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RESEARCH ARTICLE

INTEGRATION OF AEROMAGNETIC AND REMOTE SENSING METHODS FOR MAPPING GOLD MINERALIZATION IN KABO AND ITS ENVIRONS, NORTHWEST NIGERIA

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ABSTRACT

In this paper, the mineralization potential of Kabo and its environs have been investigated using satellite remotely sensing and geophysical methods. The study area is located within the Southwestern parts of Kano State which lies between longitudes 11°30′0″N to 12°0′0″N, and latitudes 8°0′0″E to 8°30′0″E. The integrated approach facilitated the assessment of the subsurface geology with the purpose of delineating the geological features on mineralization potential of the study area. Aeromagnetic data acquired from Nigeria Geological Survey Agency and United State Geological Survey (USGS) were analyzed and interpreted with the aid of Oasis Montaj, ArcGIS, and Envi software and subjected to different enhancements, analysis and reduction such as regional to residual separation, reduction to magnetic equator, vertical derivatives, analytical signal, CET (centre for exploration targeting) grids analysis, source parameter imaging, lineament density, false colors Red, Blue, Green (RGB) image, and band ratios maps. The result of residual anomaly indicated that, it has a low and high magnetic intensity values which ranges from -81.0nT to 64.9nT. First Vertical Derivative (FVD) shows gradient values varying between 0.204nT/m and 0.253nT/m. additionally results of magnetic and remote sensing data signifies strong correlation between lineaments which shows a trend of NE to SE major lineaments (sheared zone) inferring to be fractures/fault and fold system in the study area. The SPI results also indicate a varying depth ranging from 86.5m to 194.2 m, and 216.5m to 870.1m signifying shallower and deeper sources respectively. The SPI and Lineament results indicate that the structures are deep-seated and this may indicate that the gold mineralization which can served as a conduit to the transportation and deposition of the gold mineralization along the vein system in the study area.

KEYWORDS

Aeromagnetic, Remote Sensing, Gold Mineralization, Structural Lineaments.

1. INTRODUCTION

Nigeria is a country with abundant mineral resources, including gold. The northwest region of Nigeria is known to have significant gold deposits and various small mining activities take place in the area. (Musa et al., 2025). The commercial value of Nigeria's solid minerals has been estimated to run into hundreds of trillions of dollars, with 70 percent of these buried in the bowel of Northern Nigeria (Udegbe, 2014). Specifically, the solid mineral resources in Kano State include gold, chromite/nickel, silver, cassiterite (tin ore), and columbite (Obaje, 2009). Some part of Kano is known to be a mineralized zone in the northwestern Nigeria Basement Complex area, where abandoned artisanal pits are reported and mining activities being carried out by some unauthorized individuals on local scale, with little contribution to national treasury. In the light of the current challenges in improving economic base of the country, there is a need to derive detailed information on the extent, the trend and depth to structures (e.g., dykes, shear or fracture/fault zones) that might be controlling emplacement of mineral deposits in the area. Few geophysical studies in relation to mineral prospecting have been carried out in Kano State and information about the distribution of the minerals can be said to be inadequate. Regional gravity survey was done in Southern Kano and they reported the presence of a residual anomaly around Rano (Jamaluddeen et al., 2018; Ajakaiye and Verheinjen, 1979).

Aeromagnetic survey has been a powerful tool for geological mapping and mineral exploration purposes. The magnetic anomalies in the earth's magnetic field resulting from the magnetic properties of the underlying rocks are based on this method of investigating the subsurface geology. The total gradient of the magnetic field can be measured in mineral exploration, particularly near hydrothermal alteration areas. This helps highlight the structural features of the region, which can point to pathways that might have allowed hydrothermal fluids to circulate. These pathways are important for understanding where minerals could have accumulated (Akpano et al., 2024).

The Landsat program, initiated on July 23, 1972, with the launch of the Earth Resources Technology Satellite (later renamed Landsat), is the longest-running enterprise for earth satellite imagery acquisition. Landsat 8, the most recent addition to the program, was launched on February 11, 2013. Some years back, Landsat instruments have captured millions of images, archived in the United States and Landsat receiving stations globally. In some fields like agriculture, cartography, geology, and education, these images serve as a unique resource. Accessible through the USGS 'EarthExplorer' website, Landsat data supports global change research and diverse applications by (Opara et al., 2012). In line of this, remote sensing appears to be a crucial technique for local investigation ofsignificant mineralization especially that which arises from hydrothermal alteration processes.

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Previous work was based on a single method (aeromagnetic data) utilization in (Kabo Augie and Sani, 2020). However, such integrated studies especially the ones integrating remote sensing and traditional techniques (such as aeromagnetic) had not been carried out in the study area.

Therefore, the main objective of this study is to identify the hydrothermal alteration zones that may contain gold and to extract surface lineaments using Landsat 8 OLI/TIRS while obtaining subsurface structure information from Airborne Magnetic. This will supplement existing data that may be lacking from the use of a single technique. We used a combination of aeromagnetic data and remote sensing.

2. Location And Geology Of The Study Area

The study area is located within the Southwest part of Kano State between longitudes 11°30′0″N and 12°0′0″N, and latitudes 8°0′0″E and 8°30′0″E. The study area covers Kabo LGA and the other neighboring LGAs such as; Shanono, Gwarzo, Rimin Gado, Tofa, Ungongo, Gwale, Kano Municipal, Tarauni, Kumboston, Karaye, Madobi, Kiru, Kura, Garum Mallam, Bunkure, Bebeji and Rano areas as shown in Figure 1 Geologically the study area falls under the Basement Complex rocks of northern Nigeria, which divide into three groups of rocks namely; migmatites, high-grade gneisses derived from Birri main sedimentary rocks through high-grade metamorphism and granitization, and the Younger Metasediments of the Upper Proterozoic (Bagare et al., 2018). These comprise Granite, Rhyolite, Biotite-Granite, Metaconglomerate, Marbles, Quartz-Mica schist, Migmatite, Sandstones, Ironstones, Laterites, Gneiss and Older Granite.

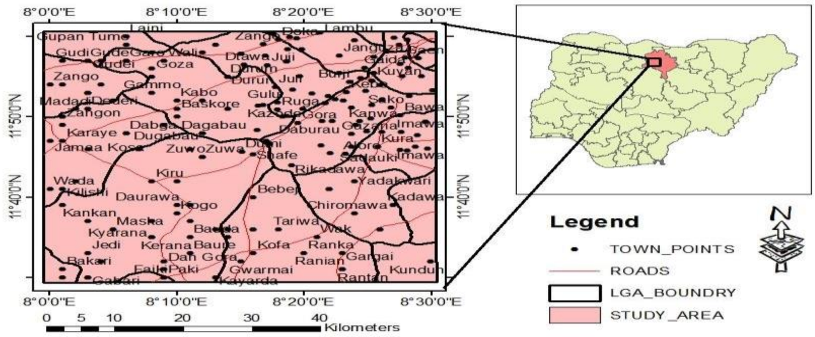

Figure 1: Map of the Study Area. Source (Published by NGSA 2006) Modified by Augie and Sani, (2020).

3. Methodology

3.1 Data acquisition

The aeromagnetic data used for this work were obtained from Nigerian Geological Survey Agency (NGSA), services (ngsa.gov.ng, 2018). The data were published in form of grid on half-degree sheets. The study area is located within the Southwestern parts of Kano State which lies between longitudes 11°30′0″N to 12°0′0″N, and latitudes 8°0′0″E to 8°30′0″E. comprising sheet 56, 57, 79 and 80 (kano). The data who acquired the digital data for the entire country between 2006 and 2007 by Furgro airways were obtained as part of a nationwide aeromagnetic survey sponsored by the geological survey of Nigeria. The data were acquired at a flight altitude of 80m along with a series of NW – SE flight lines with a spacing of 500m. The four sheets were merged as a unified block to give the Total Magnetic Intensity (TMI) map of the study area, and the data were extracted using Oasis Montaj Software.

3.2 Method

data enhancement is a routine in potential field studies; the type of enhancement carried out depends on the information needed. The main aim is to subdue some features of the data and accentuate others not too apparent in the original map. In aeromagnetic studies, reduction to pole/equator, regional/residual separation, continuations, derivatives and depth estimation are the common techniques used (Telford et al., 1990). Interpretation of aeromagnetic data and remote sensing can be carried out both quantitatively and qualitatively. Quantitative interpretation involves making numerical estimates of the depth and dimensions of the sources of anomalies and this often takes the form of modeling of sources which could, in theory, replicate the anomalies recorded in the survey (Biswas et al., 2017; Singh and Biswas, 2016; Biswas, 2016, 2015). Processing of the Landsat 8 data was carried out using ENVI software, where the source parameter imaging, lineament density, false colors Red, Blue, Green (RGB) image, and band ratios maps was enhanced through layer stacking and sub-setting techniques to improve visual interpretation and analysis.

Table 1: Summary of datasets, tools, techniques, and outputs used in this study

Dataset	Software Used	Analytical Techniques	Output Products
Aeromagnetic data (NGSA)	Oasis Montaj	RTE, regional residual separation, FVD, ASA, CET grid analysis, SPI	Structural maps, depth-to-basement estimates
Landsat-8 OLI imagery	ENVI	Band ratios (6/7, 4/2, 6/5), false-colour composites	Hydrothermal alteration maps
DEM / Lineament data	ArcGIS	Lineament extraction, density analysis	Lineament and density maps
Integrated datasets	ArcGIS	Spatial overlay and interpretation	Gold mineralization potential map

3.3 Aeromagnetic Data Processing and Theoretical Basis

3.3.1 Regional Residual Separation

It was used in this research because it is a filtering technique that projects data taken at a particular elevation to a higher elevation removing noise caused by high frequency. The upward continued ΔF (the total field magnetic anomaly) at a higher level (z = - h) is given by: (Dobrin, 1997). The regional magnetic field was estimated using a second-order polynomial fitting based on the least-squares method, and subsequently subtracted from the TMI data to obtain the residual magnetic field. The polynomial expression adopted follows (Ugwu et al., 2013):

$$r = a_0 + a_1(x - x_{ref}) + a_2(y - y_{ref}) \quad (1)$$

where $r$represents the regional magnetic field; $x_{ref}$and $y_{ref}$are the x- and y-coordinates of the geographic center of the dataset; and a_0, a_1, and $a_2$are polynomial coefficients.

3.3.2 Reduction to the Magnetic Equator (RTE)

Reduction to the magnetic equator (RTE) was applied to the TMI data to reposition magnetic anomalies directly over their causative bodies, a necessary step in low-latitude regions such as Nigeria. At low magnetic inclinations, magnetic anomalies are asymmetrical and displaced from their sources, complicating structural interpretation (Mendonça and Silva, 2003).

Magmap tool in Oasis Montaj is used in performing the RTE transformation, consistent with the International Geomagnetic Reference Field (IGRF), employing an inclination of 1.27° and a declination of −1.05°. The amplitude correction follows the formulation described by (Ugwu et al., 2013):

$$L(\theta) = \frac{1}{(\sin I + i \cos I \cos(D-\theta))^2} \quad (2)$$

where I is the geomagnetic inclination, I_a is the inclination used for amplitude correction, D is the geomagnetic declination, and θ represents the wave-number direction. To avoid instability near the magnetic equator, an auxiliary inclination was introduced to stabilize the amplitude of the filter (Mendonça and Silva, 2003).

3.3.3 Vertical Derivative Filtering

This filtering method is effective in enhancing anomaly due to shallow sources, because it sharpen the response of geophysical features, narrows the width of anomalies and also very effective in locating source bodies more accurately. The FVD is given as:

$$\text{FVD} = \frac{\partial M}{\partial z} \tag{3}$$

The second vertical derivative (SVD) further enhances local features while suppressing broad regional effects, making it useful for identifying subtle lineaments and structural discontinuities (Kearey et al., 2002):

$$\text{SVD} = \frac{\partial^2 M}{\partial z^2} \tag{4}$$

3.3.4 Analytic Signal Amplitude

This is based on the use of the first derivative of magnetic anomalies to estimate source characteristics and to locate positions of geologic boundaries such as contacts and faults. As a study the analytic signal of the magnetic anomaly M of a 3D source can be defined as a complex vector (Roest et al., 1992)

$$A(x,y) = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2 + \left(\frac{\partial M}{\partial z}\right)^2} \tag{5}$$

3.3.5 CET Grid Analysis

The structural lineaments was extract from the aeromagnetic data by employing the Centre for Exploration Targeting grid analysis . The method uses statistical measures, including standard deviation, to identify zones of high structural indicators of deformation and mineralization potential (Yisa et al., 2011).

4. Results And Discussion

Table 2: Comparison of the present study with some works on gold mineralization in north-western Nigeria

Author(s)	Study Area	Data Used	Analytical Methods	Depth Estimation	Major Findings
Jamaluddeen et al. (2018)	Kano Schist Belt	Aeromagnetic	RTE, vertical derivatives, Euler deconvolution	Limited	Identified structurally controlled mineral zones
Augie & Sani (2020)	Kabo and environs	Aeromagnetic	RTE, analytic signal, derivatives	Not emphasized	Fault-controlled gold mineralization potential
Daniel et al. (2019)	Parts of Kano State	Aeromagnetic	Horizontal gradients, Euler deconvolution	Yes	Delineated prospective gold zones
Andongma et al. (2020)	Malumfashi Schist Belt	Remote sensing	Band ratios, alteration mapping	No	Identified hydrothermal alteration zones
This study	Kabo and environs	Aeromagnetic + Landsat-8	RTE, ASA, FVD, CET, SPI, band ratios, GIS integration	Yes (SPI)	Integrated structural–alteration targets for gold mineralization

4.1 Aeromagnetic Results

4.1.1 Total Magnetic Intensity and Magnetic Field Components

The main magnetic map (Fig.1a) was created using high resolution data on a 250 m grid. The magnetic readings range from 32,970.8 nT to 33,066.6 nT, shows the different types of rocks sitting underground from granites to schists. The brighter, high magnetic spots are likely rocks rich in magnetite, like biotite granites. On the other hand, the darker, low magnetic spots represent schists or areas changed by hot, mineral rich fluids. Basically, this map shows us a complex, messy underground structure, which is exactly the kind of place we look for gold.

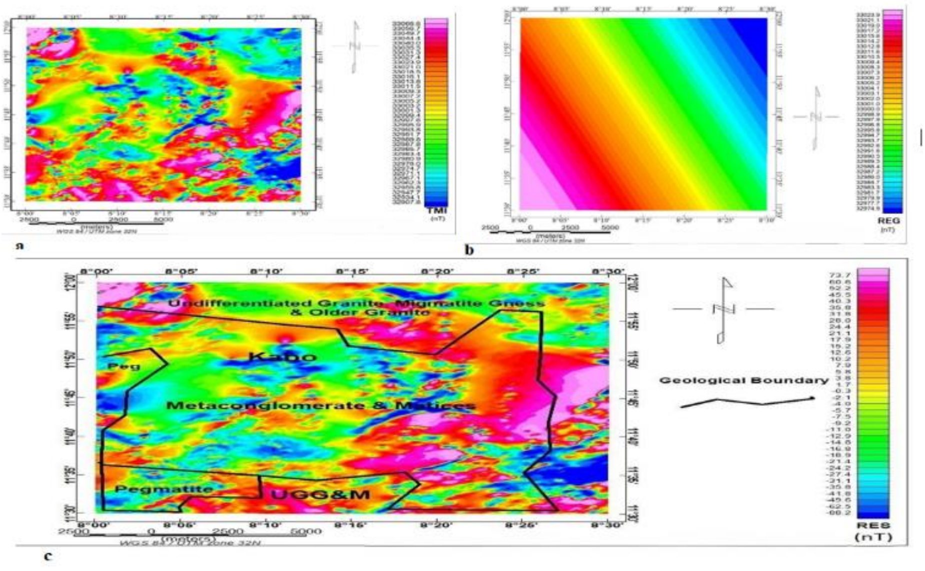

Figure 1: a) Total Magnetic Intensity of the Study Area. b) Regional Trend Map of the Study Area. c) Residual Magnetic Intensity Map of the Study Area.

To view what was happening closer to the surface, we first had to filter out. We extracted the regional magnetic field (Fig.1b), which shows a smooth trend from NE to SW this is the deep seated geological fingerprint of the ancient Pan-African tectonic movements. By removing this deep regional from our main map, we were left with the residual magnetic map (Fig.1c). This map is much more interesting because it zooms in the shallow stuff.

5.1.2 Reduction to the Magnetic Equator (RTE), Analytic Signal Amplitude (ASA) and First Vertical Derivative (FVD)

Look at the high-resolution magnetic data proves exactly that the ground here is a complex patchwork, because this usually a place where gold is found. The main magnetic map (Fig. 2a) divides the high spots and low spots. By separating the deep, ancient background (Fig. 2b) from the shallower layers (Fig. 2c), we seen a web of lines and curves. These are not just patterns; they represent the faults and fractures we are looking for. Finally, by correction the data with the reduction to equator technique (Fig .2a), everything clicked into place revealing two major structural paths NE to SW and NW to SE that likely acted as the plumbing system for gold bearing fluids.

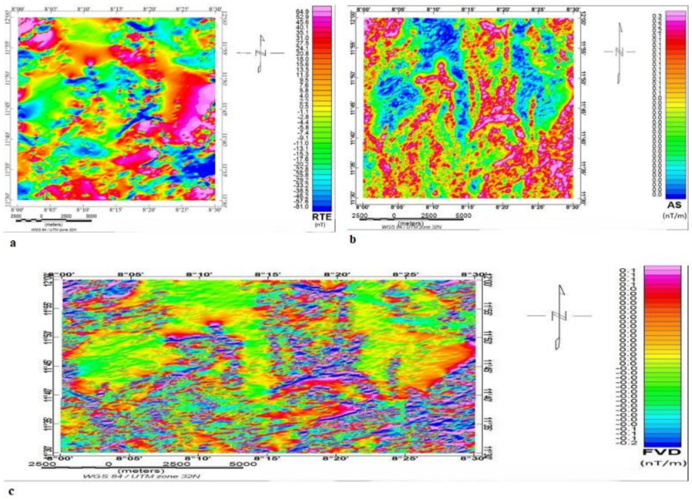

Figure 2: a) Reduction to Magnetic Equator Map of the Study Area. b) Analytical Signal Map of the Study Area. c) First Vertical Derivative Map of the Study Area.

5.1.3 Source Parameter Imaging (SPI) and Structural Lineaments

The Source Parameter Imaging (SPI) results (Fig. 3a) provide a quantitative view of the depth of magnetic sources in the study area. Two main depth populations were observed: shallow sources between 86.5 m and 194.2 m, and deeper sources between 216.6 m and 870.1 m. The shallow sources are closely aligned with major lineament zones and are interpreted as near-surface, making them particularly good for gold mineralization. The deeper sources correspond to basement lithological contrasts. The depth distribution exhibits a dominant NE to NW trend, reflecting regional tectonic controls.

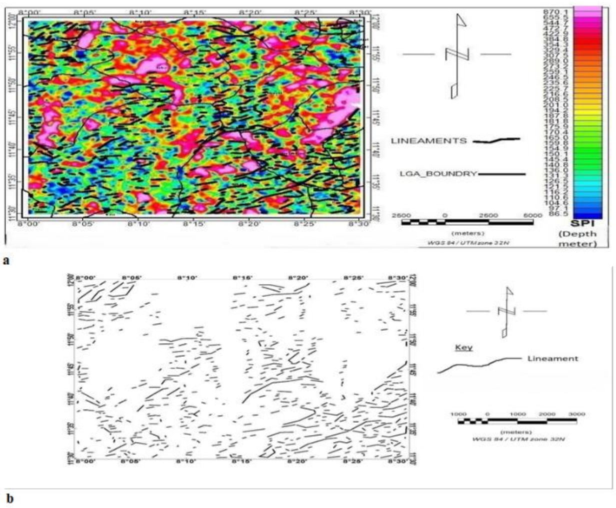

Figure 3: a) Source Parameter Imaging (SPI) Map of the Study Area. b) Lineaments Map of the Study Area.

5.2 Remote Sensing Results

5.2.1 Surface Lineaments and Lineament Density

Surface lineaments extracted from DEM and Landsat data were integrated with subsurface magnetic lineaments to create the lineament density map (Fig. 4). Areas of high lineament density are interpreted as zones of high deformation and fracturing, which are good for hydrothermal fluid circulation and gold deposition.

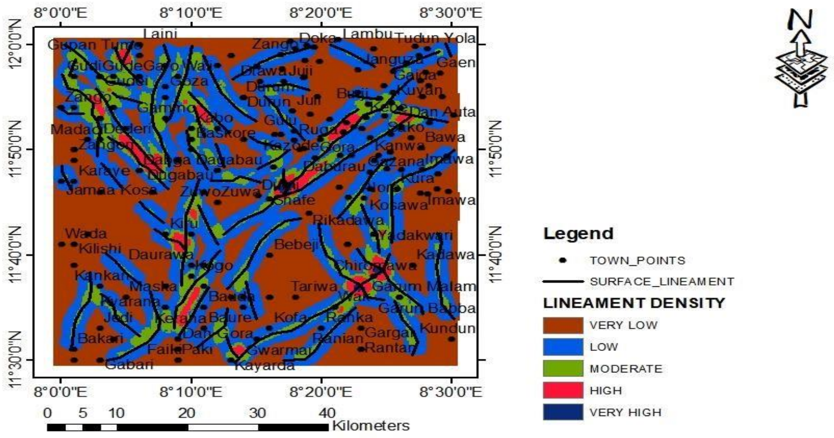

Figure 4: Lineament Density Map of the Study Area

5.2.2 Hydrothermal Alteration Mapping

Landsat 8 OLI data analysis using band ratio techniques shows clear hydrothermal alteration patterns around the study area. Hydroxyl-bearing minerals such as clays and alunite was shown by the 6/7 band ratio (Fig.5a) , which are commonly associated with hydrothermal processes. The 4/2 band ratio (Fig.5b) delineates ferric iron minerals, while the 6/5 ratio (Fig.5c) improves the detection of ferrous bearing minerals.

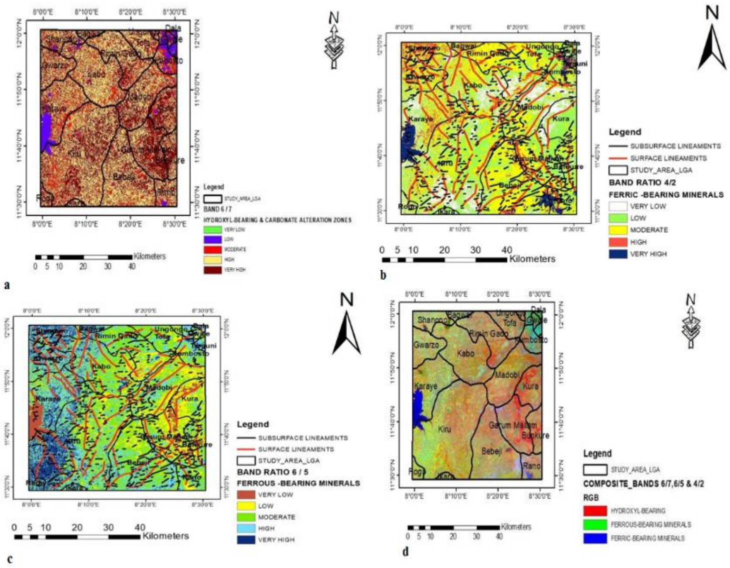

Figure 5: a) The band ratio is 6/7 for the Alunite and Clay Minerals Map of the Study Area. b) Band Ratio 4/2 (ferric-ion bearing) Map of the Study Area. c) Band Ratio of 6/5, sharpening the ferrous-bearing minerals d) False-color composite image of Band Ratios: 6/7, 6/5, and 4/2 as RGB

A clear visualisation of alteration zones was provided by a false colour composite image integrating the three band ratios (6/7, 6/5, and 4/2) as RGB channels (Fig.5d). The hydroxyl-bearing minerals appear in pink to yellow, ferrous minerals in green, and ferric iron minerals in blue. the lineament intersections are spatially associated with the alteration zones, suggesting that hydrothermal processes are structurally controlled and that these intersections may represent favourable sites for gold mineralisation.

5.3 Integrated Interpretation and Gold Mineralization Potential

We immediately saw a huge correlation when we finally layered our magnetic map on top of the satellite imagery; areas with shallow magnetic anomalies were also packed with faults and showed clear signs of hydrothermal changes on the surface. The intersection between NE to SW and NW to SE structured the analytic signal in high alteration signals, which shows the spot for gold

6. Conclusion

This study successfully integrates aeromagnetic and remote sensing data to map the structural controls and potential gold zones in the Kabo Local Government Area of Kano State. By studying the aeromagnetic data, we were able to point out variations in the rock types and deformation patterns within the Basement Complex terrain. using the advanced processing techniques like reduction-to-equator, analytic signal analysis, and source parameter imaging we extract those hidden subsurface structures into sharp focus.

The results shows that gold mineralization in the study area is strongly controlled by NE–SW and NW–SE trending faults and shear zones. the shallow magnetic sources at depths between 86.5 m and 194.2 m, was identified by the Source parameter imaging which coincide with zones of high structural and lineament density. The hydrothermal alteration minerals, including hydroxyl-bearing, ferric, and ferrous minerals was successfully mapped by the Remote sensing analysis using Landsat-8 band ratios, which spatially correlate with the structurally favourable zones identified from aeromagnetic data.

The integration of aeromagnetic and remote sensing datasets significantly improved the delineation of potential gold mineralization zones compared to single-dataset interpretation. This integrated methodology provides a reliable, cost-effective framework for regional mineral exploration in Basement Complex terrains and contributes valuable geoscientific insight into the mineral potential of Kabo and its environs.

References

Ajakaiye, D. E., and Verheijen, P. J. T., 1979. Gravity interpretation and basement structure of parts of northern Nigeria. *Geological Survey of Nigeria Bulletin, 32,* Pp. 15–29.

Akpano, E., George, N. J., and Obot, I. B., 2024. Structural controls on hydrothermal mineralization inferred from aeromagnetic data interpretation. *Journal of African Earth Sciences, 206,* 105074.

Augie, M., and Sani, A., 2020. Aeromagnetic investigation of mineralization potential in Kabo area, Kano State, Nigeria. *Nigerian Journal of Earth Science, 9*(1), Pp. 33–47.

Bagare, A., Danbatta, U. A., and Musa, A., 2018. Basement complex geology of northern Nigeria: Implications for mineral exploration. *Journal of Geology and Mining Research, 10*(4), Pp. 52–64.

Biswas, A., 2015. Interpretation of potential field data using advanced derivative and analytic signal techniques. *Journal of Applied Geophysics, 121,* Pp. 107–121.

Biswas, A., 2016. Interpretation of magnetic data through source parameter imaging and modelling. *Geophysical Prospecting, 64*(3), Pp. 764–781.

Biswas, A., Sharma, S. P., and Mohanty, W. K., 2017. A comparative study of magnetic data interpretation techniques for structural mapping. *Journal of Applied Geophysics, 139,* Pp. 177–189.

Dobrin, M. B., and Savit, C. H., 1997. *Introduction to geophysical prospecting* (4th ed.). McGraw-Hill.

Jamaluddeen, A., Olayinka, A. I., and Bala, A. E., 2018. Gravity and magnetic investigation of basement structure in southern Kano, Nigeria. *Nigerian Journal of Geosciences, 4*(2), Pp. 78–91.

Kearey, P., Brooks, M., and Hill, I., 2002. *An introduction to geophysical exploration* (3rd ed.). Blackwell Science.

Mendonça, C. A., and Silva, J. B. C., 2003. Reduction to the pole at low latitudes using a stable Fourier-domain method. *Geophysics, 68*(5), Pp. 1574–1581.

Nigerian Geological Survey Agency. 2018. *High-resolution aeromagnetic survey data of Nigeria.* https://www.ngsa.gov.ng

Obaje, N. G., 2009. *Geology and mineral resources of Nigeria.* Springer.

Opara, A. I., Onuoha, K. M., and Anakwuba, E. K., 2012. Application of Landsat imagery for geological and structural mapping. *International Journal of Remote Sensing Applications, 2(*3), Pp. 45–55.

Roest, W. R., Verhoef, J., and Pilkington, M., 1992. Magnetic interpretation using the 3-D analytic signal. *Geophysics, 57*(1), Pp. 116–125.

Singh, A., and Biswas, A., 2016. Application of magnetic derivatives in structural interpretation. *Geoscience Frontiers, 7*(5), Pp. 689–699.

Telford, W. M., Geldart, L. P., and Sheriff, R. E., 1990. *Applied geophysics* (2nd ed.). Cambridge University Press.

Udegbe, M., 2014. Solid mineral potentials in northern Nigeria and economic implications. *Nigerian Mining Journal, 6*(1), Pp. 12–21.

Ugwu, S. A., Onwuemesi, A. G., and Ezeh, C. C., 2013. Polynomial trend analysis and regional-residual separation of aeromagnetic data over parts of Nigeria. *Journal of Mining and Geology, 49*(1), Pp. 35–46.

Yisa, A., Udensi, E. E., and Nur, A., 2011. Application of centre for exploration targeting (CET) grid analysis in aeromagnetic structural interpretation. *Nigerian Journal of Physics, 23*(2), Pp. 45–56.