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Processing and Interpretation of lgbeti Sheet Aeromagnetic Data for Mineral Exploration

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Abstract:
This research aims to estimate the depths to magnetic source body boundaries using the aeromagnetic sheet of Igbeti (sheet 201) in Oyo State, western Nigeria. The structural analysis of the Igbeti area was performed by detecting source edges/discontinuities using edge-detection techniques, namely the Horizontal gradient method and Tilt derivatives. The magnetic source depth was also performed in the area using the source parameter imagery technique. Edge detection highlighted linear structures, and this infers the effects of such features on the tectonic events of the Igbeti area. In order to correct for phase shifts of magnetic anomalies of the study area due to the local direction of the geomagnetic field vector, RTE was calculated. Regional-residual separation Technique was used in this research to separate the observed magnetic field into two main components: the regional component and the residual component. Edge detection filtering aimed at locating the boundaries of magnetic source bodies and to come up with a structural map of the study area. Regional structural grains, including fractures and faults, are revealed by the prominent NE-SW lineaments in this area, which are associated with the emplacement of quartz-schist and muscovite-schist. The notable geological features and their geometric structures have been confirmed as a viable prospect for mineral exploration in the region.

Keywords: Aeromagnetic data; lineaments; Migmatite-Gneiss; source parameter imaging; tilt derivative.

1. Introduction

A geophysicist's task in data processing is to separate the signal from noise and interpret the data in a geologic context (Kearey et al., 2002). A magnetic survey measures the strength of the Earth's magnetic field with respect to time. After which, the data is presented as a graph showing variation of the measured quantity together with unwanted variation from non-geologic features. Geophysical processing is separating the signal from the unwanted signal, while Geophysical interpretation is interpreting the signal in terms of geologic structure. The separation is commonly employed to distinguish and isolate geological information of interest from background magnetic variations caused by regional geological structures and other sources. In data processing, convolution and correlation accomplish filtering. This is done in either spatial or the wavenumber domain/frequency domain. Magnetic data undergoes several Fourier transformations. The recent acquisition of high-resolution aeromagnetic data over the entire country of Nigeria has highlighted the importance of magnetic basement map, especially in relation to mineral exploration. The aeromagnetic method has been very effective in mapping subsurface anomalies and structures that host mineral resources worldwide (Bello et al., 2022). In this research, the high-resolution aeromagnetic data of Igbeti, Southwestern Nigeria was obtained from the Nigeria Geological Survey Agency (NGSA). Standard data enhancement Geophysical techniques such as residual-regional separation, tilt derivative, horizontal gradient method, and source parameter imagery (SPI) were used to delineate the lineament, map the short wavelength magnetic anomalies and depth to basement (Ekwok et al., 2019). The structural analysis was interpreted qualitatively using Horizontal Gradient Magnitude, and the depth to basement was done quantitatively using source parameter imagery (SPI).

The study area, Igbeti is bounded by longitudes 4°00′ E to 4°30′ E and latitude 8°30′ N to 9°00′ N with an average elevation of 366m above sea level. The lithological units are the Precambrian basement complex of southwestern Nigeria (Obaje, 2009) and comprises of five major groups of rocks which are: Migmatitegneiss complex, slightly migmatised to unmigmatised paraschists and metaigneous rocks, Charnockitic rocks, older granites and youngest unmetamorphosed cholerite dykes. Migmatite gneiss complexes are the most prominent rock types in the study area (Fig. 1). Migmatitie-Gneiss complex which comprises of biotite and biotite hornblende gneisses, quartzites, quartz schist, and small lenses of calcsilicate rocks resulted from a complex association of deformative shearing and folding, and granitization and migmatization processes. This is also in agreement with Nurudeen et al. (2020), who inferred that the region's lithological makeup includes Pan-African Granite, early metamorphic tectonites, metasedimentary rocks, with quartz and amphibolite schist intrusions.

The four orogenic cycles that took place in the area are Liberian, the Eburnean, the Kibaran, and the Pan-African cycles, which give rise to the basement rock of Igbeti. The orogenic cycles are cycles of deformation, metamorphism, and remobilization. The Nigerian basement was affected by the heterogeneous Neoproterozoic PanAfrican deformation, resulting in the reworking of the Liberian (2700 ± 200 Ma) older crust, of Eburnean (2000 ± 200 Ma) and a probable Kibaran (1100 ± 200 Ma). The tectonic events of Eburnean age evidently affected a large region of Nigeria, which was possibly accompanied by deformation, folding metamorphism, sedimentation and syntectonic igneous activity. The NW-SE and NE-SW lineament trends are a good hint about the pre-Pan-African and Pan-African orogenic activities 650 ±150 Ma.

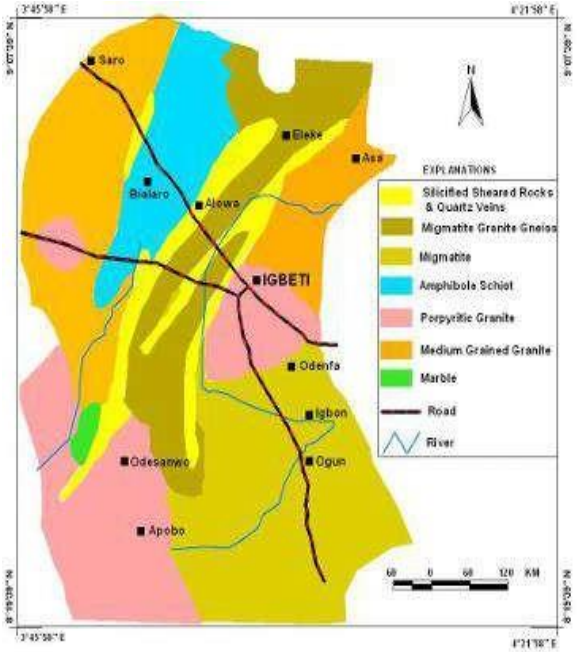


Figure 1. Geologic map of the study area

2. Material and Method

Digitized aeromagnetic data is a part of the data set of aeromagnetic survey acquired by (NGSA), which was aimed at reinvigorating solid mineral sector in Nigeria. obtained from the Nigeria Geological Survey Agency (NGSA). The study area is Igbeti and environs is sheet designated 201 of the gridded aeromagnetic data. The data was acquired by Fugro Airborne Surveys. Series of NW – SE flight lines spacing of 500 m and sensor average terrain clearance of 80 m magnetic data were acquired.

With the removal of geomagnetic gradient (employing IGRF), the data were produced as digitized data in the form of coordinates and intensity (X,Y,Z). Data processing, analysis and interpretation were done using Oasis Montaj (Geosoft) software (6.4) and ArcGIS 10.8. The edge detection filters: tilt derivative and horizontal gradient method were utilized in delineating the magnetic source edges at the area. Polynomial Fitting method were used to separate the regional magnetic field data from the residual magnetic field data.

Tilt derivative

The tilt derivative and its total horizontal derivative are useful for mapping shallow basement structures and mineral exploration targets. This was used to enhance the edges of sources. It is the most important edge-detection filter. The tilt derivative or tilt angle was first proposed by Miller and Singh (1994) as a tool for locating magnetic or gravity sources on magnetic or gravity profile data. For the gridded data the generalized tilt derivative is defined as shown in Eq. 1.

$$\theta = \frac{\tan^{-1}\frac{\partial f}{\partial z}}{HGM} \tag{1}$$

Where $\frac{\partial f}{\partial z}$ is the first vertical derivative of the field while HGM is the horizontal gradient of the field. The magnetic tilt angle is a normalized derivative based on the ratio of the vertical and horizontal derivatives of the magnetic field (Salem et.al, 2007). The tilt is restricted to value between $-\pi/2$ and $+\pi/2$ ($+90^0$ and-90^0) regardless of the amplitudes of VDR (first vertical derivative) or THDR. This fact makes this relationship function like an automatic gain control (AGC) filter and tends to equalize the amplitude output of magnetic anomalies across a grid or along a profile (Verduzco et al., 2004). TDR crosses through zero at or near the edge of a vertical-sided source and is negative outside the source region (Miller and Singh, 1994). The technique involves finding places/discontinuities where the contour value is zero and that is the contact/edge. The TDR is therefore very effective in allowing anomalies to be traced out along strike. The Tilt Derivative (TILT) is the angle formed between the amplitude of the analytic signal vector and its horizontal projection, to estimate the dip angle of the magnetic source.

Horizontal derivative magnitude

The horizontal gradient magnitude (horizontal derivatives) is the vector sum of the horizontal derivatives of the magnetic field in a presume direction, it enhances lateral changes in the magnetic field (Salawu et al., 2019). The horizontal gradient magnitude (HGM) is given by the square root of the sum of the squares of the horizontal derivatives of the potential field (Eq.2).

$$HGM = \sqrt{(\frac{\partial f}{\partial x})^2 + (\frac{\partial f}{\partial y})^2} \tag{2}$$

Source parameter imagery

In this research, the SPI which stands for Source Parameter Imaging or SPI™ was used to determine magnetic source depth. The SPI™ are trademark of Geoterrex. SPI is a procedure for automatic calculation of source depths from gridded magnetic data. Source Parameter Imaging estimates the depth solution from the local wavenumber of the analytical signal (Layade, et al., 2016). The depth solutions are saved in a database. The SPI utilizes relationship between source depth and the local wavenumber (k) of the observed field for any point within a grid of data through the horizontal and vertical gradients grids (Al-Banna & Daham, 2019). The source depth is equal to n/k at peaks in the local wave number grid, where n depends on the assumed source geometry (analogous to the Euler deconvolution's structural index). For example, n is equal to 0, for a contact, n is equal to 2 for a dyke. The peak tracking algorithm is used to identify the peak wavenumber grid. The SPI method has advantages over Euler deconvolution or spectral depths because of the following facts: i) The computation time is relatively short. ii) No moving data window is involved. SPI is easier to use, and it produces a more complete set of coherent solution points (Al-Banna & Daham, 2019). This method basically assumes that the inverse depth is defined by the peaks of the local wave number. The SPI therefore assume a step-type source model. For this model, the following formula holds.

$$\text{Depth} = \frac{1}{K_{max}} = \frac{1}{\left(\sqrt{(\frac{\partial \text{Tilt}}{\partial x})^2 + (\frac{\partial \text{Tilt}}{\partial y})^2}\right)_{\text{Max}}} \quad (3)$$

$$\text{Tilt} = \arctan\left(\frac{\frac{\partial T}{\partial Z}}{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2}\right) = \arctan\left(\frac{\frac{\partial T}{\partial x}}{HGRAD}\right) \quad (4)$$

Where Kmax is the peak value of the local wavenumber over the source (horizontal gradient of Tilt derivative)

T is the Total Magnetic Intensity grid

∂ Tilt is the Tilt Derivative grid

∂x x is the horizontal derivative in the x-direction

∂y y is the horizontal derivative in the y-direction

∂y y is the horizontal derivative in the z-direction (first vertical derivative).

The pre-processed grids tilt grid, ∂x, ∂y, and ∂y from the reduced to magnetic map were used to calculate the source parameter imaging (Sani et al., 2018).

3. Results and Discussions

Magnetic data is provided by variations in magnetic susceptibility due to magnetite. These variations can give rise to patterns and anomalies that can provide information on rock types, structures, alteration, and mineral deposits.

Total magnetic intensity MAP

The TMI was gridded using the maximum curvature griding algorithm and this is referred to as the vector resultant of the strength of both geomagnetic and crustal fields (Salawu et al., 2019). The gridded size used is 125. The International Geomagnetic Reference Field (IGRF) was applied to the aeromagnetic data by Fugro to remove the geomagnetic field effect. The total magnetic intensity (TMI) statistic report value ranges from -297.76nT to 176.32nT. The TMI map shows prominent low-amplitude anomalies at southwestern and northeastern portions of the study area while the high-amplitude anomaly dominates the southern part of the study area (Fig. 2). Zones of low magnetic intensity match areas of sedimentary rocks, while intermediary intensity matches to granitic rocks, and those of high magnetic intensity are associated with igneous rocks. The gneiss complex rocks comprise of granite gneiss, migmatite gneiss and biotite gneiss give rise to the positive magnetic anomaly amplitude. These rocks make up the major lithologic units in the area.

Regional-residual separation technique was used in this research to separate the observed magnetic field into two main components: the regional component and the residual component. The former is a field associated with deep magnetic sources, while the latter is associated with the shallow magnetic sources (Fig. 3 & 4). The residual component is of our interest because we are looking at shallow structures that host minerals. Thus, Regional-Residual separation is a critical step in the interpretation of aeromagnetic data for geological and mineral exploration purposes. Residual components can be analyzed and interpreted to identify and locate geological features of interest, such as ore bodies, faults, or geological boundaries. “Polynomial method, also known as polynomial trend surface analysis or polynomial regression, was used to do the separation. The Polynomial method is a mathematical technique that involves fitting a polynomial equation to the aeromagnetic data to describe and visualize the trend or surface within the data. The separation is commonly employed to distinguish and isolate geological information of interest from background magnetic variations caused by regional geological structures and other sources. The presence of Intrusive bodies such as latholiths, batholiths or dyke within the sedimentary basin could give rise to positive anomalies (Mamah et al., 2000, Ofoebgu, 1985b) but places that have low magnetic give rise to negative anomalies (Fig. 3). The residual magnetic and RTE magnetic anomaly maps reveal strong contrasts between the basement rocks, which indicate significant susceptibility differences (Eshanibli et al., 2025). The magnetic intensity revealed from the

statistical calculations with Oasis Montaj software on the residual map of the study area ranges between -224.7nT and 127.6nT. This is highly dominant in the northern and northwestern regions of the study area. Areas with low magnetic intensities between -0.674 and -63.203 nT area predominant at the Northeastern and at the middle of the map (Fig 3).

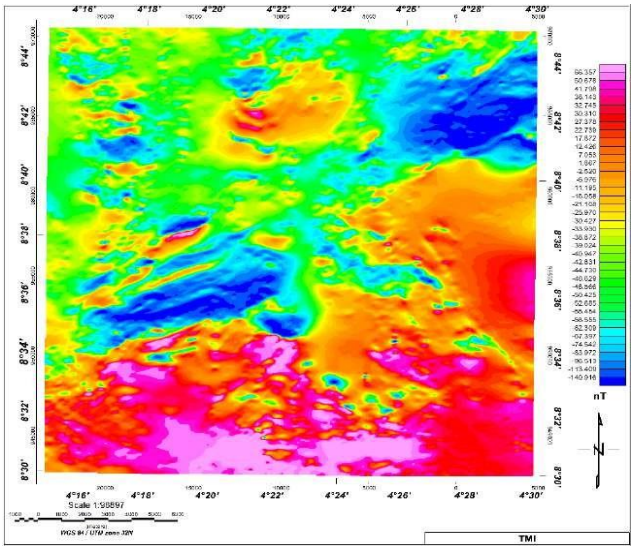


Figure 2. Total magnetic intensity (TMI) of the area

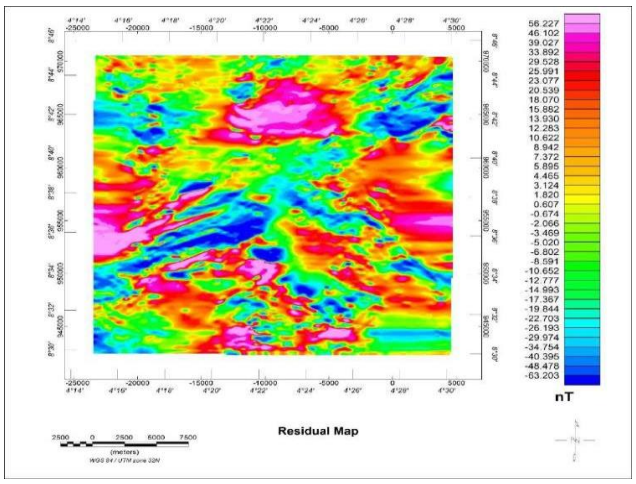


Figure 3. Residual map of the area

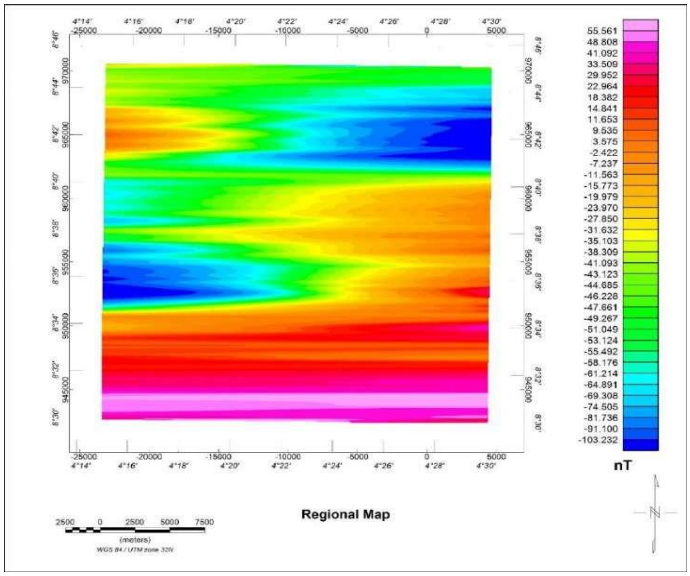


Figure 4. Regional map of the study area

Since the area under study is much closer to the magnetic equator, thus, reduction to the equator was applied to the data. Reduction to the equator simplifies the total-field maps and changes the actual inclination to be vertical (Eze and Mode 2022). The TMI was reduced to the equator to correct for phase-shifts of magnetic anomalies of the study area due to the local direction of the geomagnetic field vector (see Fig. 5). It is easy at high magnetic latitudes but more difficult at low magnetic latitudes. The average magnetic inclination and declination of 9.75° and 1.30° across the area, respectively, were used. The intensity value ranges between -43.1 and 143.6 nT. Reduction to equator has simplified the total field map to be vertical.

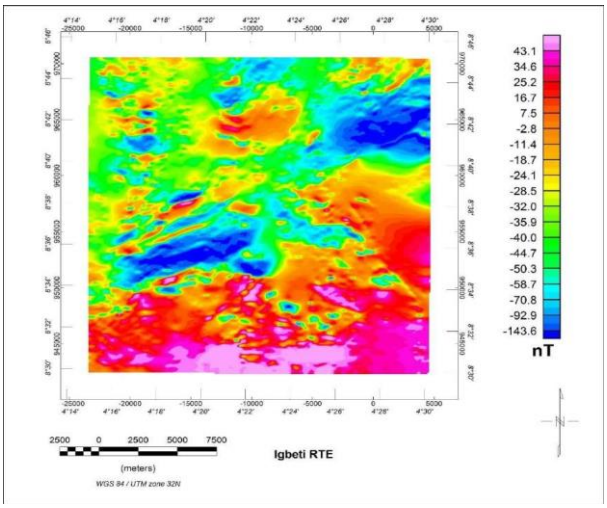


Figure 5. Reduction to the equator (RTE) of the study area.

Derivative filters

The use of derivative works best in shallow depth and that is the bases for using it. In mineral exploration, shallow depth is required, not as deep as in hydrocarbon. The RTE grid was filtered using tilt derivative filter to enhance the shallow basement structural features which is mineral exploration targets (Salawu et al., 2019). TDR map was obtained by application of tilt derivative filter to the reduction to the equator map to enhance

structures (joints, edges of sources, fault, etc) (Okpoli, 2019) in form of lineaments. This was detected by tracing the tilt zero values (Mekkawia et al., 2022). Tilt derivative involves finding places or discontinuities where the contour value is zero. it represents boundary of different magnetic susceptibilities high and low magnetic source bodies. The tilt values range from 1.38 radian to 1.35 radian (Fig. 6). The shallow sources and geologic boundaries were delineated by the tilt derivative filter and horizontal derivative method (HGM).

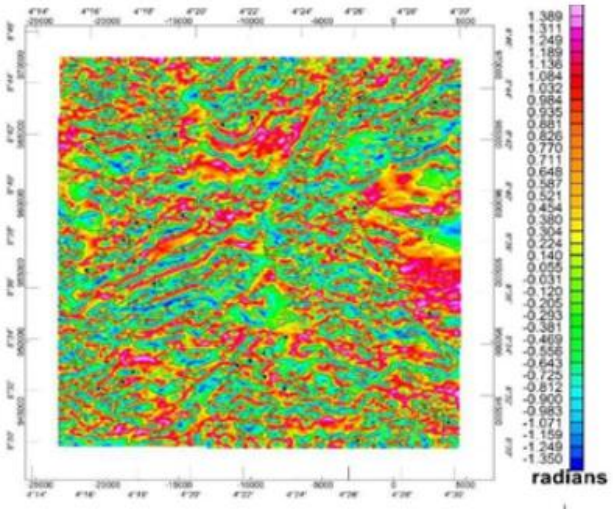


Figure 6. Igbeti tilt derivative map showing the contact (zero contour)

Horizontal gradient method

This technique involves using edge detection which is finding places/discontinuities where the local maxima in the HGM are aligned and the magnetic source body can be interpreted at these locations. If those bodies align together, they form a linear feature (Fig. 7).

Lineamen

Lineaments are indicators of subsurface faults, contacts, and tectonic structures. These structures serve as a pathway and a host for hydrothermal fluid and base metals (Eldosouky et al., 2022). Lineament deduction is paramount in the study of linear features in geology. According to Megwara & Udensi (2013), the most favourable structural conditions controlling mineral deposits are the lineament pattern. Lineaments also provide a regional structural pattern because they indicate the general geometry of subsurface structures (Onyewuchi et al., 2012).Good correlation exists between areas of high lineament density and places where minerals such as gold, iron ore, cassiterite, tantalite, clay and uranium occur. To highlight the source edges, the Horizontal gradient method and the zero-contact contour of the tilt derivative were used to delineate the lineaments. At the correlation point between the peaks of the horizontal gradient method and the zero contour lines of the tilt derivative, linear features occur (see Fig. 7). These features were delineated, forming the lineament in Fig. 9. The HGM detector positioned maxima over source borders and created sharp and clear edges for magnetic sources. The NW-SE and NE-SW lineament trends are a good hint about the pre-Pan-African and Pan African orogenic activities 650 ±150 Ma. The rose diagram of the study area is shown in Fig 7. Oladejo et al. (2019) identified three prominent fault trends in Ibadan, namely NE-SW, ENE-WSW, and NW-SE, which exhibit sinistral/dextral faulting.

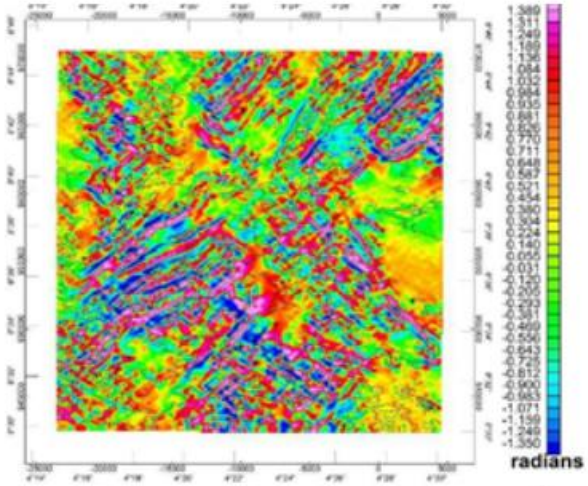


Figure 7. Horizontal derivative map of Igbeti superimposed on zero contour map of tilt map

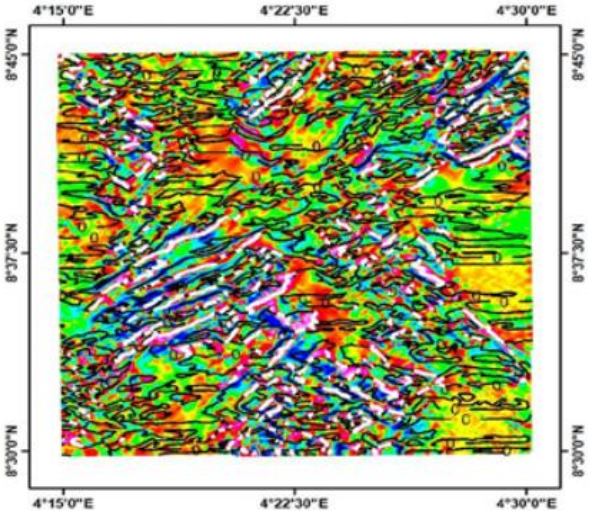


Figure 8. Lineaments superimposed on horizontal derivative and zero contour map of tilt map of Igbeti.

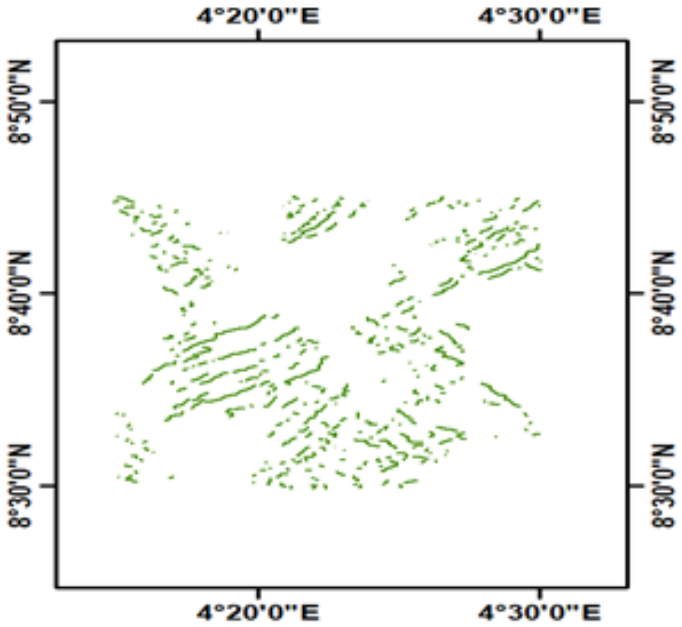


Figure 9. Lineament map of the study area Rose diagram

To observe the structural trends and geological processes of Igbeti, a rose diagram was constructed. The Rose diagram reveals the frequency and orientation of the extracted lineaments, which reflect younger, older, and deeper tectonic trends in the area (Nnaemeka et al., 2021). The directions with the highest frequency in the Rose diagram correspond to the predominant orientations of fractures and joints.

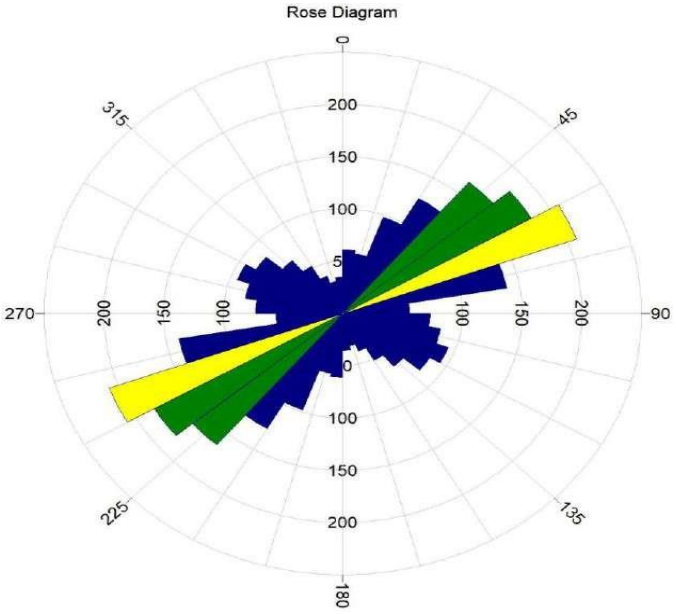
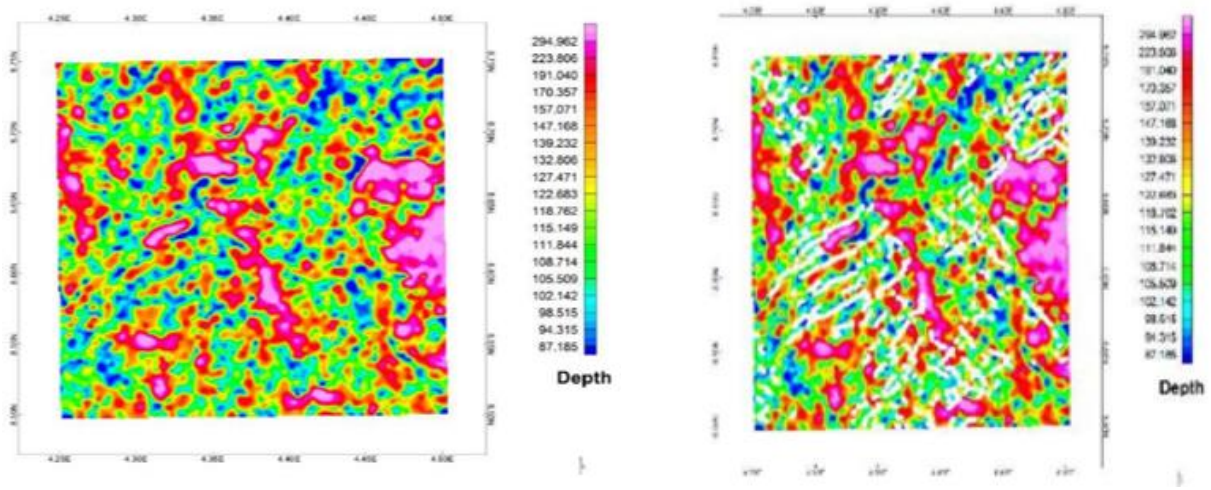


Figure 10. The lineament rose diagram

The major orientation of the lineaments beneath the surface of the study area, as shown in Figure 10, is NE-SW direction, which agrees with the trend of the basin (Megwara & Udensi, 2014).These structural trends are indicators of subsurface faults, contact deformation structures associated with the basement (Eldosouky et al., 2022, Megwara & Udensi, 2014). The NW-SE and NE-SW lineament trends confirm pre-Pan-African and Pan-African orogenic activities in Nigeria. Granitic rocks, a Pan-African belt, were affected by two episodes of granite plutonism represented by an older augen gneiss and a younger, relatively undeformed, coarse-grained porphyritic granite.

Source parameter imagery

Depth to basement knowledge can be necessary in several geological contexts and applications, such as hydrogeological studies, tectonic analyses, hydrocarbon exploration, etc. Interpretation and analysis of magnetic anomalies are geared towards inferring the morphology of the basement beneath the sedimentary basin (Florio et al., 2020). From the statistical report of depth to source values estimated using SPI imaging technique, the maximum depth value is 653.4m while the minimum depth is 60.9m (Eze et al., 2017). The SPI image map in fig. 11 shows spatial location of various magnetic sources at various depths (Sani, et al., 2018). This means that the magnetic basement lies between 760.6m and 63.64m. The shallow sedimentary thickness could also be found around basement complex and volcanic areas of the study area. (Salako, 2014). The maximum depth value is the depth to the deep-lying magnetic bodies, while the minimum depth value is the depth to the shallow magnetic bodies. The extracted lineament is overlaid on the SPI map, as illustrated by Fig. 11b map indicating that the lineaments are situated at shallow depth.



a **b**

Figure 11. (a) Source parameter imaging map (b) Source parameter imaging map, overlain by the lineament

4. Conclusion

The aeromagnetic investigation successfully revealed the subsurface geological and structural characteristics of the study area. The TMI and residual magnetic maps showed variations in magnetic susceptibility associated with sedimentary, granitic, and basement rocks. Reduction to the equator and derivative filters enhanced shallow structures and enabled the delineation of faults, contacts, and lineaments. The horizontal gradient method and the zero contour of the tilt derivative further provided clear images of geological features by enhancing and delineating magnetic signatures associated with the structural features of the study area. The dominant NE–SW and NW–SE lineament trends indicate the influence of pre-Pan-African and Pan-African tectonic activities. Source Parameter Imaging estimated magnetic source depths ranging from approximately 60.9 to 653.4 m. Overall, the results provide valuable information on the geological framework and identify structurally favorable zones for further mineral exploration.

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