h highlights magnetic sources with high signal amplitudes, which are indicative of shallow, high-susceptibility rocks such as granitic or mafic intrusions that may host mineral deposits like tin, columbite, base metals, or iron oxides. Unlike vertical derivatives (1VD, 2VD) and Tilt Derivative (TDR), which emphasize structural edges or tilt angles, AS directly quantifies the strength of magnetic sources, offering a clearer delineation of potential mineralized zones. This technique has been widely used in Nigeria's Basement Complex to map mineralized intrusions, as demonstrated in Keffi, where AS identified pegmatite-hosted rare metals (Blakely, 1995; Steven *et al*., 2018).

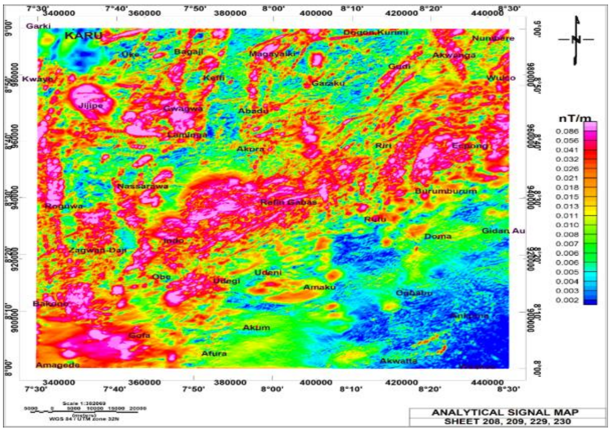

Figure 10: The Analytical Signal Map of the Study Area, Area with Positive Analytical Signal Response Is Depicted in Pinkish Coloration Representing the Areas with Most near Surface Intrusive Activity

CONCLUSION

This study successfully delineates the litho-structural controls on mineralization in Keffi, Akwanga, Udegi, and Doma using integrated aeromagnetic, topographic, and geological data. High-priority mineralization zones—Uke, Gudi, Magayaiki, Keffi, Akwanga, Nasarawa, Garaku, and BagajiUke—exhibit high to very high structural intensity, shallow SPI depths (~85.432 m), high geophysical anomalies (AS, 1VD, High pass, Bandpass), and high elevation (~446.285 m), hosted by schist, granite, migmatite-gneiss, and biotite granite. These areas are prospective for tin, columbite, rare metals (Ta-Sn-Li-Be), and gold, driven by NE-SW faulting and exposed basement rocks. Secondary zones—Udeni, NE Brumburum, and NW Gofa—show high structural intensity in sedimentary lithologies (sandstone, shale), with deep SPI depths (up to 1256.634 m) and Lowpass signals, indicating potential for base metals (lead, zinc) and iron oxides. Low-priority areas (Afura, Amagede, Ogbabu) with low struc tural intensity and sedimentary cover (alluvium, shale) may host placer deposits or hydrocarbons. The multi-method approach, combining geophysical (Figures 4.4) topographic, and lithological data, provides a robust framework for mineral exploration, highlighting the study area's economic potential and contributing to Nigeria's mineral resource development.

REFERENCES

Adamu, B. S., Nuhu, D. U., & Abdulhakim, U. S. (2026). Geology And Petrography Of Rocks Around Butawa, Kafin Magaji And Environs, Part Of Sheet 79ne Northwestern Nigeria. Fudma Journal of Sciences, 10(4), 37-44. https://doi.org/10.33003/

Adetona, A.A., Udensi, E.E. and Agelaga A.G. (2007): Determination of depth to buried magnetic rocks under the lower Sokoto Basin, Nigeria, using Aeromagnetic Data. Nigerian Journal of Physics, 19(2). P. 325.

Agbata, P. C., 1989. Gypsum in the Dukamaje and Dange Formations of the Rima River, Sokoto Basin. M.Sc. Dissertation, A. B. U. Zaria, pp.42-48.

Blakely, R.J. and Simpson, R.W. (1986). Approximating edges of source bodies from magnetic or gravity anomalies. Geophysics, 51:1494-1498.

Blakely, R. J. (1995). *Potential Theory in Gravity and Magnetic Applications*. Cambridge University Press

Campbell, W.C. (2000). Introduction to geomagnetic fields. Cambridge University Press, Cambridge.

Chemin, J. Y., Desjardins, B, Gallagher, I., Grenier, E. (2006). Mathematical geophysics: an introduction to rotating fluids and the Navier-Stokes equations. Oxford lecture series in mathematics and its applications. Oxford University Press. Pp. 9 – 12

Clark, D. A. (1997). Magnetic petrophysics and magnetic petrology: Aids to geological interpretation of magnetic surveys. *Australasian Institute of Mining and Metallurgy Publication Series*, 2/97, 119–146.

Nabighian, M. N., *et al*. (2005). The historical development of the magnetic method in exploration.

Ofoegbu, C.O. and Onuoha, K.M. (1991). *Analysis of magnetic data over the Abakaliki Anticlinorium of the Lower Benue Trough, Nigeria.* Marine and Petroleum Geology, 8:174-183.

Olasehinde, O.D. (2009). Investigation of the Geothermal Source Potential of part of the Niger-Delta Nigeria using Aeromagnetic *Data.* Unpublished M. Tech Thesis, Federal University of Technology, Minna, Niger, Nigeria. Pp. 34-44 *Geophysics*, 7 0(6), 33ND–61ND. https://library.seg.org/doi/10.1190/1.2133784

Reeves, C.V. (2005). Aeromagnetic Surveys Principles, Practice and Interpretation, Geosoft.

Salako, K. A. (2023). Geophysical assessment for gold mineralization potential over the southern Parts of Kebbi State using aeromagnetic data. *Academia.edu* https://www.academia.edu/ *101023456/Geophysical_assessment_for_gold_mineralization_potential over the southern_part_of_Kebbi_State_using_aeromagnetic_data*

Spector, A. and Grant, F.S. (1994). *Statistical models for interpreting aeromagnetic data;* Geophysics, vol.35; pp 293-302.

Steven, E. J. Adepitan, A. E. & Suleiman, A. (2018). Geological and mineralization expression of hosted mineralization of Keffi Sheet 208 NE. *American Journal of Modern physical and Application*, 5(4), 53–69. http://www.openscienceonline.com/journal/ajmpa

Telford, W.M. Geldart I.P, Sheriff, R.F and Keys D.A. (1976) *Applies Geophysisc First Edition.* Cambridge University Press, Cambridge.