

Aeromagnetic Evaluation of Structural Features and Depth to Basement at the Basement-Dahomey Basin Transition Zone, Abeokuta and Environs, Southwestern Nigeria

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ABSTRACT

This study was aimed at evaluating a contact zone and structural framework between the Basement Complex and the Dahomey Basin of Southwestern Nigeria. Qualitative and quantitative analyses were used to delineate the geologic structures as well as the sedimentary thickness of ~55m to 575m by measurement of depth to magnetic sources. The qualitative analysis on the total magnetic intensity (TMI) data was attained by applying different filters which include reduction to the magnetic equator (RTE), tilt angle derivative (TDR), analytical signal and lineaments extraction to enhance magnetic anomalies. The quantitative analysis which includes Source Parameter Imaging (SPI) and 3D-Euler deconvolution (ED) aided the assessment of structural depth to magnetic sources. The qualitative interpretation revealed the distribution of magnetically susceptible anomalies with varying intensities across the study area. The TMI showed rightly positioned magnetic intensity range of 33,028nT to 33,087nT revealing areas of high and low magnetic intensity. The TDR ranged between -1.4nT to 1.4nT while the Analytic signal ranged between 117nT/m and 8615 nT/m with magnetic peaks in the northeast, west and southwest parts of the study area; interpreted as faulted basement blocks with delineated fault-zones trending northeast. The SPI was used in determining depth to basement and with a range of 54.1m to 599.1m. The 3D-ED ranged between -251.7m to 575.4m with observed anomaly trending in direction of NE-SW implying its conformity to Pan-African Orogeny. The Interpretation of structural features is highly significant for entrapment which can aid accumulation of valuable mineralization and localization of competent areas for proposed engineering construction.

Keywords:

Abeokuta,
Dahomey Basin,
Lineament,
Euler Deconvolution,
Aeromagnetic.

INTRODUCTION

Geophysics is a very vital tool of exploration and it is consistently used in reconnaissance and surveys. There are a lot of geophysical survey methods which include gravity, magnetic, radiometric, seismic and electrical resistivity each of which has a unique operative physical property of the Earth like; density, magnetic susceptibility, radioactivity, propagation of seismic waves and electrical conductivity respectively (Kearey et al., 2002). These methods through ground measurement or airborne have been employed to investigate the subsurface geology of an area of interest.

In particular, aeromagnetic surveys extend the vision of geology way beyond the dominion of surface mapping

and drilling. They allow key aspects of geology through much of the Earth's crust to be seen, and provide a foundation for building 3-dimensional geological models (Isles & Rankin, 2013). The geological environments where aeromagnetic data add value are broad, to the point where many governments worldwide either have, or planning to have complete coverage of their country with semi-detailed surveys (Isles & Rankin, 2013).

The Nigerian economy currently depends primarily on crude oil production, but since the crude oil price in the world market is neither stable nor sustainable, hence the country's economy has been greatly affected (Lawal, 2020; Akinduko et al., 2022). However, Nigeria owns some abundant mineral deposits in various regions of the

country that can be economically attractive, nevertheless the majority of such deposits in some cases have not been fully accessed of their occurrence and composition (Ogungbemi et al., 2018).

In order to evaluate such deposits, aeromagnetic measurement is essential given its capability in the prospection of minerals (Lawal, 2020) and the delineation of metalliferous deposits (Petra et al., 2013; Wemegah et al., 2015). Interpretation of aeromagnetic data is vital to delineate and map the subsurface for possible rocks, zones, major lineaments and extension of geological structures that can serve as favorable areas of mineral deposits (Eldosouky et al., 2017; Sehsah et al., 2019; Lawal, 2020; Eldosouky & Mohammed, 2021). Lineaments are basically geological features that represent extensive faults, joints, lithological contacts, shear zones and foliations, which are valuable sites for extracting information in geological and tectonic studies of regions (Masoud & Koike, 2006; Solomon & Ghebreab, 2006; Marghany & Hashim, 2010; Hashim et al., 2013; Pour et al., 2016). Therefore, mapping the lineaments is significant to understand the tectonic origin and division, and to clarify their impact on mineralized occurrences (Chouhan et al., 2022).

Aeromagnetic survey is a common type of airborne geophysical survey which has been recognized as a principal mapping tool for materials that are strongly magnetized (Murthy, 2007). The physical principles of aeromagnetic methods are centered on taking measurements of the magnetic susceptibility of the surface geology, as well as using the data to determine the distribution of magnetic minerals and hence changes in lithology (Reynolds et al., 1990; Telford et al., 1990). Rocks have widely varying magnetic properties (Carmichael, 1982; Clark, 1997). The magnetic susceptibility of most rock forming minerals is low, and magnetism in rocks is as a result of the presence of magnetic minerals (Kearey & Brooks, 2002). The presence of different types of magnetic minerals in various compositions in rock formation results in different rock formations having different magnetic susceptibility values. At the regional scale, magnetic highs are commonly associated with major igneous provinces in crystalline basement but by contrast, magnetic lows often occur in areas dominated by thick sedimentary basin (Olurin et al., 2016), or where, for example, igneous rocks are altered and magnetite is replaced by hematite when hydrothermal fluids have migrated along faults (Hildenbrand et al., 2001).

Aeromagnetic data is one of the utmost and significant geophysical tools in mapping magnetic anomaly associated with subsurface geological structural settings in form of lineaments (Anderson and Nash, 1997; Wemegah et al., 2015). Furthermore, aeromagnetic measurements have the benefit of being able to quickly cover wide areas that are difficult to access (Mattsson et

al., 2018). They reflect the variations in the distribution and type of magnetic minerals below the Earth's surface. The continuity of information provided by airborne geophysical surveys cannot be matched by ground geophysical surveys (Boyd, 1967). Geomagnetic variations can be mapped from the surface of the Earth to varying depth in the Earth crust depending on the dimension, shape, and the magnetic property of the rock. The Earth is a weak magnet which exhibit spatial variation in magnetic intensity due to local concealations of diverse ore bodies, variation in rock chemistry and the external imposition from the magnetosphere laterally (Kearey & Brooks, 2002).

Aeromagnetic survey has proven essential in revealing the spatial distribution and relative abundance of magnetic minerals and nonmagnetic minerals in the upper crust, which can help in the visualization of the geology and geological structures of the upper crust of the earth (Gun, 1975). Aeromagnetic survey may also be used as guidance for exploration of epigenetic, stress-related mineralization in the surrounding rocks (Paterson & Reeves, 1985). Geologic structures such as faults, folds, lineaments and intrusions play a vital role in the task of mineral deposits localization, but their visualization from the graphical representation of raw aeromagnetic data is not straightforward (Lawal, 2020). Therefore, signal enhancement techniques are needed to be applied to the magnetic data. The desire to deepen the body of knowledge and characterize the subsurface features for better understanding of the geology of the study area steered this research. This study is focused at addressing geology related challenges using aeromagnetic data. For instance, with sedimentary thickness (depth to basement) evaluation, one can predict the rock or mineral potentials of an area of interest (Nabighian & Hansen, 2005). Also, the knowledge of fractured regions can help in siting engineering works like road construction and setting up high-rise buildings. Groundwater development is another societal problem that can be solved through this method because the basement topography and structures control the accumulation and distribution of groundwater around the transition zone (Osinowo & Olayinka, 2013). This study is therefore important in the study of structures and lineament that may host valuable mineralization and also serve as guide for exploration of prospective areas.

Aeromagnetic dataset was used in this study to understand the nature and regional structures of the subsurface after subjection to different enhancement techniques. Maps of the processed data were interpreted qualitatively and quantitatively in relation to patterns in geology. These patterns were employed to delineate and outline the local geological structures and distribution of magnetic anomalies. This study thus permits a broader understanding of how magnetic data are being filtered, processed and interpreted.

Study Area

Location and Geology of the Study Area

The study area is Abeokuta and its environs, found at the eastern part of Dahomey basin, southwestern Nigeria. Abeokuta, the capital of Ogun State, is the prominent urban settlement of the state and lies within the southwestern Basement Complex of Nigeria whose rocks belong to the youngest of the three major provinces of the West African Craton (Ishola et al., 2016). These rocks were rejuvenated during the Pan-African orogeny about six hundred million years ago. The basement complex rocks of Ogun State make up one-quarter of the surface area of the state while the sedimentary rocks aspect covers about three quarter of the surface area of the state (Ishola et al., 2016). It is located on the east bank of the river Ogun in southwestern Nigeria and covering a total area of about 879 square kilometers. Ogun state is bounded in the west by Benin Republic, in the south by Lagos, in the north by Oyo and Osun, and in the east by Ondo state (Figure 1 and 2). The study area is found within latitudes

$7^{\circ}00'N$ to $7^{\circ}30'N$ and longitudes $3^{\circ}00'E$ to $3^{\circ}30'E$ which corresponds to sheet number 260 on the sheet index map of Nigeria (Ajibade & Fitches, 1988). The sheet covers an area of about 3025km square ($55km \times 55km$) and it falls into UTM zone 31 north. The topography of the area has an elevation ranging from 100 to 400m above sea level. The relief is generally low with the gradient in the north-south direction. The Ogun River takes its source from the Iganran hills at elevation of about 530m above mean sea level and flows directly southwards over a distance of about 480km, before it discharges into the Lagos Lagoon (Ajibade, 1979). Gneiss-migmatite complex is the most widespread rock group in the study area, and it comprises gneisses (the most widespread rock types), quartzites, calc-silicate rocks, biotite-hornblende schists and amphibolites (Rahaman, 1976; Figure 3). The older granites occur in and around Abeokuta, and they are Late Precambrian to early Proterozoic in age with magmatic origin (Jones & Hockey, 1964).

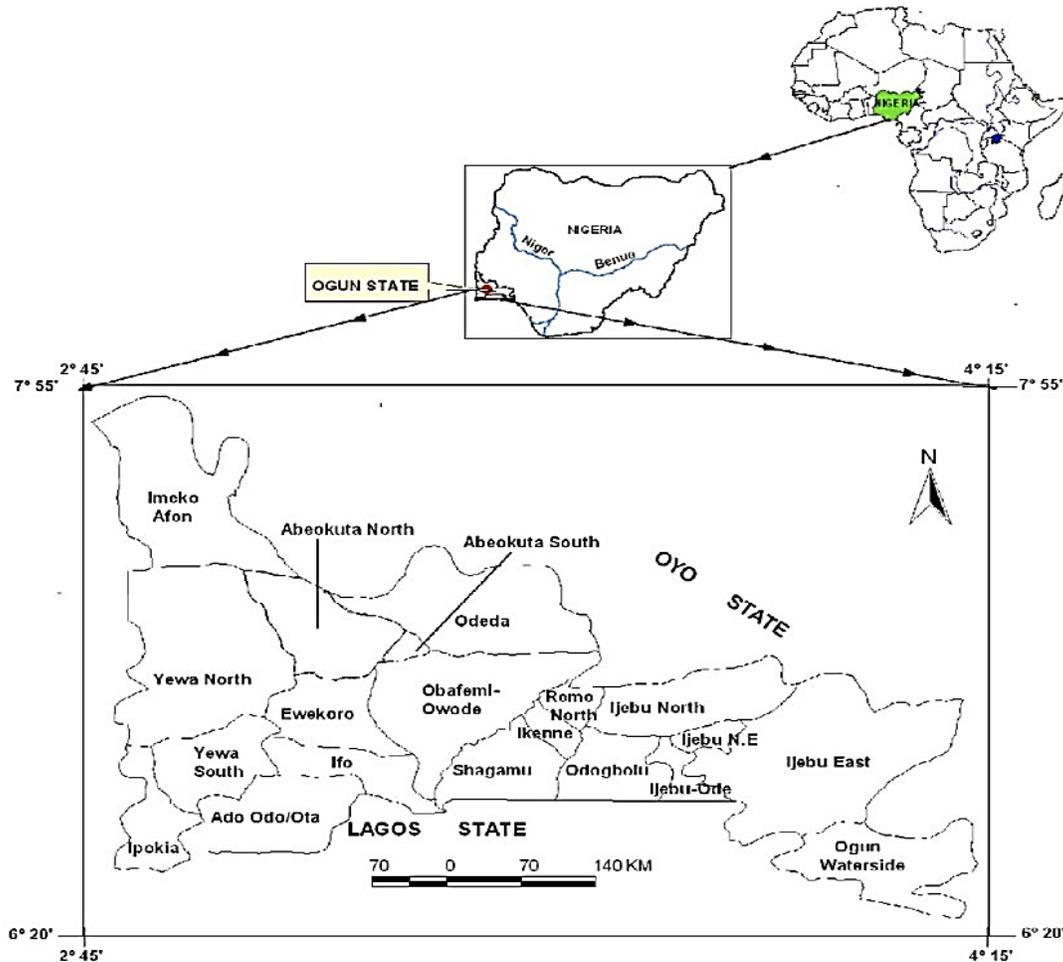


Figure 1: Location Map of Abeokuta and its Environs Showing the Major Localities with Intersected Maps of Africa and Nigeria (After Olurin et al., 2016)

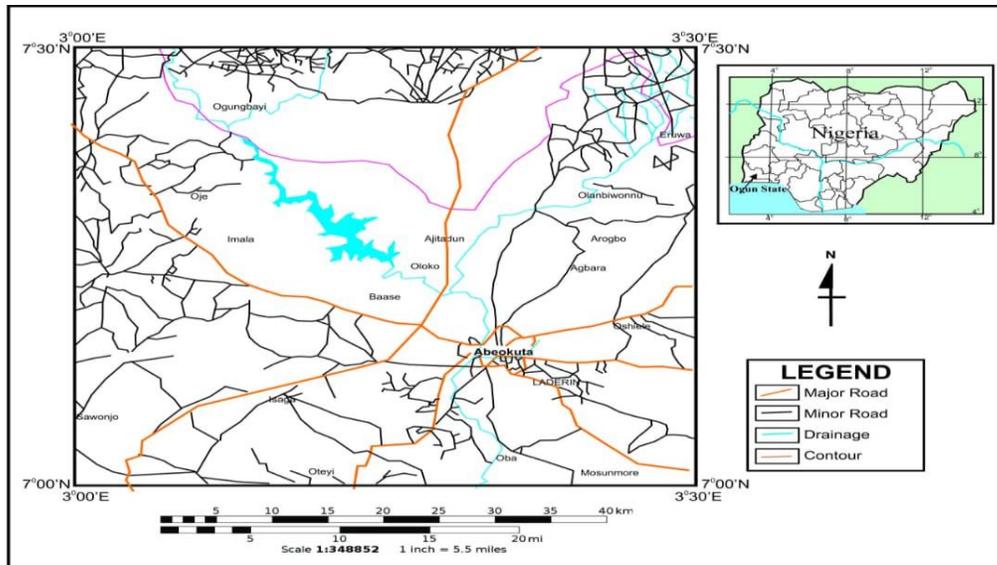


Figure 2: Location Map of the Study Area (Oyebolu et al., 2025a)

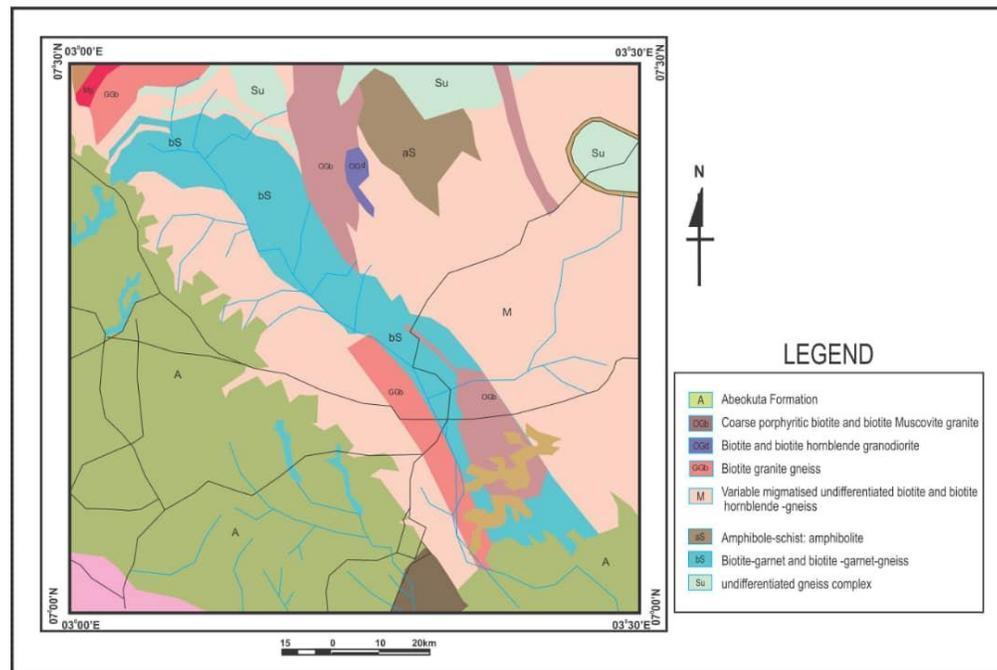


Figure 3: Geology Map of the Study Area (Oyebolu et al., 2025b)

MATERIALS AND METHODS

Magnetic susceptibility is a measure of the ease with which particular rocks are magnetized when subjected to a magnetic field. The ease of magnetization is ultimately related to the concentration and composition (size, shape and mineralogy) of magnetizable material contained within the sample (Wemegah et al., 2009). Magnetizable minerals include the ferromagnetic minerals (strongly magnetizable), any of the paramagnetic (moderately magnetizable) minerals, and other substances (Wemegah et al., 2009).

Telford et al., (1990) indicated that although there is great variation even for a particular rock type and wide overlap between different types, sedimentary rocks have the lowest average susceptibility and basic igneous rocks have the highest. In every case, the susceptibility depends only on the amount of ferrimagnetic minerals present, mainly magnetite, sometimes titanomagnetite or pyrrhotite. The values of chalcopyrite and pyrite are typical of many sulphide minerals that are basically non-magnetic.

Mathematically, magnetic susceptibility is expressed in equation (1) and (2) as:

$$\chi_m = \frac{\partial M}{\partial H} \approx \frac{M}{H} \quad (\text{weak response} \approx \frac{\mu_0 M}{B}) \quad (1)$$

$$B = \mu_0(H + M) \quad (2)$$

where $\mu_0 = 4\pi \times 10^{-7} \text{ VsAm}^{-1}$

H = Applied force

M = Magnetic Moment/Volume

B = macroscopic magnetic field intensity (induction) χ_m

$B = \mu_0 (1 + \chi_m)H$ (Telford et al., 1990)

Data Acquisition

The aeromagnetic dataset was acquired from the Nigeria Geological Survey Agency (NGSA). It is part of the data acquired during the high-resolution airborne geophysical survey of Nigeria between 2003 and 2009 by Fugro Airborne surveys (NGSA, 2006). The data were acquired via an aircraft hovered at a height of 80 m with 500m tie line spacing, 80m mean terrain clearance, flight direction of 135 azimuths and tie line direction at 45 azimuths at 5000m with grid cell size of 125m (MMSD, 2010). The aeromagnetic data were obtained using a 3 x Scintrex CS3 Cesium vapour magnetometer with resolution of 0.01 nT and it covers the Abeokuta sheet 260 corresponding to latitudes 7° 00' N to 7° 30' N and longitudes 3° 00' E to 3° 30' E. The topographical sheet covers an area of about 3025 km² (55 km x 55 km).

Data Processing and Enhancement

The aeromagnetic data acquired was processed and interpreted using maps, digital data sets, grids or profiles. Methods were also applied to remove damping spurious noise and signals that come along with the magnetic anomaly, thereby increasing signal to noise ratio. Data reduction and processing also involves the elimination of effects of time-varying external fields such as IGRF and Reduction to Magnetic Pole.

The acquired data was first imported into the database through the American standard Code for Information Interchange (ASCII) of the Oasis Montaj, after which it was gridded using the minimum curvature to generate the Total Magnetic Intensity map. Other maps like the Tilt derivative, Magnetic Anomaly are also generated from the Magmap menu of the software. Typical aeromagnetic data are made up of three sets of information: The magnetic field measurement which is indicated by the letter Z. The latitude indicated as X and the longitude indicated as Y.

While the basic Total Magnetic Intensity (TMI) grid may not be the form of data usually used for interpretation, it is imaged as initial step in interpretation and initial display of the corrected survey measurements and reference point when working with filtered and transformed version of the data (Isles & Rankin, 2013). All interpretations were performed using the Geosoft Oasis Montaj v.9.x software with structural index, SI = 1 for contact/dyke models, the unprocessed data is extracted and positioned in x and y

form corresponding to the longitude and latitude coordinate system (re-projection to Universal Transverse Mercator zone 31N), which make up the pre-processing stage. The second phase consist of four procedures: firstly, gridding was done to interpolate the data from the measurement locations to nodes of a regular mesh thereby, creating a fundamentally new different construct of the data (Foss, 2011). Calculation of the residual magnetic field by subtracting International Geomagnetic Reference Field (IGRF) from total magnetic data measured from the field (Oladunjoye et al., 2016) constituted the second procedure. Thirdly, micro-levelling the whole data set to get rid of any form of errors and finally integrating the different windows for each different type of data.

Magnetic data filtering is a prelude to magnetic data interpretation. It involves a wide range of transformations of the processed data which assist in its ultimate interpretation. This usually involves the application of mathematical filters or models. The objective is to make anomalies simplified and enhanced in order to define prominent interests as well as to make others (noises) less significant, and finally relate the measured field anomalies to rock properties.

A low-pass filter is a filter that passes low-frequency signals and attenuates (reduces the amplitude of) signals with frequencies higher than the cut off frequency. The filtering was accomplished at wavelength cut-off of 2000m and filter standard deviation of 0.5 with cut-off frequency of 0.1 cycles/km with filter type and order being of low-pass butterworth and second order. The actual amount of attenuation for each frequency varies depending on specific filter design. Low-pass Butterworth filter was applied to the total magnetic intensity (TMI) data to remove regional effects. The low-pass filter was applied because of its high sensitivity to noise unlike the high pass filter which allows the passage of noise causing false lineation in the map. An ideal low-pass filter completely eliminates all frequencies above the cut off frequency. All the enhancement techniques were performed with Geosoft (Oasis Montaj). The MagMap extension in Geosoft, which offers a number of utilities for processing of magnetic data was used on the magnetic residual anomaly grid (TMI - IGRF) with IGRF-14 model. The necessary filters were applied and it was displayed as an image using the Grid and Image tool. Two-Dimensional Fast Fourier Transformation (2D-FFT) filters were applied to enhance the quality of the data. The 2D-FFT filters used includes the total magnetic intensity, Analytic Signal, tilt derivatives, Vertical Derivatives, radially average power spectrum.

Regional and Residual Separation

The interpretation of the magnetic field begins with the separation of the long-wavelength anomalies of the regional field component, which is attributed to deep and

large scale sources from the shorter wavelength features constituting the residual field assumed to arise from shallow and small scale sources. The residual data is obtained as a derivative of the total field data.

Total Field = Regional Field + Residual Field

Residual Field = Total Field - Regional Field

Reduction to the Equator (RTE)

Although the reduction to pole (RTP) is a fundamental process which in most situation yields imagery representing the geometry of magnetic rock units much better than TMI data, and transforms TMI data measured at any Earth's field inclination, except at very low latitudes, to that which would be observed as if the survey were conducted at the magnetic poles 90° (Baranov & Naudy, 1964), the correction was based on the Reduction to the Equator (RTE) because the study area has relatively low latitudes.

Correction for inclination and declination of the Earth's Magnetic field is required as a result of the dipolar nature of magnetic anomalies which makes interpretation difficult. Even though the magnetic field is more complex at the equator than the actual magnetic field at the pole, a reduced to the equator map has been described as less complex and more accurate than a reduced to the pole map (Mosuro et al., 2021). For this study, the RTE was done to center the peaks of magnetic anomalies over their sources in order to enhance interpretation of the data while still preserving their geophysical meaning.

Analytic Signal Amplitude

The application of analytic signals to magnetic interpretation was devised by Nabighian, (1972) primarily as an apparatus for computing depth and position of sources. The analytic signal method is a notable method that tracks the loci of the shallowest edges of a magnetic body irrespective of the orientation of the body's magnetization and Earth's magnetic field direction (Ibraheem et al., 2019). This implies that all bodies with similar geometry have the same analytical signal (Milligan, 1997). Analytic signal is a key tool that enables one to deal with complex and difficult interpretation situations.

Tilt Derivative

The tilt derivative is the arctan of the ratio of the first vertical derivative (1VD) and the modulus of the total horizontal derivative (Miller & Singh, 1994). It produces pattern similar to 1VD, but portray responses from deeper and shallower sources (Isles & Rankin, 2013). A positive tilt angle corresponds to the source, negative value indicate distance from the source (Miller & Singh, 1994) while the zero values correspond to the edge or near edge and abrupt changes between positive and negative anomalies (Mosuro et al., 2021). Such abrupt

changes are common along faults, which are generally depicted by magnetic lineaments.

Depth to Basement

Attempt was made to estimate the depth to basement of the magnetic body. The Geosoft Oasis Montaj. Depth to Basement extension was used to determine the position (distance along the profile and depth), dip (orientation) and intensity (susceptibility) of magnetic source bodies for a magnetic profile. The depth to the source of the magnetic anomaly was calculated from the spectrum calculation and display tool on the oasis Montaj. The radial average spectrum was used. The signatures displayed in the radial average spectrum shows wavelength in association with depth.

Lineament Analysis

The Centre for Exploration Targeting (CET) grid analysis is another set of plugins (algorithms) used in the extraction of lineaments associated with the study area. It is developed by the Centre for Exploration Targeting, based at the University of Western Australia, which is incorporated into the Oasis Montaj Software as an executable. This computation and analysis is to identify areas of structural complexity through texture analysis, lineation detection, lineation vectorization and skeletonization, as well as thresholding. The Tilt derivative grid was used as the mother grid for these computations and the extracted lineament map. In this study, Oasis Montaj software was used for interpretation of the aeromagnetic data. The software has several attributes and functions which can be used for interpretation of geophysical data.

RESULTS AND DISCUSSION

The results obtained from the aeromagnetic data of Abeokuta and environ were presented in a qualitative and quantitative interpretation which involves the estimation of the depth to the top of the magnetic basement, magnetic profiles and the magnetic surface map respectively. Discussion is in line with the geophysical interpretations of the results into more meaningful geological parameters which include but not limited to the location and depth of magnetic sources.

Qualitative Interpretation

Qualitative interpretation was carried out on these images to visualize the contact zone and identify the geological structures. The rocks in the study area showed different aeromagnetic responses which can be related to their lithology and tectonic activities that have resulted in subsurface structures. The following qualitative interpretations were made;

Total Magnetic Intensity (TMI) and Regional Magnetic Intensity (RMI)

The digitized dataset of Abeokuta and its environs (sheet 260) was presented after gridding as TMI map (Figure 4). It represents the total magnetic intensity map of the study location with three major distinctive magnetic intensities category of low, intermediate and high magnetic values. A magnetic amplitude range of 33,087 nT to 33,028 nT as total field values was reflected from the legend of the figure. Lower magnetic values of 33,028 nT to 33,046 nT observed around western to southwestern corner with splashes of its dots around the northeastern region.

The intermediate magnetic intensities were found to be between 33,048 nT to 33,072 nT which are partly distributed all over the study area but principally trending W-E direction while the high magnetic signatures correspond to values of 33,075 nT to 33,087 nT can be observed at the north, northeast and west of the maps. The low, medium and high magnetic intensities are depicted as blue color, green to yellow color and pink color respectively which correspond to the color scale of the maps.

The differences in the lithological distributions (sedimentary, metamorphic and igneous rock units) result in the differences of magnetic intensity in the area. Abeokuta and its environs are predominantly covered with magnetic anomalies of intermediate intensities which possibly indicate the presence of magnetically susceptible minerals that are majorly Migmatite-Gneiss complex (Obaje, 2009). Anomalies with low magnetic responses observed at Sawonjo, Mashayi Ibooro, Jiga and Ishaga areas possibly predict the presence of some sedimentary rock units like shale and gypsum (Telford et al., 1990). These observations conform to the geological realities in the research area in real sense, as these areas correspond to the Abeokuta group in the eastern part of the Dahomey basin as indicated on the geologic map of Abeokuta and environs according to (Edunjobi, 2021).

Residual Anomaly (Reduction to Equator)

Low latitude effect cause magnetic signatures to be wrongly positioned over their sources and also make them skew along a particular direction (Baranov & Naudy, 1964; Keating & Zerbo, 1996). This can be seen as abnormal elongation of magnetic anomalies on the TMI map. Residual Anomaly also Reduction to Equator thus remove the skewness of the anomalies and make it symmetric over the source which is magnetized by induction only, remove influence of magnetic latitude and reduce effect of dip magnetization. The residual anomaly is TMI reduced for IGRF.

The Residual Anomaly was accomplished relying on the Earth total intensity (33039nT), magnetic field inclinations (12.15°) and declination (-1.26°). Residual anomaly shows magnetic intensity ranging from -19nT to 18nT. This implies different lithology unit in the bedrock

of the study area. The major fault lines are around SE parts of the study area which have been made more noticeable because anomalies have been rightly positioned over their sources. The anomaly trends in direction of NE-SW was observed implying the uniqueness of the Pan African Orogeny.

Tilt Angle Derivative

The tilt derivative map (Figure 5) enhances shallow geologic features such as faults and fracture represented by blue and green colors. It provides accurate information about structural settings, tectonic trends, and depths of anomalous bodies in the study area. It enhances short-wavelength components of the anomalies responsible for shallow bodies while de-emphasizing long-wavelength components. The derivative has similar and general trends of NE – SW with range between -1.4 nT to 1.4 nT. It is observed that the southeastern, northeastern and central part of the map is characterized by short-wavelength anomalous bodies implying shallow depth of the causative magnetic bodies.

Correlation of the tilt derivative map (Figure 6) with Regional anomaly map (Figure 5) shows a significant improvement and distinctness of structural geologic settings such as faults, fractures and folds. Elongated features are significantly enhanced in Figure 6 as a linear feature with NE-SW trending direction. Structural features correlate with migmatite, biotite garnet schist and biotite garnet gneiss on surface geologic map may act as a conduit for hydrothermal alteration in the study area.

Analytical Signal

The Analytical Signal map (AS) displayed as Figure 7 showed the boundaries and edges of anomalies with values ranging between 117nT/m and 8615 nT/m. AS broadly tracks the location of the shallowest edges of a magnetic body irrespective of the body's magnetization (Isles & Rankin, 2013). This makes AS a powerful and effective tool in mapping edge locations at low field inclinations and in the presence of remanent magnetization. The AS shows evidence that the lineaments were responsible for shallow magnetic bodies found.

High magnetic value between 3325nT/m and 8615nT/m (pink color) which are dominant in the northeast corner, west and southwest part of the map interpreted as faulted basement blocks having high magnetization. The high magnetic signatures represented on the map are related to quartz schist, biotite garnet schist and amphibolites. These high signatures may be due to the presence of hydrothermal deposits along the lineaments or presence of Cu-Fe rich bearing rocks because high magnetic signatures in geophysical surveys are frequently associated with hydrothermal deposits particularly Iron Oxide Copper-Gold (IOCG) system and related ore bodies because the hydrothermal process often

precipitates large volumes of magnetic minerals such as magnetite and pyrrhotite (Austin et al., 2014; Clark, 2014). These signatures are created through the precipitation of magnetic minerals when hydrothermal fluids which are hot mineral-rich brines, circulate through fractures and porous rocks depositing minerals as they cool or interact with host rocks (German and Sayfried, 2014; Laos-Santos et al., 2022; Liu et al., 2022); concentration in copper-iron rich rocks through IOGC deposits and magnetite-rich alteration zones (Austin et al., 2014; Clark, 2014; Schlegel et al., 2020; Laos-Santos et al., 2022); structural control of mineralization since hydrothermal fluids often travel along major faults and shear zones. Magnetic anomalies can map these structures, as the mineralization and magnetite alteration are concentrated within these zones producing high-intensity often linear anomaly patterns (Austin et al., 2014; Clark, 2014; Schlegel et al., 2020; Laos-Santos et al., 2022). Therefore, in exploration studies, a high magnetic signature in a region with known copper-iron rich geology is often an indicator for mapping potential hydrothermal mineral deposits as it outlines the zones where magnetite was introduced or created by mineralizing fluids (Clark, 2014; Schlegel et al., 2020; Laos-Santos et al., 2022).

Low magnetic value between 117 nT/m and 333 nT/m represented by blue color is observed in the southeastern part of the study area. The low signature corresponds to sedimentary rock (Abeokuta formation of the Eastern

Dahomey Basin) with low magnetic minerals compared to the basement rocks.

Lineament Map

The tilt derivative was used to extract lineaments by CET grid analysis through skeletonization on Oasis Montaj and is displayed as Figure 8. The Centre for Exploration Targeting (CET) grid analysis is another set of plugins (algorithms) used in the extraction of lineaments associated with the study area. It is developed by the Centre for Exploration Targeting, based at the University of Western Australia, which is incorporated into the Oasis Montaj Software as an executable.

From the lineament map (Figure 9), analysis of the dominant lineaments reveal NE – SW trend. This trend is associated with the shear zone crossing the Pan African belt. It is also similar to the oceanic fractured zones that infringed into the study area from the Atlantic Ocean, all in agreement with Pan-African structural pattern (Kaki et al., 2013), tectonic trend of Nigeria (Dike, 2002) and evolutionary origin of Dahomey Basin (Gulraud, 1990).

The lineaments extracted can possibly serve as geologic contacts, faults and entrapments for the accumulation of mineralized targets. This computation and analysis is to identify areas of structural complexity through texture analysis, lineation detection, lineation vectorization and skeletonization, as well as thresholding. The Total derivative map (Figure 5) grid was used as the mother grid for these computations and the extracted lineament map is presented as Figure 9.

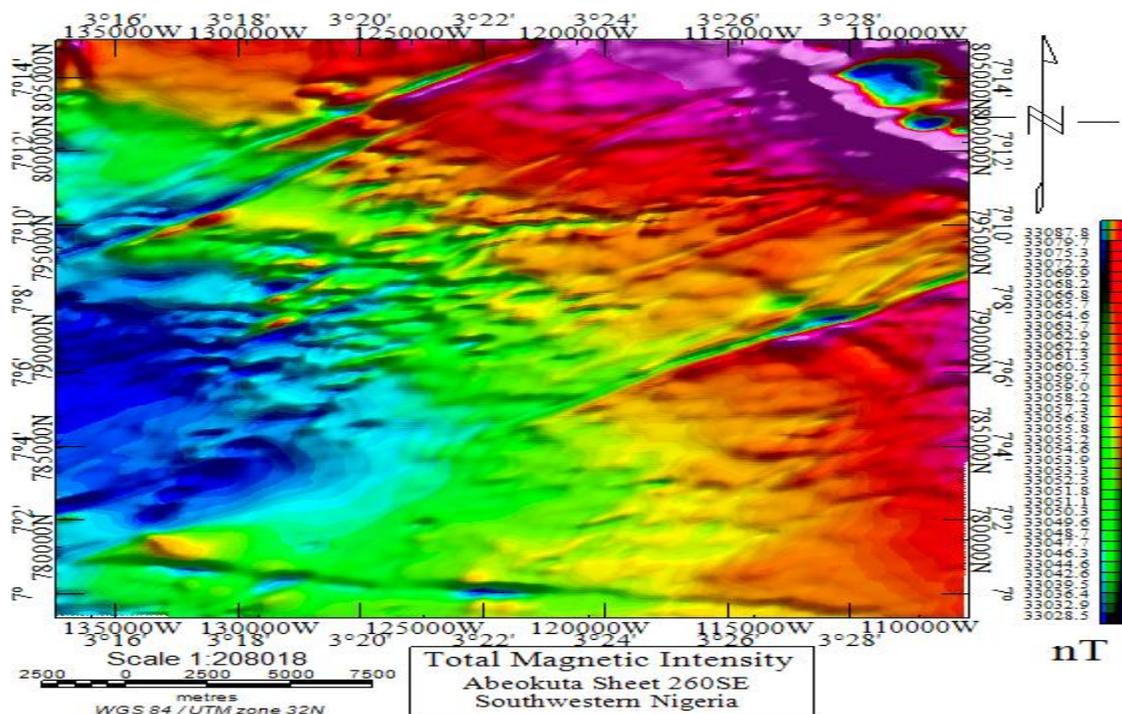


Figure 4: Total Magnetic Intensity of Abeokuta Sheet 260SE, Southwestern Nigeria

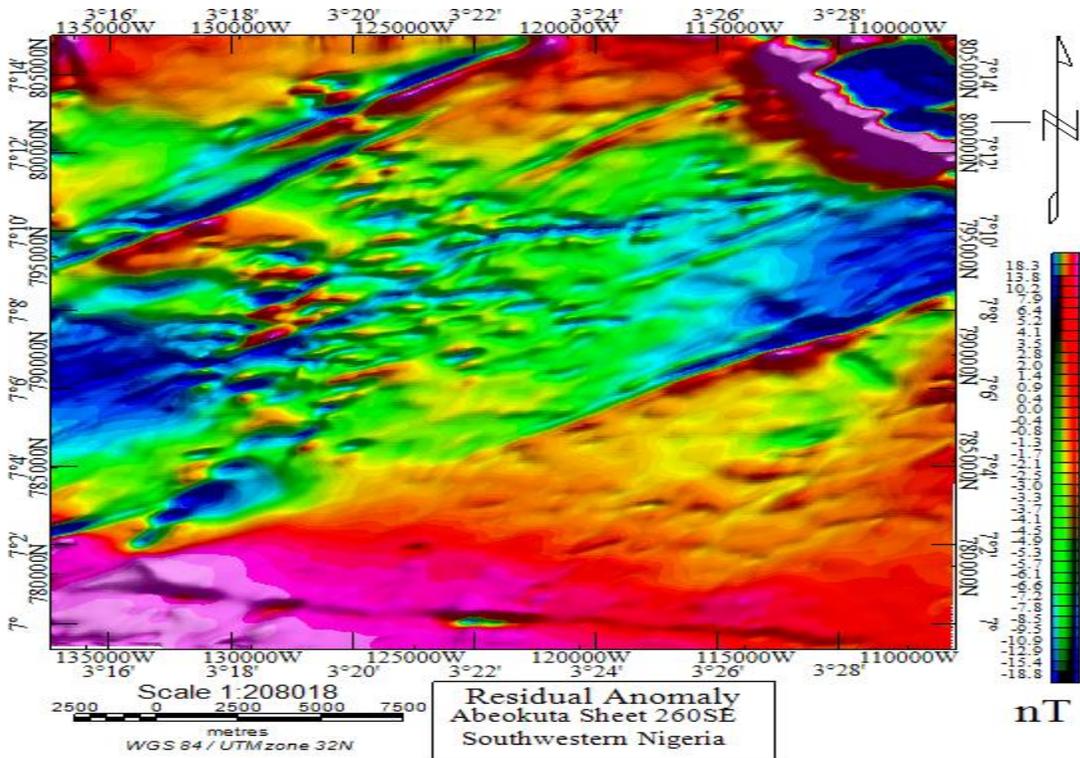


Figure 5: Regional Magnetic Intensity of Abeokuta Sheet 260SE, Southwestern Nigeria

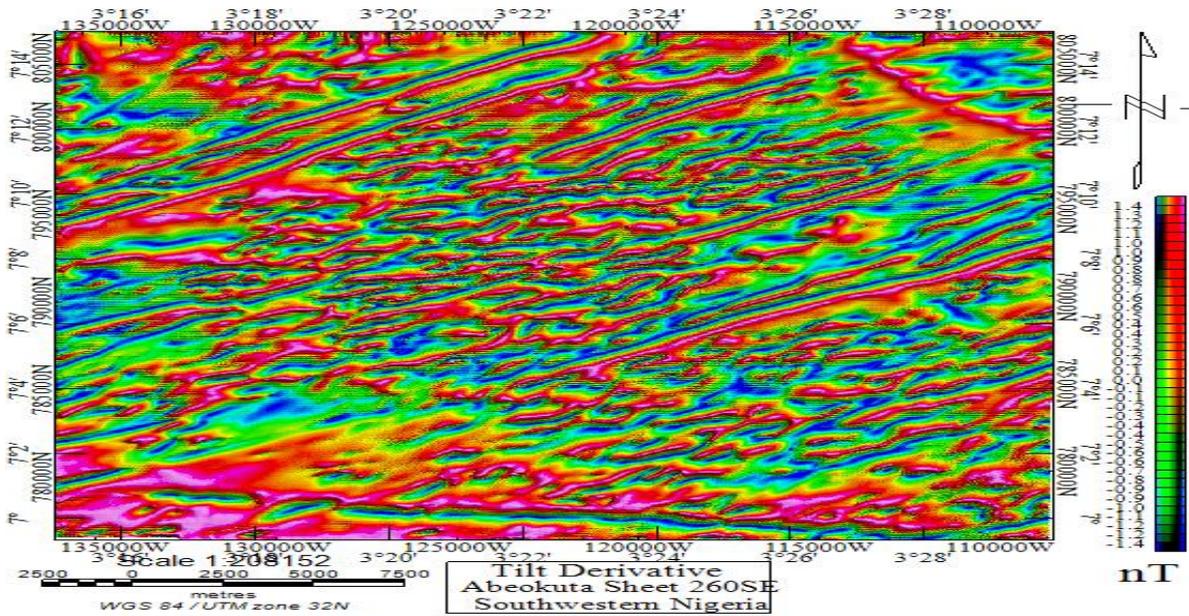


Figure 6: Tilt Angle Derivative of Sheet 260SE, Southwestern Nigeria Abeokuta

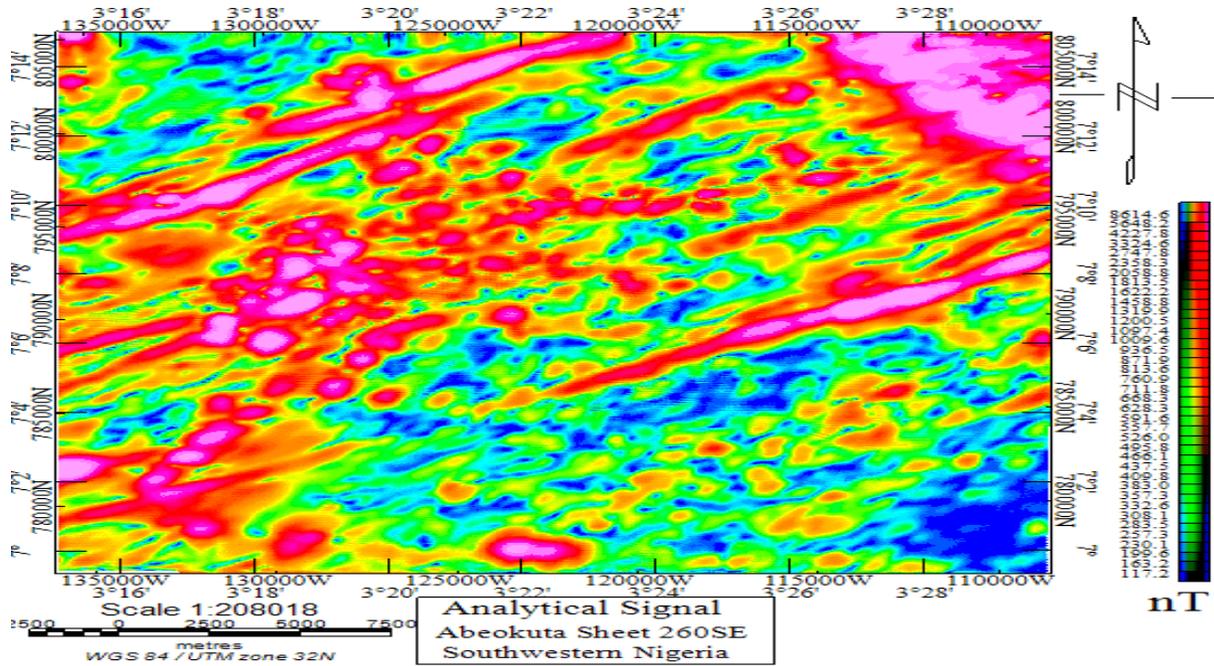


Figure 7: Analytical Signal of Abeokuta Sheet 260SE, Southwestern Nigeria

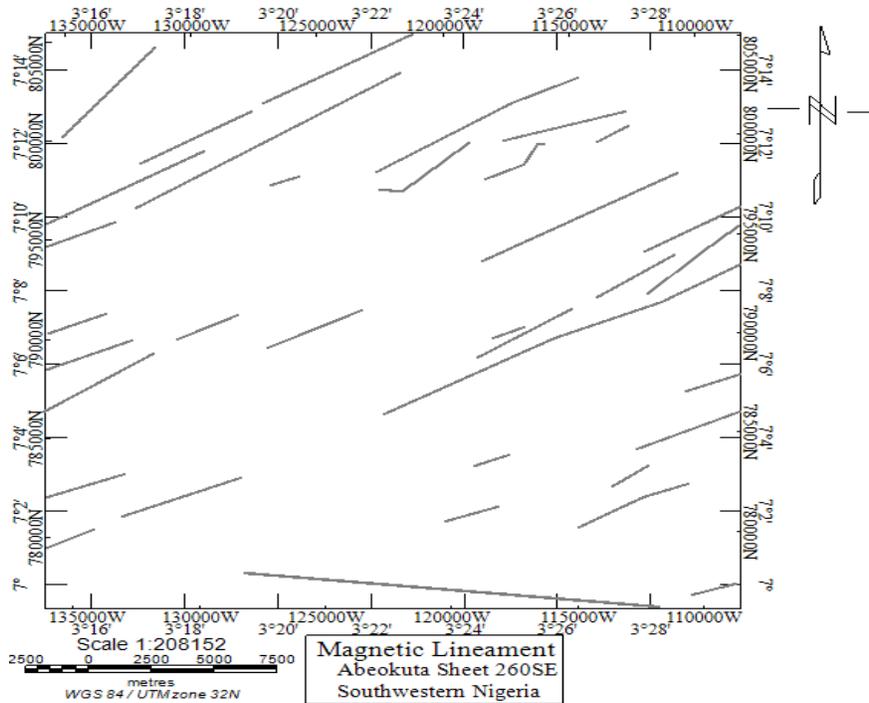


Figure 8: Lineament Map of Abeokuta Sheet 260SE, Southwestern Nigeria

Quantitative Interpretation

This involves using numerical values to estimate the depth and dimensions of the sources of anomalies and this often takes the form of modeling of sources which could replicate the anomalies recorded in the survey.

Radially Averaged Power Spectrum

The power spectrum method was utilized to segregate the local (residual) and regional magnetic fields, detect the depth of shallow and deeper structures, and delineate subsurface geologic structures (Spector & Grant, 1970; Ganguli et al., 2021). Attempt was made to estimate the depth to basement of the magnetic body. The Geosoft

Oasis Montaj depth to basement extension was used and a 2D power spectrum curve was attained (Figure 9).

The depth is evaluated from the slope of the plot between the logarithmic power spectrum and wave number. Figure 9 display signatures of long wavelength, which are associated or proportional to the increase in depth to the magnetic source in the study area which is vice-versa in the case of short wavelength. The Radially Averaged Power Spectrum (Figure 9) can be interpreted as two linear slope segments and has been applied to estimate the depth of magnetic interface which represents the average depth to the lower and upper surface of the magnetized body. Possible noise level can also be estimated.

Source Parameter Imaging (SPI)

Depth to basement evaluation of magnetic sources through SPI is displayed as Figure 10 and the legend of the figure reflects a minimum depth range of 54.1m to 83.4m which represents the depths of shallow magnetic bodies. The maximum depth range is 325.7m to 599.1m which corresponds to the depths of deeply seated magnetic anomalies. Spots of low and high magnetic anomalies can be observed to be coalesced in the study area due to the variations in magnetic susceptibilities of sources and undulations of the terrain. The linearly pronounced magnetic lows around the southeastern and central portions coincide with the major faults of the area. Areas of high sedimentary thickness (high depth to basement) are the sedimentary terrain which correspond with the Benin, Ewekoro and Abeokuta group of the Dahomey basin, while areas of low sedimentary thickness are the basement complex concentrated at the central and southeastern part of the study area.

Euler Deconvolution

Figure 11 shows the 3D Euler solution map. This solution is considered more fitting because it contains less spurious solutions after windowing. Meaningful geological interpretations can be deduced from the map. A depth range of -251.7 to 575.4 m is seen on the figure. The figure displays a minimum depth range of -251.7 to -11.5 m which is considered to be the depth range of near surface intrusive rocks while the maximum depth range of 411.9 to 575.4m depicts the location of long wavelength magnetic anomalies. The negative values displayed in Euler deconvolution solutions for the aeromagnetic survey of the study area which theoretically represent sources located above the ground surface (or negative depth; these are probably caused by inaccuracies in the input parameters and data preprocessing, poorly removed regional field/unfiltered data, low magnetic latitude effect, complex geological structures/composite geological realities, high noise content and possible interfering anomalies (Chukwu et al., 2023). The method assumes a simple, isolated, and homogeneous source and deviations from this model often leads to unrealistic negative depth. The quality of depth estimation depends on the choice of the correct structural index (SI). According to Reid et al., (2014), SI of 0, 1, 2 and 3 is used for investigation of geologic contact, dyke of fault, vertical or horizontal cylinder and sphere geometry respectively. The SI used for the Euler deconvolution is 1 in order to understand the trending of structural features. The patterned continuous elongation of contours around the southeastern parts conforms to the fault structures interpreted in qualitative analysis and when compared with the geological map (Figure 3) of Abeokuta and environs. Comparison of the SPI and 3D Euler Deconvolution reveal very close depth results.

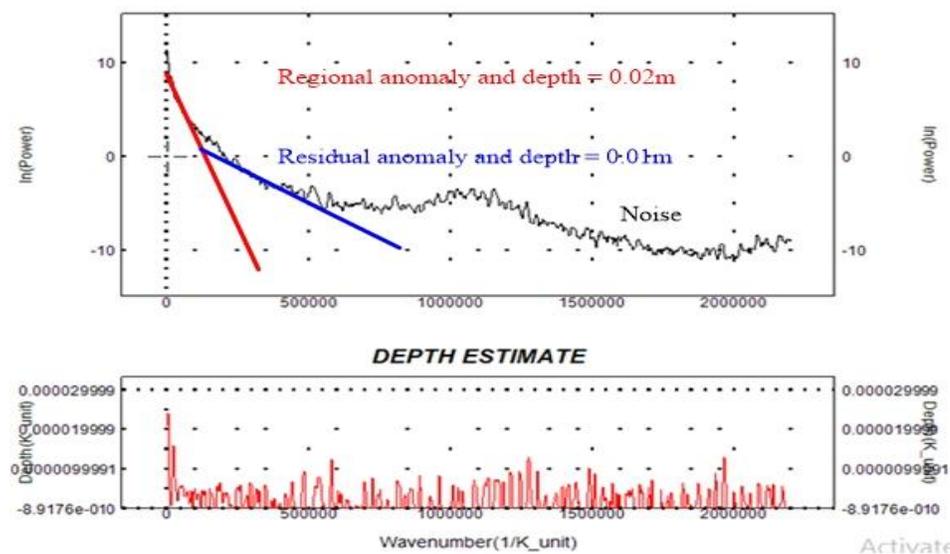


Figure 9: Power Spectrum of Abeokuta Sheet 260SE, Southwestern Nigeria

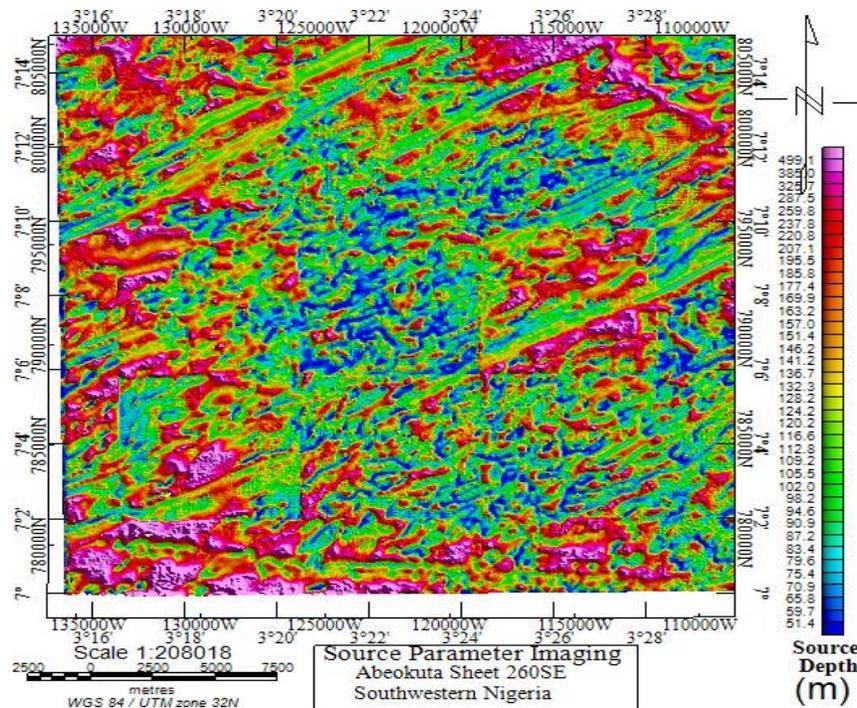


Figure 10: Source Parameter Imaging of Abeokuta Sheet 260SE, Southwestern Nigeria

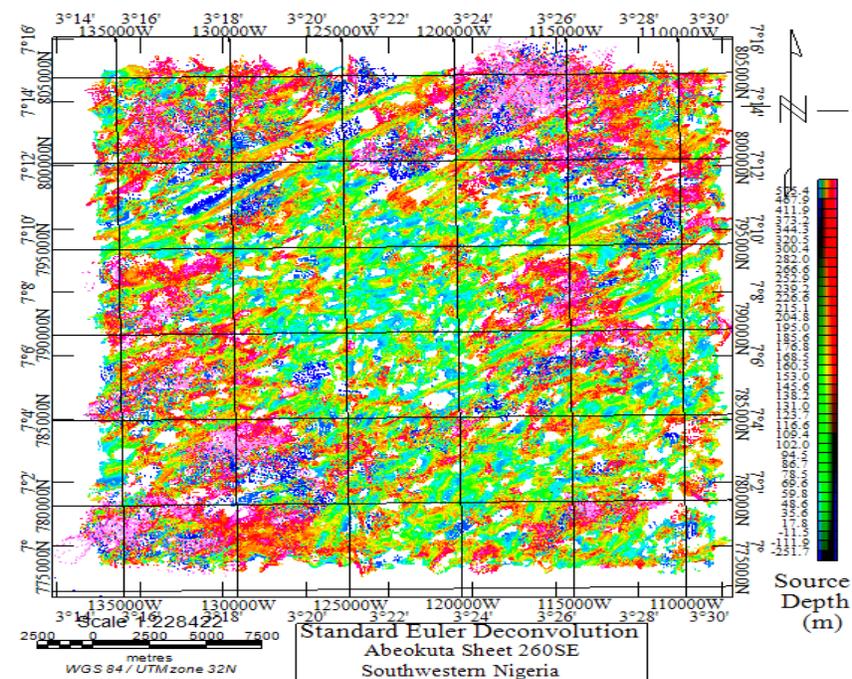


Figure 11: Euler Deconvolution Map of Abeokuta Sheet 260SE, Southwestern Nigeria

CONCLUSION

The analyses of Aeromagnetic Data of sheet 260 of Abeokuta and its environs were achieved by delineating structural features and lithological boundaries. The objectives of this study included applying the aeromagnetic data for delineating and evaluating a contact zone and structural framework between the Basement

Complex and the Dahomey Basin of Southwestern Nigeria. Qualitative and quantitative analyses were utilized in the delineation of the geologic structures as well as the sedimentary thickness of by measurement of depth to magnetic sources. The qualitative analysis on the total magnetic intensity (TMI) data was attained by applying different filters which include reduction to the

magnetic equator (RTE), tilt angle derivative (TDR), analytical signal and lineaments extraction to enhance magnetic anomalies. The quantitative analysis which includes Source Parameter Imaging (SPI) and 3D-Euler deconvolution (ED) aided the assessment of structural depth to magnetic sources. The qualitative interpretation revealed the distribution of magnetically susceptible anomalies with varying intensities across the study area. The TMI showed rightly positioned magnetic intensity range of 33,028nT to 33,087nT revealing areas of high and low magnetic intensity. The TDR ranged between -1.4nT to 1.4nT while the Analytic signal ranged between 117nT/m and 8615 nT/m with magnetic peaks in the northeast, west and southwest parts of the study area; interpreted as faulted basement blocks with delineated fault-zones trending northeast. The SPI was used in determining depth to basement and with a range of 54.1m to 599.1m. The structural features with the observed anomaly are trending in the NE-SW direction and can found to be in conformity with the Pan African Orogeny with the 3D-ED ranging between -251.7m to 575.4m. Steep gradient of contours observed by visualizing the maps are the possible fault lines in the study area, these fault lines serve as possible pathways to mineralizing fluids making them potential entrapments for the accumulation of valuable mineralization. Qualitative analysis of the data aided the magnetic distributions of the study area into low, moderate and high magnetic intensities. The distribution is due to the likely presence of sedimentary, metamorphic and igneous rock units respectively. Quantitative analysis and interpretation of the data by the depth estimation techniques revealed sedimentary thickness range of about ~575m to 55m. 3D Euler deconvolution and SPI delineated the various geologic structures (such as faults, contacts, void, and so on) of the study area more conspicuously. In general, the basement topography configured and other techniques used are guides to address various societal challenges. Areas identified as basement complex will be suitable for siting engineering constructions like railway, roads and other high-rise buildings while areas associated with fault lines should be avoided for these purposes because of the tendencies of quick cracks.

Finally, conclusion can be made that the area is highly affected by the tectonic related to Pan African Orogeny and basin evaluation. It is affecting both basement and sedimentary rocks, dividing the study area into several faulted blocks.

This study therefore recommended integrated geophysical techniques involving a detailed investigation and interpretation of aeromagnetic data with other geophysical method such as aero-radiometric and gravity surveys in order to understand possible mineralization potential along structures delineated. Also, variation in the distribution of magnetic intensities may be due to

variation in the concentration magnetic minerals. Geochemical studies may equally be employed on areas delineated with high magnetic signatures. This is to evaluate such areas for their potential as ore deposits

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