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Analysis of Aeromagnetic Data for Subsurface Structural Features Hosting Minerals of Sumaila Local Government Area (L.G.A.) of Kano State, Northwestern Nigeria.

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Abstract

Magnetic anomalies are frequently caused by lava flows, faults, dykes, and other natural phenomena. In regolith research, the magnetic method is a powerful tool that can be used effectively. Because the technique offers a helpful indicator of lithology, structure, weathering, and alteration processes in addition to a reasonably direct mapping of the abundance of magnetic minerals. The present study analyzes aeromagnetic data for the geologic and structural characteristics of Sumaila, a local government area in Kano, Nigeria. The area under study contains indicators such as faults, fractures, and contacts that are significant in mineral exploration. Aeromagnetic data was acquired from the Nigerian Geological Survey Agency (NGSA). The data was subjected to various analyses and processing such as regional/residual separation, reduction to the equator (RTE), vertical derivatives (VD) (First & Second), and analytic signal (AS) using the Oasis Montaj software. Regional/residual separation revealed an NE-SW trend of the magnetic anomalies. The residual anomalous map contains low amplitude field values between -75.7nT and 93.2nT. The FVD map shows a smooth, shallow magnetic body comprising positive and negative magnetic signatures ranging between -0.20nT/m and - 0.17nT/m. The SVD map shows an irregular magnetic signature of low amplitude with values from -0.00151nT/m to 0.00154nT/m. The analysis of vertical derivatives revealed magnetic structures that depict shear zones and possible zones of mineralization. The AS map indicates magnetic anomaly edges and their source positions with values 0.01nT/m to 0.32nT/m. Three major features are isolated: the first cuts through Bunturu, Retsida, and Ringi, the second lies through Gangadugu and Farin Dutse, while the last passes through Gandama Gandarma, Wayo, and Birnin bako.

Keywords: Analytic signal, Minerals, Shear zones, Structural Features, and Vertical Derivatives.

INTRODUCTION

For all life on Earth, rocks are the building blocks. One way to conceptualize minerals is as the building blocks of rocks (Rafferty, 2012). There are generally five major groups of minerals that compose rocks. The silicate group contains many of the minerals found in the Earth's crust. The remaining four major classes are oxides, sulfides, sulfates, and carbonates. These are referred to as the non-silicates. There are numerous subgroups of minerals, including phosphate, borate, nitrate, and sulfosalt. Certain minerals, like gold, silver, copper, and platinum, are composed of only one element, referred to as native elements. Minerals are vital

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components of human existence. They are parts of the plants and animals humans eat. They are used as the raw material for concrete, to shore up or establish the foundation for roadways, and to make metal alloys that are used in pipes, wire, structures, and bridges. Because they are utilized in electric and hybrid car batteries, computer processors, and high-tech devices, minerals are an essential component of the current information revolution. Given their importance to life on Earth, they merit further study (Rafferty, 2012).

The magnetic approach has been applied for a wide variety of problems dealing with the subsurface to find buried highly magnetic, iron ore deposits. The approach is a passive exploration technique built on a map of Earth's inherent magnetic field. The geomagnetic field, which is ever present, varies both spatially and temporally (Hinze et al., 2013). These variations must be eliminated from the observed data to create measurements that can be understood since they alter the field due to local subsurface circumstances of interest in magnetic surveying. The International Geomagnetic Reference Field (IGRF) is a mathematical model that geophysicists have created to represent the Earth's magnetic field, including its intensity and distribution over its surface. The difference between the measured and appropriately corrected earth's magnetic field which reflects what the global model would predict is called a magnetic anomaly (Lowrie, 2007). Magnetic anomalies are frequently caused by lava flows, faults, dykes, and other natural phenomena. In regolith research, the magnetic method is a powerful tool that can be used effectively. Because the technique offers a helpful indicator of lithology, structure, weathering, and alteration processes in addition to a reasonably direct mapping of the abundance of magnetic minerals.

Many geophysical surveys have been carried out in Kano and its environment. Borehole depth and regolith aquifer hydraulic characteristics of bedrock types in some parts of Kano including Sumaila have been carried out (Emmanuel et al., 2011). The characterization of gold mineralization zones was conducted by (Ahmad et al., 2019). Their results revealed a NE-SW/NW-SE trend of a major lineament with a depth range of 100m to 700m. A reconnaissance survey to determine probable mineral zones surrounding the schist belt area of Kano was carried out (Shehu et al., 2019). According to a detailed follow-up study conducted by (Shehu et al., 2021), the depth to magnetic source bodies in the study area ranges from 6.5m to 51.3m, confirming the reliability of the aeromagnetic data in (Shehu et al., 2019). The work of (Dayo & Saleh, 2018) tends towards delineating host mineralization for gold in Sumaila local government area of Kano State. However, no attempt has been made to analyze the structural features and to delineate the depth to the basement of the anomalies.

Analysis of structural features in the subsurface is very important as it allows us to gain information about the subsurface regarding host minerals. It also helps us to determine the safety of the location for, say, high-rise buildings and other geotechnical applications. This work analyzes the geologic and structural features of the magnetic sources.

THE STUDY AREA

The research area lies within the Nigerian basement complex of the Pan African and older (Precambrian) rocks of age 600MA and the migmatite-gneiss complex (MGC). The study area is mainly underlain by the schist belt, older granites, undeformed acid, and basic dykes of the basement complex (Obaje, 2009). The study sheets are bounded by latitudes 10^0 48´0´´N to 11^0 42´30´´N and longitudes 8^0 42´0´´E to 9^0 54´0´´E, thus covering the eastern parts of Kano, southern parts of Jigawa and the northern part of Bauchi (Figure 1). The study area is bounded by latitudes 11° 05´ 00´´N to 11° 25´ 00´´N and longitudes 8° 45´ 00´´E to 9° 05´ 00´´E. It consists mainly of porphyritic granite and migmatite as identified in the geological map of the study area (Figure 2).

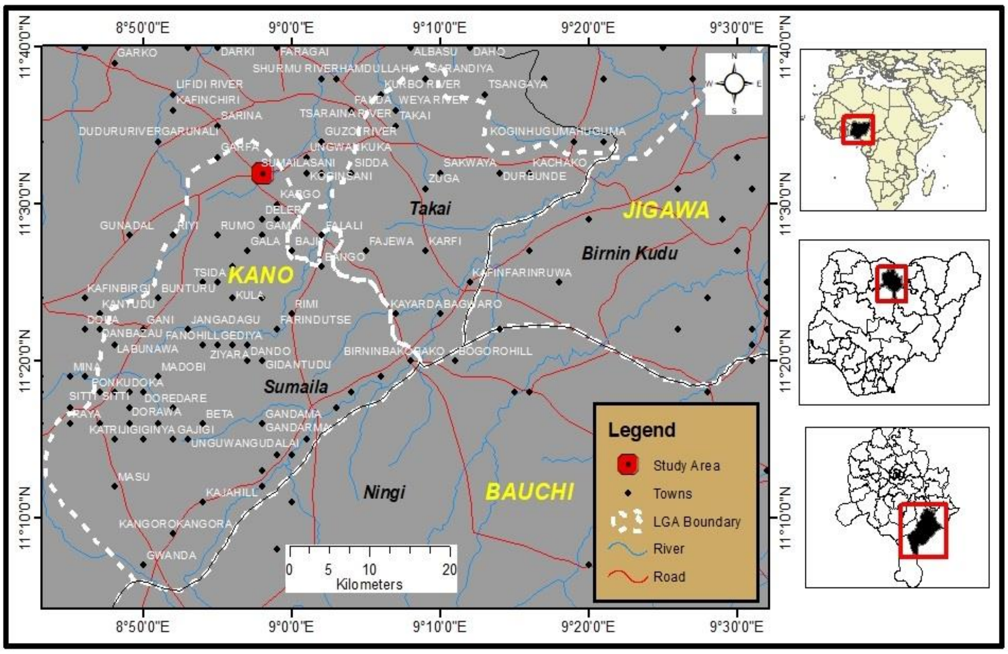

Figure 1: Map of the study sheets showing Sumaila local government (Rabiu, 2022).

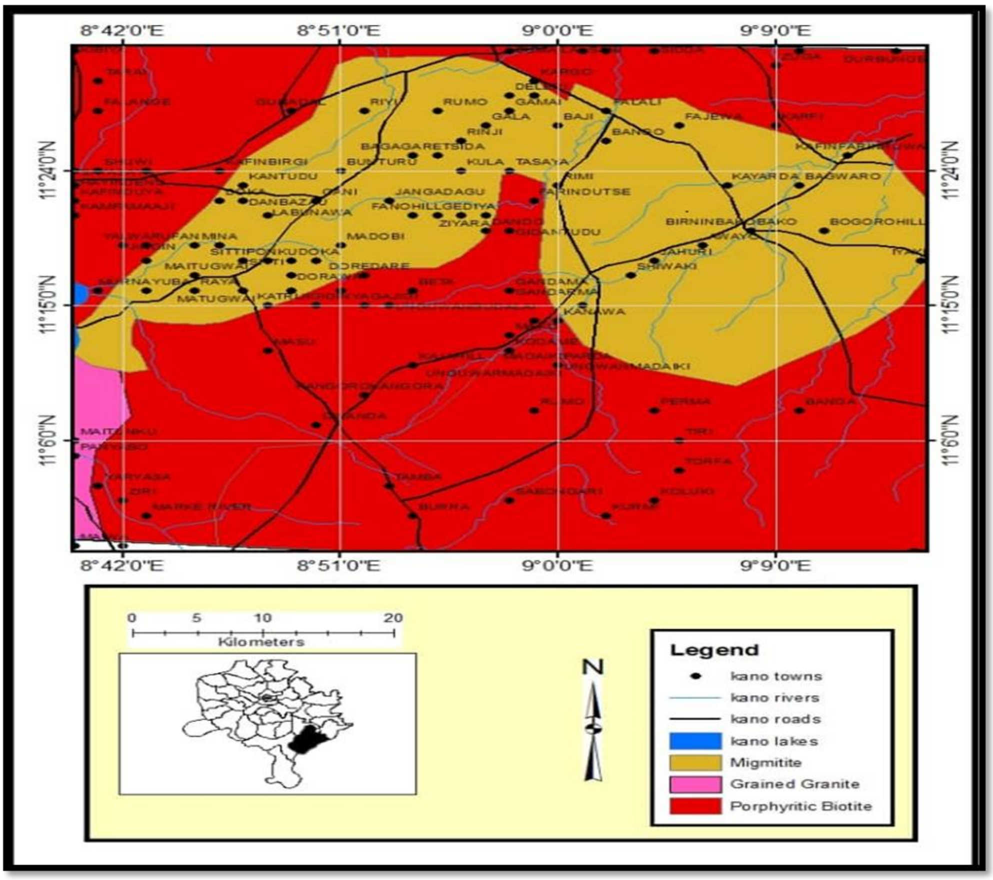

Figure 2: Geological map of Sumaila L.G.A (Rabiu, 2018).

MATERIALS AND METHOD

The materials used in this work are:

a. Aeromagnetic data sheets (104 and 105).
   As part of promoting mineral exploration in Nigeria, a high-resolution airborne geophysical survey was carried out by the Nigerian Geological Survey Agency (NGSA). The Scintrex CS3 Cesium Vapour magnetometer was used in the aeromagnetic data acquisition between 2006 and 2007 by Fugro Airborne Surveys. The data was acquired through the division of the country into multiple sections, resulting in the creation of an aeromagnetic map covering the entire country. Two sheets with the numbers 104 and 105 included the aeromagnetic data that was used in this study and was acquired from NGSA. The overall area of the sheets is 6050 square kilometers since each sheet is a square block that is 55 by 55 km^2.
b. Oasis montaj software
   This software is highly efficient in solving partial differential equations and conducting various operations such as convolution, correlation, and filtering. It is extensively applied in the analysis of aeromagnetic data.
c. Arcmap software.
   This is used to carve out the study area from the aeromagnetic data sheets.

METHODOLOGY

Convolution and correlation are data processing and enhancement processes that are accomplished by filtering, residualizing, continuing, etc., using the Fourier Transform (FT) in the frequency domain. The FT is the basis of data processing, an aspect of the FT is a two-dimensional discrete Fourier Transform (DFT) ($F_d(k,l)$), expressed according to (Naidu & Mathew, 1998) as

$$F_d(k,l) = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} f(m,n) exp\left\{-j2\pi\left[\left(\frac{mk}{M}\right) + \left(\frac{nl}{N}\right)\right]\right\} \quad (1)$$

while the discrete inverse Fourier transform($F_d(m,n)$) is given by,

$$F_d(m,n) = \frac{1}{MN} \sum_{k=0}^{M-1} \sum_{l=0}^{N-1} F(k,l)\, exp\left\{+j2\pi\left[\left({}^{mk}/_{M}\right) + \left({}^{nl}/_{N}\right)\right]\right\} \quad (2)$$

For $0 \leq k \leq M-1$ and $0 \leq l \leq N-1$. Where $f(m,n)$ is the sequence of the input magnetic field data, m, and n are the time domain indexes of the input samples, j is √-1, k and l are the index of the DFT output in the frequency domain, M and N are the number of samples of the input sequence and the number of frequency points in the DFT output.

These two equations are useful in digital signal and image processing, they are available in computer software in the Fast Fourier Transform (FFT) algorithm. In addition to performing other operations like convolution, correlation, filtering, and so forth, they are effective at solving partial differential equations. The transform equation is utilized in windowing, and as a result, is used in magnetic studies for data augmentation and filtering since magnetic data takes the form of two-dimensional discrete values. The most common enhancement methods in magnetic studies are reduction to pole/equator, regional-residual separation, vertical derivatives, analytic signal analysis, and deconvolution among others.

REGIONAL - RESIDUAL SEPARATION

The regional and the residual fields combine to form the total magnetic field intensity. When comparing the values of the regional fields (deep magnetic sources) to the residual fields (shallow seated magnetic bodies), the regional fields' values are consistently very high. Thus, breaking up the deep-seated and shallow magnetic entities requires regional-residual separation. Polynomial fitting with multiple regression analysis is used to accomplish this (Oghuma et al., 2015). Deducting the computed regional values from the initial magnetic field intensity values, the residual values are produced. The surface linear equation is stated by (Oghuma et al., 2015) as;

$$P(x, y) = a + bx + cy \quad (3)$$

where P (x, y) is the magnetic field value at x and y coordinates; x and y are distances in the x and y axes; and a, b, and c are constants.

The observed magnetic strength (B) residual anomaly function (R) is then expressed as follows:

$$R = B - P \quad (4)$$

REDUCTION TO POLE/EQUATOR

The magnetization of a source body that leads to the generation of an anomaly is contingent upon its inclination and declination, the inclination and declination of the local earth's magnetic field, and the orientation of the body in relation to the magnetic north. It is imperative to conduct a standard phase shift operation known as "reduction to the pole/equator" on the observed magnetic field. In regions near the magnetic equator, where the inclination is less than 15°, the reduction to the pole method tends to be inherently unstable. In certain cases, the redirection of a magnetic field to the equator rather than the pole is influenced by the latitude of the study area. The RTE operator is comprised of two components, one of which is the amplitude component $\sin I$ and the other is the phase component $i \cos I \cos(D - \theta)$. The reduction to equator operator is expressed by (Tawey et al., 2020).

$$L(\theta) = \frac{1}{[\sin(I) + i\cos(I)\cos(D-\theta)]^2} \quad (5)$$

where I is the inclination, D represents the magnetic declination, and θ is the wavenumber direction.

VERTICAL DERIVATIVES

Analogously to using a gradiometer to directly see the vertical gradient, computing the First Vertical Derivative (FVD) in an aeromagnetic survey is similar (Telford et al., 1990). Suppressing deeper sources and improving the resolution of closely spaced sources are the benefits of using vertical derivatives. When FVD is applied to the residual map, the edges are sharpened, improving the identification of anomalies. This process yields a more distinct representation of the shallow (high frequency) causative bodies in the vertical domain. FVD has been a usual approach for utilizing the Laplace transformation equations to calculate high frequency features at the expense of low frequency features (Bello et al., 2017):

$$\frac{\partial^2 f}{\partial z^2} = -\left[\frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}\right] \quad (6)$$

$$F\left[\frac{\partial^n f}{\partial z^n}\right] = K^n . F(f) \quad (7)$$

Where f is the input to be filtered, K is the wave number (frequency), and F is the field's Fourier representation.

The wave number (K) filter response for the vertical derivative computation is given by:

$$K(u, v) = \sqrt{u^2 + v^2} \quad (8)$$

where u and v are spatial frequencies respectively.

The n^{th} vertical derivative is computed using equation (8). Large curvatures are linked to shallow anomalies, according to Second Vertical Derivatives (SVD), a measure of curvature

(Telford et al., 1990). Additionally, the anomalies appear vertical using the SVD filter. The filtering technique is based on equation (7) but with n = 2.

ANALYTIC SIGNAL

The analytic signal method is used to identify magnetic sources, contacts, and edges. Peaks in the signal amplitude, derived from the first horizontal and vertical derivatives are used to obtain the location of the contacts and their striking directions (Abu El Ata et al., 2012). The application of this method to the observed magnetic field yields precise horizontal locations for contacts and sheet sources, independent of their geological dip or geomagnetic latitude. The analytic signal method uses the square of the analytic signal amplitude, defined as, (Al Garni et al., 2010)

$$|A(x,y)|^2 = \left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2 + \left(\frac{\partial M}{\partial z}\right)^2 \qquad (9)$$

where M is the anomalous magnetic field.

RESULTS AND DISCUSSION

TOTAL MAGNETIC INTENSITY

The aeromagnetic data sheets were integrated and visualized to produce the Total Magnetic Intensity (TMI) Map using Oasis Montaj software. Furthermore, ArcMap software was applied to delineate Sumaila's map. The processed data comprises a grid-formatted representation of the total magnetic field intensity (TMI) serving as a map of the study area. The map utilizes various colors to depict magnetic intensity values at several locations. The noticeable color contrasts and variations vividly portray the magnetic intensity values across the map (Bello et al., 2017). The variation in coloration observed in the aeromagnetic map is attributed to geological structural features, disparities in lithology, and variations in the magnetic susceptibility of minerals within the basement complex, indicating specific magnetic properties and geological characteristics (Bello et al., 2017). The legend next to the map provides information about the degree of susceptibility variations. Negative values signify areas with low magnetic activity, while positive values signify areas with high magnetic activity.

The processed data is referred to as the Total Magnetic Intensity (TMI) Map (Figure 3), illustrating the amplitude range of the magnetic field between 32911.2nT and 33168.0nT. The TMI map illustrates regions characterized by high (red and pink) magnetic anomalies, indicating areas of intense magnetic activity and low (blue and green) magnetic anomalies suggesting relatively deep magnetic sources and non-magnetized bodies within the surveyed area. The TMI map reveals the presence of magnetic low regions in both the northern and southern sectors, with magnetic highs prevailing in the western, eastern, and central areas.

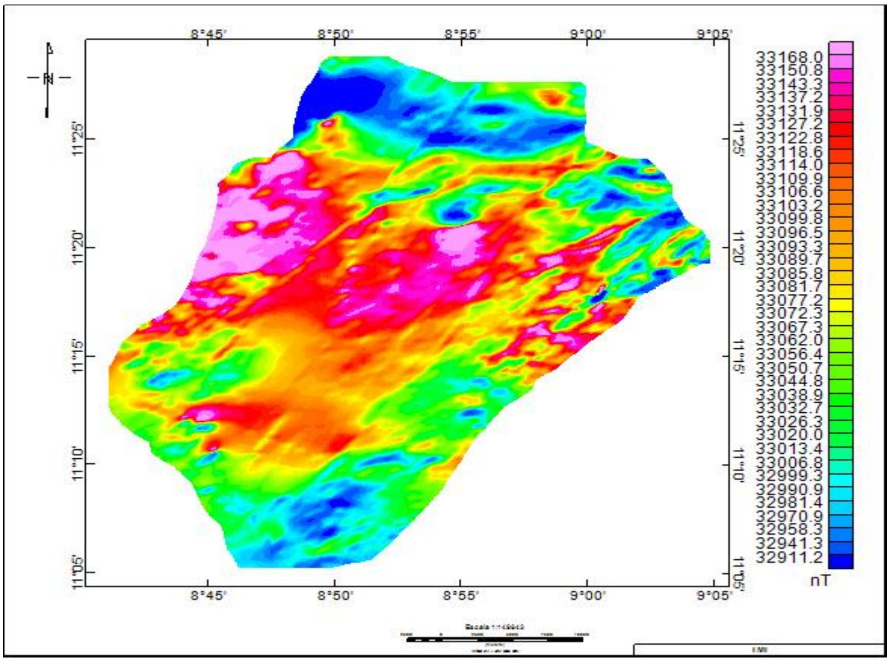

Figure 3: Total Magnetic Intensity (TMI) Map of Sumaila L.G

REGIONAL- RESIDUAL SEPARATION

Regional- Residual separation was performed on the observed magnetic field by removing the IGRF values. The multiple regression analysis of the TMI data leads to the solution of equation (4), where a, b, and c were found to be 10.3963044nT, 0.000212117nT/m, and -0.001100818nT/m respectively. The Residual map in Figure 4 shows only shorter wavelength zones due to shallow causative sources. The residual aeromagnetic values represent anomalies separated from the overall magnetic field highlighting shallow positive and negative bodies with values ranging from -75.7nT to 93.2nT, that trend along the NE-SW direction. The residual anomalous map contains low amplitude field values depicting structural and lithologic signatures.

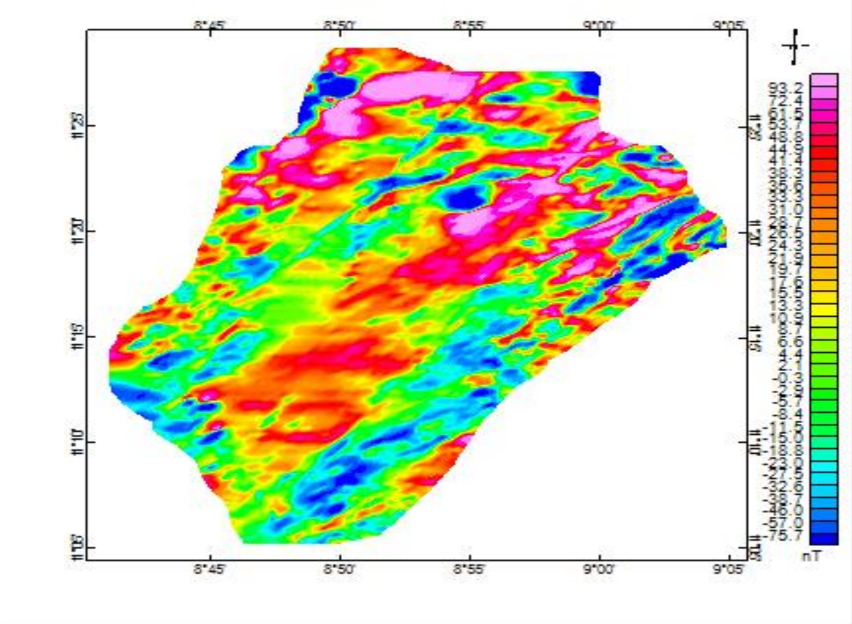

Figure 4: Residual Map of Sumaila L.G

REDUCTION TO EQUATOR

Reducing the residual map to the equator to account for the impact of latitude, and to ensure that the magnetic anomalies were centered symmetrically over their sources was carried out. The reduction to the equator (RTE) was applied using an inclination of 0.3 and a declination of -1.5, which are the geomagnetic field parameters at the central location of the study area. The RTE map (figure 5) is slightly different from figure 4, this is due to the small changes in the variation of the angle of inclination (0.3) in the study area. The magnetic anomalies have values -70.4nT to 83.7nT.

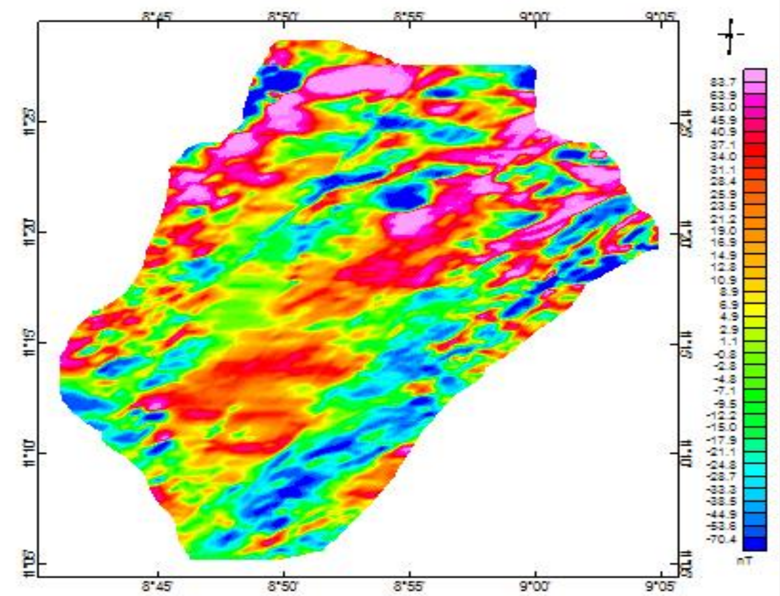

Figure 5: Reduced to Equator (RTE) Map of Sumaila L.G

VERTICAL DERIVATIVES

The FVD filter (equation 8) is multiplied with the FT of the observed field data reduced to the equator to give the inverse Fourier transform from which the vertical derivatives are obtained. The enhancement of the edges of the shallow sources has successfully revealed the presence of anomalous bodies trending in the NE-SW direction (Figure 6). The negative signatures correspond to minerals with low iron content, whereas the positive signatures indicate the existence of iron-rich minerals clarifying the structural and lithological features. However, this also could be attributed to the porphyritic biotite and migmatite found within the study area, which may contain gneisses and granitic leucosomes. Granitic leucosomes contain vital elements such as quartz, feldspar, and sometimes even mica that hold economic importance due to the presence of potential minerals (Obaje, 2009). Furthermore, the overlapping positive and negative anomalies suggest the presence of shear zones linked to mineralization veins, indicating the potential for mineral resources in the study area. The FVD values range between -0.20nT/m and 0.17nT/m.

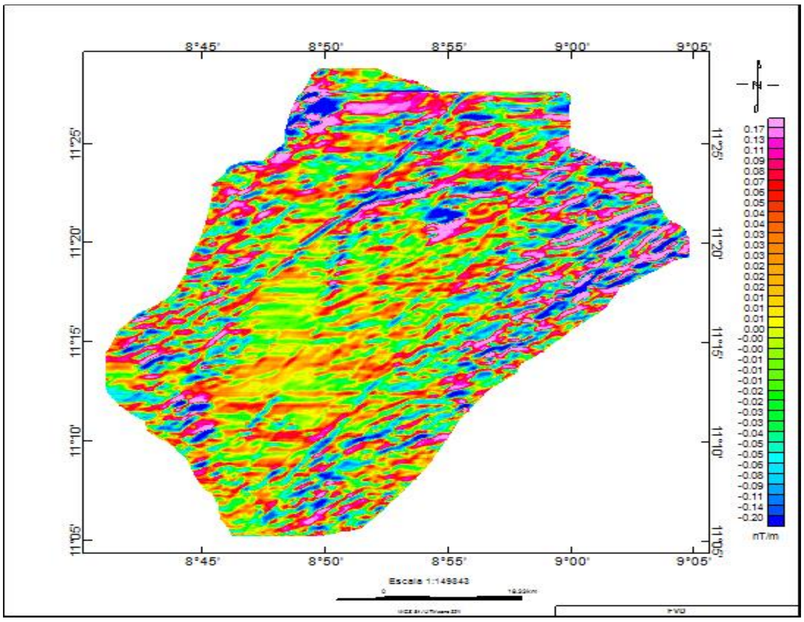

Figure 6: First Vertical Derivative Map of Sumaila L.G

The SVD map in Figure 7 shows irregular (overlapping of positive and negative) magnetic signatures of low amplitude values of -0.00151nT/m to 0.00154nT/m. The irregularity of the map depicts faults and lineament as possible zones of mineralization. The presence of a large lineament is observed from the map, and it is found to be within latitude 8° 48´00´´ longitude 11° 19´00´´ and latitude 8° 56´00´´ longitude 11° 27´00´´.

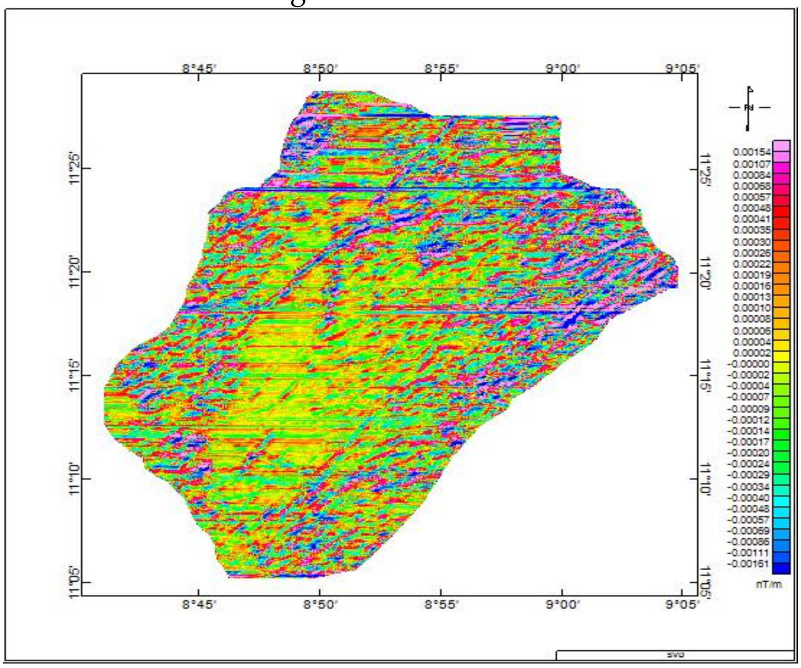

Figure 7: Second Vertical Derivative Map of Sumaila L.G

ANALYTIC SIGNAL

The Analytic signal method uses the Fast Fourier Transform (FFT) to perform the analysis using equation (9). The AS map (Figure 8) reveals high frequency field values revealing smooth edges of the structural features and source positions in a NE-SW trend with values between 0.01nT/m to 0.32nT/m. Three major anomalous areas are isolated in the map. The first cuts through Bunturu, Retsida and Ringi, the second lies through Gangadugu and Farin

Dutse, while the last passes through Gandama gandarma, Wayo and Birnin bako as shown in Table 1.

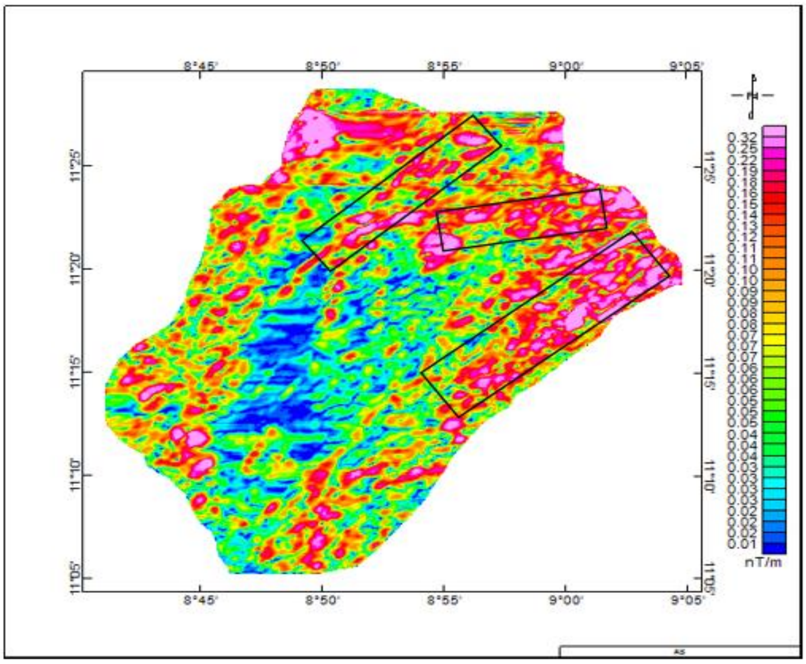

Figure 8: Analytic Signal Map of Sumaila L.G

Table 1: Location of the Major Anomalous Areas

Area	Longitudes	Latitudes	Towns
Area I	11°19′ 00''	8°48′ 00''	Bunturu, Retsida and Ringi
	11°27′00''	8°56′ 00''	
Area II	11°22′ 27''	8°54′ 14''	Gangadugu and Farin Dutse
	11°23′43''	9°02′ 31''	
Area III	11°20′52''	9°04′ 29''	Gandama gandarna, Wayo and Birnin Bako
	11°13′99''	8°55′ 91''	

CONCLUSION

The analysis of the aeromagnetic data has revealed the presence of subsurface structural features in the study area. The features were found to be oriented mainly in the NE-SW trend. Shear zones hosting faults, lineaments, and contacts are identified within the research area as veins forming network systems revealing the mineral potential and possible zones of mineral accumulation of the study area. These results were derived through the application of vertical derivatives and analytic signal processing. To comprehensively ascertain the minerals within the study area, it is imperative to employ additional geophysical methods in the pertinent major anomalous zone.

REFERENCES

Abu El-Ata A.S., El-Khafeef A.A., Ghoneimi A.E., Abd Alnabi S.H., and Al-Badani M.A., 2012: "Applications of Aeromagnetic Data to Detect the Basement Tectonics of Eastern Yemen Region". Egyptian Journal of Petroleum, vol 22, pp 277-292.

Ahmad B.M., Jimoh R., and Suleiman M.S., 2019: "Characterization of Gold Mineralization Zones Using Aeromagnetic Data at Dutsen Dan-Baqoshi, Dushi Area of Kano State Northwestern Nigeria", Dutse Journal of Pure and Applied Sciences (DUJOPAS) vol 5: 25, pp 121-133.

Al-Garni M.A., 2010: "Magnetic Survey for Delineating Subsurface Structures and Estimating Magnetic Sources Depth, Wadi Fatima, KSA". Journal of King Saud University (Science), vol 22, pp 87-96.

Bello R., Ofoha C.C., and Edah, H., 2017: "Qualitative and Quantitative Interpretation of Parts of Onshore Niger Delta, Nigeria, Using High Resolution Aeromagnetic Data". Geosciences Journal, vol 7:2, pp 77-88.

Dayo B., and Saleh M., 2018: "Interpretation of Aeromagnetic Data to Delineate Structures Hosting Gold Mineralization", Unpublished work M.Sc Thesis, Bayero University, Kano.

Emmanuel B.A., Martins E.O., and Jolly B., 2011: "Borehole Depth and Regolith Aquifer Hydraulic Characteristics of Bedrock Types in Kano Area, Northern Nigeria". African Journal of Environmental Science and Technology, vol 5:3, pp 228-237.

Hinze W.J., Ralph Von Frese R.B., and Saad A.H., 2013: "Gravity and Magnetic Exploration; Principles, Practices and Application", Cambridge University Press, ISBN 978-0-521-87101-3.

Lowrie W., 2007: "Fundamentals of Geophysics", Second Edition, Cambridge University Press, pp 281-324.

Naidu P.S., and Mathew M.P., 1998: "Analysis of Geophysical Potential Fields, A Digital Signal Processing Approach". Elsevier Science B.V., ISBN: 0-444-82801-X, pp. 93.

Obaje, N. G. 2009: "Geology and Mineral Resources of Nigeria". Springer, Dordrecht Heidelberg London New York, 221 pp.Potential Field Data via Generalized Hilbert Transform: Fundamental Relation. Geophysics, 49, 957 - 966.

Oghuma A.A., Obiadi I.I., and Obiadi C.M., 2015: "2D Spectral Analysis of Aeromagnetic Anomalies over Parts of Monguno and Environs, Northeastern Nigeria". Journal of Earth science & Climatic Change, vol 6: 303, pp 3.

Rabiu A., 2018: "Geological Map of Sumaila". Cartography Lab, Department of Geography, BUK.

Rabiu A., 2022: "Political map of the Aeromagnetic Data Sheets". Cartography Lab, Department of Geography, BUK.

Rafferty J.P., 2012: "Minerals", First Edition, Britannica Educational Pub. in association with Rosen Educational Services, ISBN 978-1-61530-582-7.

Shehu S.J., Aku M.O., Saleh M., Bunawa A.A., and Sharafa S.B., 2019: "A Reconnaisance Study to Delineate the Potential Mineral Zones Around the Schist Belts Areas of Kano State, Nigeria, Using Airborne Magnetic Data". Journal of Geology and Mining Research, Vol 11:2, pp 14-21.

Shehu S.J., Aku M.O., Saleh M., Bunawa A.A., Lawan M., and Sani F., 2021: "The Use of Euler Deconvolution Technique in the Estimation of Depth to Magnetic Source Bodies Around the Schist Belt Parts of Kano State, Nigeria". Jordan Journal of Physics, vol 14:1, pp19-23.

Tawey M.D., Alhassan D.U., Adetona A.A., Salako K.A., Rafiu A.A., and Udensi E.E., 2020: "Application of Aeromagnetic Data Assess the Structures and Solid Mineral Potentials in Part of North Central Nigeria". Journal of Geography, Environment and Earth Science International, vol 24: 5, pp 11- 29.

Telford W.M., Geldart L.P., and Sheriff R.E., 1990: "Applied Geophysics". Second Edition, London Cambridge University Press.