The Use of Aeromagnetic in Qualitative and Quantitative interpretation of Geology of Gboko Area and Environs

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ABSTRACT

The quantitative interpretation in this work is based on the use of Source Parameter Imagery (SPI) to estimate the depth to magnetic sources in the area. Qualitative interpretation deals with description of anomalies as revealed by their filtering techniques such as Regional-Residual separation, Reduction to equator, Horizontal derivative, Analytical signal, First and Second derivative filtering. These filters have enhanced subtle structures on total magnetic intensity grid aeromagnetic map. The major tectonic trends deduced from the filtered maps indicate that the local structures are controlled by the regional deeper structures which have E-W, NE - SW, NW – SE trends. The depth values to the magnetic basement complex which is computed by SPI method ranges between 144.9733 to 3,196.4311 m.

(Keywords: source parameter imagery, SPI, aeromagnetic survey, magnetic depth, magnetic basement, tectonic trends, filtered maps, geology, geophysics)

INTRODUCTION

The study of geophysics has helped man to access hidden treasures like mineral ore deposits. Some of the geophysical methods for accessing these treasures involve measuring reflectivity, magnetism, gravity, electricity, radioactivity, and electromagnetism. Each geophysical method investigates a unique physical property of the crustal earth which tends to solve a particular problem within the earth's subsurface (Keary, *et al*., 2002). The main aim of the aeromagnetic survey is to detect magnetic anomalies of minerals or rock rocks (Agabi, *et al.,* 2020).

Most of the magnetic materials are contained in the igneous and metamorphic rocks which constitute the basement below the surface of the Earth and the depth can be interpreted as depth to magnetic sources. Magnetic methods can be used in evaluating basement configuration (Olawale, 2020).

Aeromagnetic survey allows large areas of the Earth's surface to be covered quickly for regional reconnaissance. Aeromagnetic surveys reflect almost exclusively the distribution of magnetite and pyrrhotite in rocks (Abbas and Mallam, 2013). Aeromagnetic survey also aids in indicating major basement surface structures which reveal encouraging exploration areas that could be studied in broader detail using seismic geophysical survey method.

As the aircraft flies, the magnetometer records tiny variations in the intensity of the ambient magnetic field and the total effects of the constantly varying solar wind and spatial variations in the Earth's magnetic field. The latter being the regional magnetic fields and the total effect of magnetic minerals in earth's crust.

The traditional role of aeromagnetic studies over continental areas is to establish geologic and tectonic frame works and to explore for minerals (Oha et al. 2016). Aeromagnetic data have long been used by the petroleum industry to map structures and to delineate depth to magnetic basement (Steenland, 1965). Aeromagnetic methods traditionally are used to map crystalline basement, igneous rocks at depth, faults and for delineating buried igneous bodies in the near surface (Grauch, 2001).

This study aims at interpretation of aeromagnetic data for better understanding of geology and structural framework of the Gboko and environs. Specific objectives include: i) To delineate structural lineaments (contacts and veins) that act as hosts for mineral and hydrocarbon accumulations and ii) Estimate the depth to the magnetic causative bodies.

Geology of the Area

The geographical coordinate of the study area lie between latitude of 7.00 and 7.30N and longitude 8.30 and 9.00E and is within the Benue Trough (Figure 1). Benue Trough is an intracratonic Cretaceous basin about 1,000 kilometers in length and 50 to 100 kilometers wide in the NE-SW direction (Guidraud, *et al.*, 1989). The origin of Benue trough has been discussed extensively in the literature by different scholars who helped to form and define their stratigraphy.

The Benue Trough is a major tectonic feature in West Africa. It is an elongated rifted depression that trends NE-SW from the south, where it merges with the Niger Delta to the north (Okpoli, 2019). The following Formations make up the southern Benue Trough: Asu River group, Eze-Aku Formation and Agwu shale. There are numerous intrusive bodies injected into the shale of Eze-Aku and Asu-River Group due to the occurrence of magmatism in the area (Figure 1).

Sedimentation in the southern Benue Trough commenced with the marine Asu River group which represents the earliest classic fill of the southern Benue Trough and occupies the core of the basin (Oha, *et al.*, 2016). In addition, Akande described the Asu River Group as comprising of arkosic sand stones, volcanic, marine shales, siltstone limestone which overly the pre-Cambrian to lower Paleozoic crystalline basement rocks (Akande, *et al.*, 2011). Many authors have documented sequence of events that led to the formation of the Benue trough and among them are Benkhelil (1986, 1989); Burke, *et al.* (1970); Nwachukwu (1972); Offodile (1976); and Olade (1975).

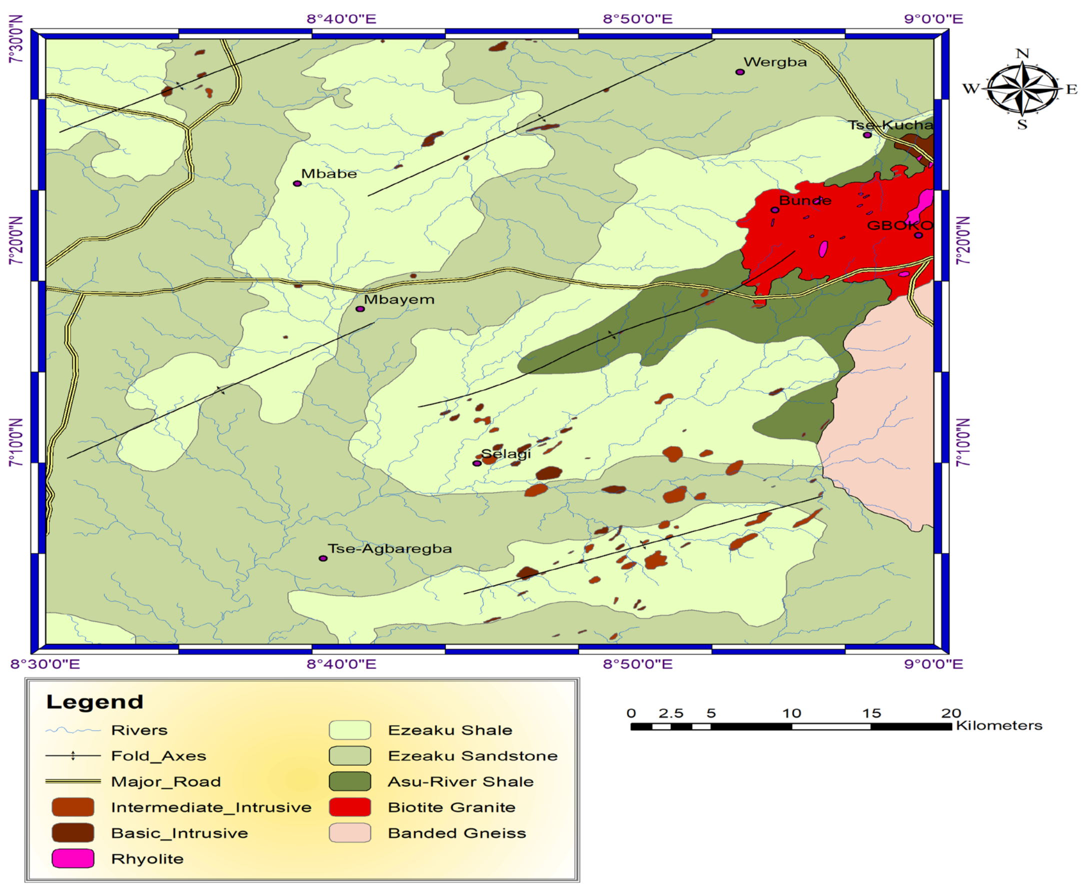

Figure 1: Geology of the Study Area.

MATERIALS AND METHODS

The total field map (TMI) of Gboko (sheet 271) was acquired from Nigerian Geological Survey Agency (NGSA) between the year 2007 and 2009. The data was flown at 500m line spacing and terrain clearance of 80 meters. The software used in processing and interpretation of the dataset is Geosoft Oasis Montaj Software version 6.4.2. The data was gridded using bi-directional method of gridding. The total magnetic intensity (TMI) grid was reduced and enhanced using different methods of filtering such as first and second vertical derivative, horizontal derivative, analytical signal (AS) to define the features that were not seen on the TMI map while for the quantitative interpretation, the Source Parameter Imaging (SPI) were used for depth-to-magnetic source imaging.

RESULTS AND DISCUSSION

<u>Residual Regional Separation</u>

A successful separation of magnetic reduction to equator grid (RTE) gave rise to residual and regional components in Figures 2 and 3.

Residual-Regional separation is needed because the primary targets of aeromagnetic survey are always shallow structures buried at shallow depths and their magnetic responses are embedded in regional field that arises from magnetic sources that are deeper (Yaoguo and Douglas, 1998).

The regional anomalies are also known as (Intra-basement) anomalies and it suggests a basement uplift in the east west direction and in the northeast and southwest directions. The residual fields is also known as supra-basement anomalies (Mekkawi, 1998). These supra-basement anomalies show shallow sources in the northwest and southeast portions.

The residual components in the map are high-frequency and short-wavelength spot-like magnetic anomalies (Abdou, *et al.*, 2012), these kinds are referred to as local anomalous by Ugwu, *et al.* (2017). The regional map is characterized by the dominance of positive and negative magnetic anomalies in the central and southern parts and is characterized by low frequency anomaly source related to deep seated bodies (Figure 2).

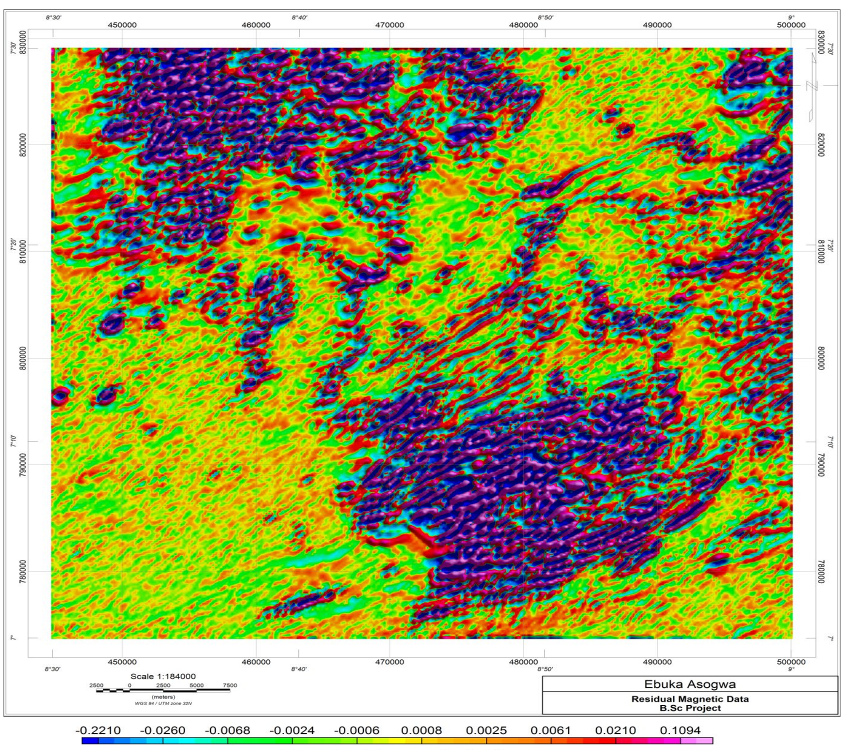

Figure 2: Residual Anomaly Map.

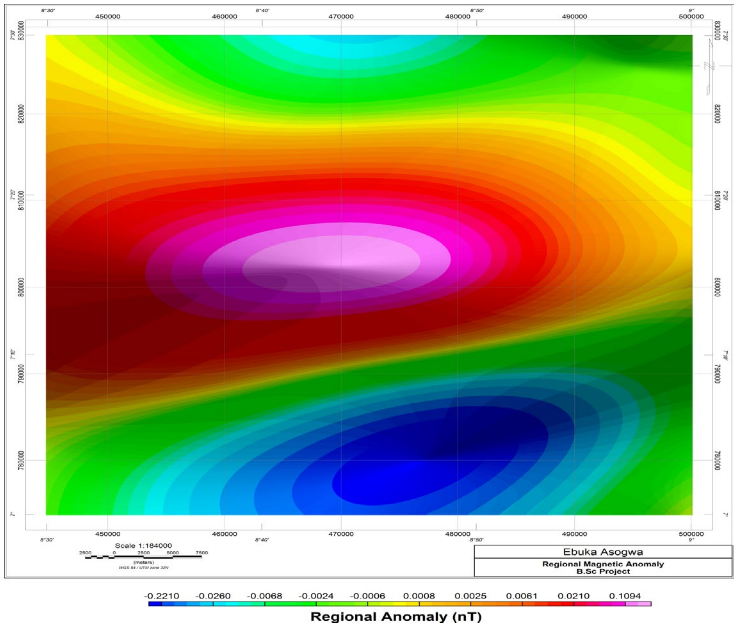

Figure 3: Regional Anomaly Map.

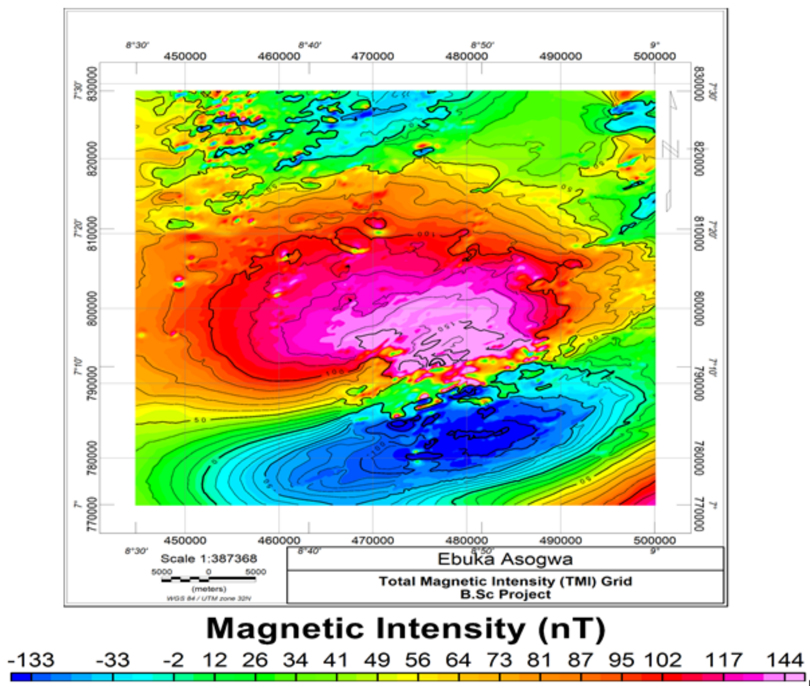

Figure 4: Total Magnetic Intensity.

The maximum intensity values with pink color at the central area have relatively high magnetic intensity (Figure 4). Also, at the southern edge of the area, there exist low residual points with deep blue color which are non-magnetic rocks.

The magnetic intensities of the study area ranged from -133nT to 144nT. Sedimentary rocks generally have very weak magnetic susceptibility compared to basement rocks.

Therefore, high magnetic intensity values are caused probably by near surface igneous and crystalline basement rocks while the low amplitudes are most likely due to sedimentary rocks or altered basement rocks.

The deep sedimentary basin anomaly has an elongated shape, low gradient, high relief, and negative polarities (Saleh, 2012). The lowest and highest magnetic intensities of this grid are -683.0nT and 341.2nT, respectively.

Reduction to Equator (RTE)

Reduction- to- equator was done to account for the wide range of magnetic inclinations and declinations across Nigeria. Reduction to equator is usually used to center the peaks of magnetic anomalies over their causative source facilitating the interpretation of geological features.

Reducing to the equator of the TMI map gives rise to negative and positive anomalies in the central and southern parts (Figure 5). The central part of the area is characterized by intense positive magnetic anomalies with several peaks which reflect high magnetic susceptibility. These anomalies may be attributed to the occurrence of near surface basic intrusions of high magnetic content at the area (Abdou, *et al.*, 2012). The magmatic/igneous intruded into the Eze-aku formation at Gboko axis (Nwosu, *et al.*, 2015).

The First Vertical Derivative

The First Vertical Derivative (FVD) tells us the rate of change of the anomaly with elevation or the variation of the anomaly with height. FVD enhances the shallow magnetic anomalies; it also suppresses the deeper ones and gives a better resolution of closely spaced sources as shown in Figure 6.

Vertical Derivative Equation:

L(r) = r^n

Where n is the order of differentiation, r is the wave number. Note r = 2πk where k is cycles used in the grid (in meter, feet etc.).The result from the first derivative in (Figure 6) shows more structures with short wavelength and are of high frequency in occurrence. The south-eastern, north-western, and north-eastern regions of the study area show magnetic lineation features.

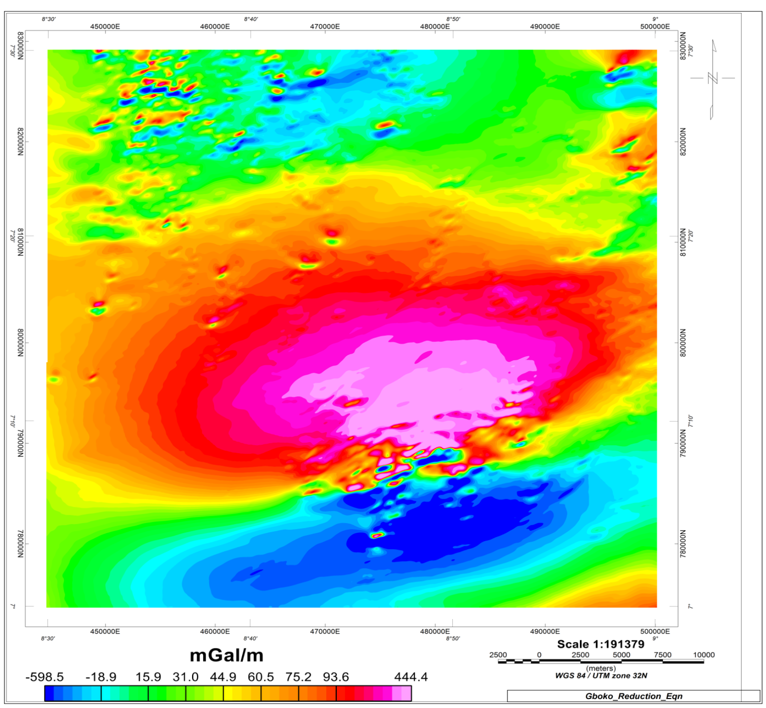

Figure 5: Reduction to Equator (RTE) Map.

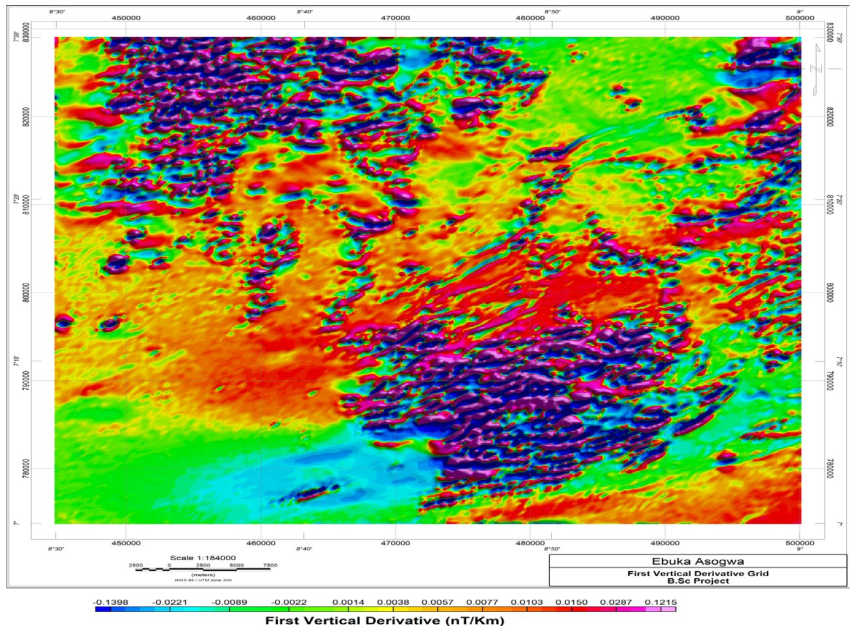

Figure 6: First Vertical Derivative Map.

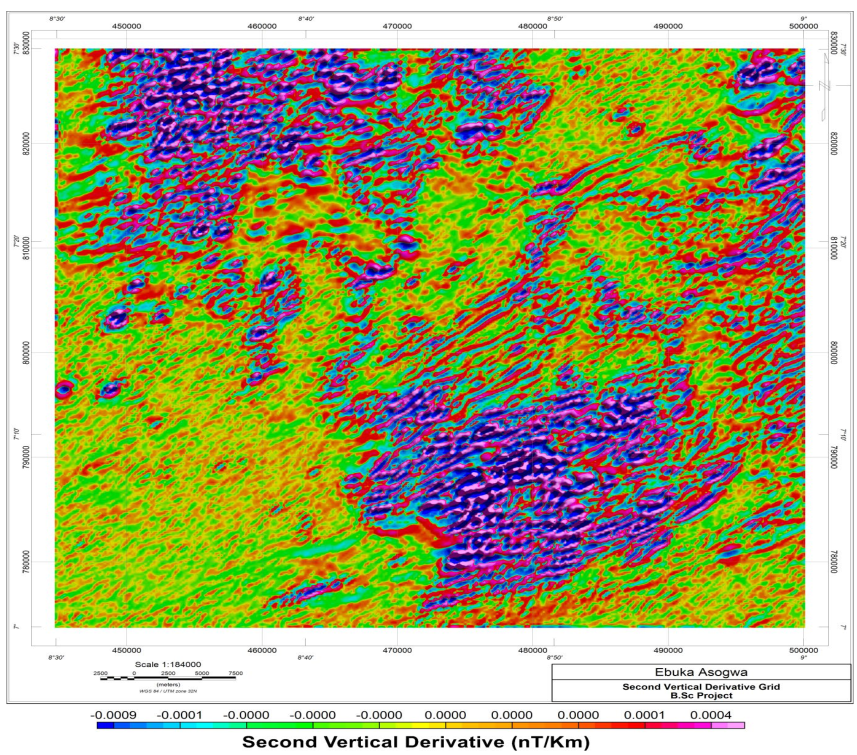

Figure 7: Second Vertical Derivative Map.

The Second Vertical Derivative

This is the rate of change of gradient with depth. The second vertical derivative is also known as the curvature of the total field anomaly. The second, third and higher derivatives may be computed to pursue the effect of the first derivative further, but it is associated with noise. This derivative sharpened the edges of the anomalous bodies or the boundary between the anomalies and offers a simple routine method of locating shallow structures (Mekkwasi, 1998).

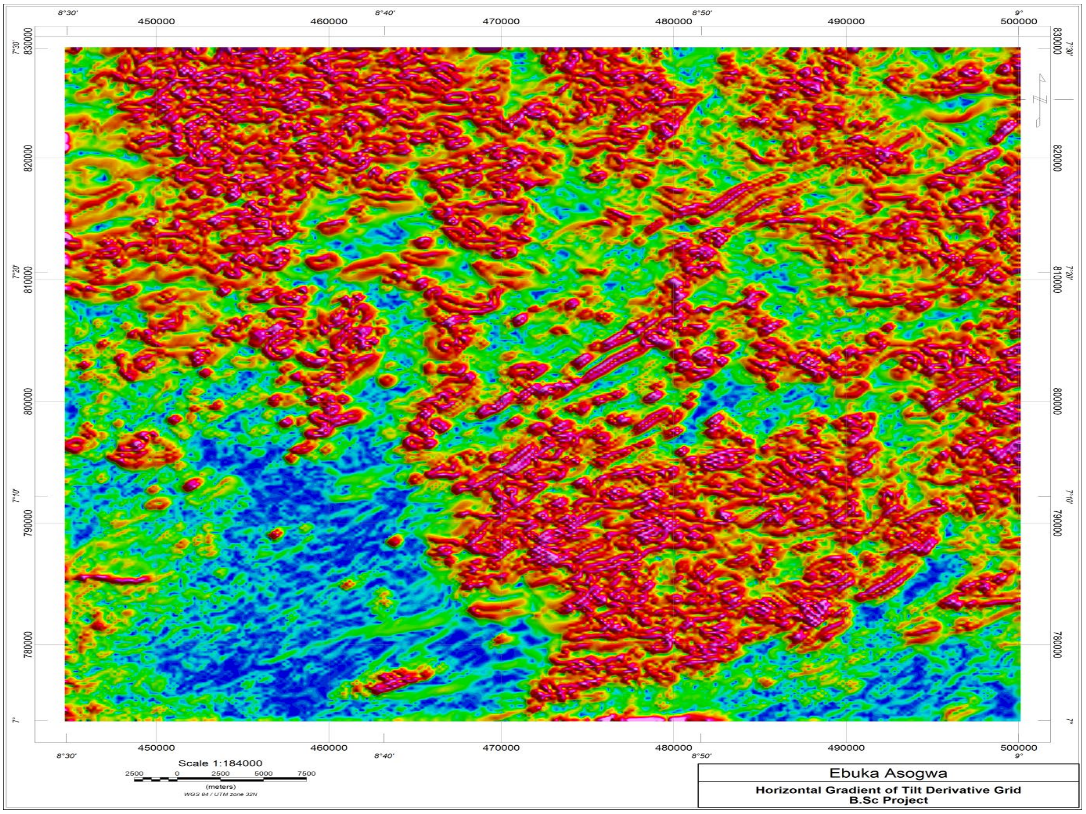

Figure 8: Horizontal Derivative Map.

Horizontal Derivatives

The horizontal gradient method measures the rate of change in magnetic susceptibility in the x and y directions and produces a resultant grid. Many modern methods for edge detection and depth to source estimation rely on horizontal and vertical derivatives.

The result from the horizontal derivative has shown that at north-west, north-east, and south-east regions, there are abundance of short wavelength signatures (Figure 8).

The Analytical Signal

Analytical signal filters can also serve as reduction to the pole, as they are subject to the instabilities that occur in transformations from low latitudes (Marcotte, *et al.*, 2005). So, this filter provides a means to analyzing low latitude magnetic fields without the concerns of the reduction to pole/equator operators (Rajagoplan, 2003).

The analytical signal of the residual map present magnetic anomaly information stripped of the dependence on the inclination of the earth inducing field so that anomalies are positive and sit directly above their sources (Nabighian, 1972; Roest, *et al.*, 1992). It is also a technique used to resolve the amplitude of the magnetic anomalies due to two dimensional structures.

The analytical signal amplitudes also revealed depth to the edges of the lithological units. Regions with high amplitude represent intrusive rocks cropping at shallow depths, while the low amplitude region represents the deep depth region (Figure 9). These intrusions are associated with ore mineralization in the area including the lead-zinc (Pb/Zn) mineralization.

Maximum amplitude in the sedimentary basins occurs in areas that have most likely experienced igneous intrusions. Nabighian, 1972, 1974 developed the notion of 2D analytical signal.

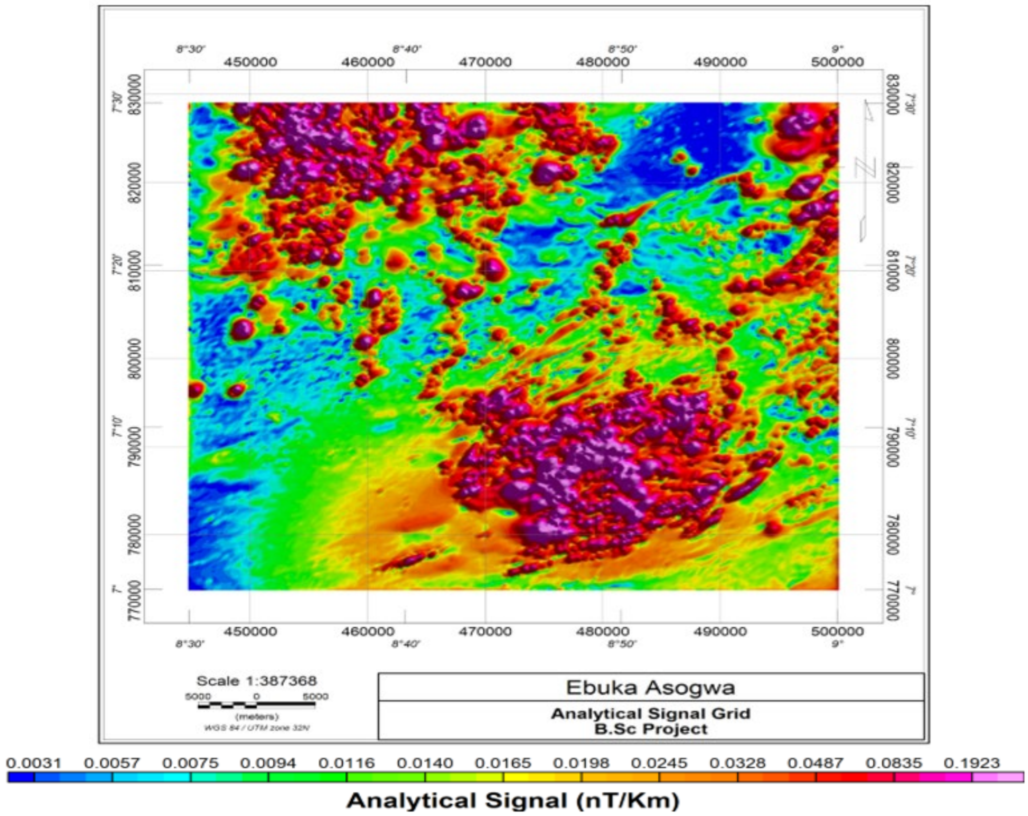

Figure 9: Analytical Signal Map.

The Analytical signal, for a 2-D contact located at x = 0 and at depth h, is described by the expression after (Nabighian, 1972):

$$|A(x)| = \alpha \frac{1}{\left(h^2 + x^2\right)^{\frac{1}{2}}}$$

Where $A(x) =$ Analytical Signal

α = amplitude factor

$$\alpha = \left(2M \sin d\left(1 - \cos^2(1)\sin^2(A)\right)\right)$$

For a constant, taking the second derivative of equation above with respect to x produces the following (Macleod et al. 1993).

$$\frac{d^2|A(x)|}{dx^2} = \alpha \frac{2x^2 - h^2}{\left(h^2 + x^2\right)^{5/2}}$$

After rearranging the equation, we obtain:

$$X_1 = \sqrt{2h}$$

Where h = depth to the top of contact

X_1 = the width of the anomaly between inflection points. Roest et al. (1992) showed that the amplitude (absolute value) of the 2D analytical signal at location (X, Y) can be derived from 3 orthogonal gradients of the total magnetic field.

The analytical signal was calculated to extract the location of magnetic sources contacts or edge. The analytical signal showed discontinuities, some of which coincide with the geological boundaries at the area (Figure 9).

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

where M= anomalous magnetic field in horizontal and vertical directions. Analytical signal was useful in locating the edges of magnetic source bodies since the study area is on the low magnetic latitude where remanence and/or low magnetic complicate interpretation (Anad and Mita, 2006).

The amplitude of the anomalies in the study area ranges from 0.0031nT/m to 0.1923nT/m. The map reveals high amplitude on the northwest and southeast portions of the study area while the south-western and part of north-eastern portion are predominant with low amplitude anomalies. (Macleod, *et al.*, 1993).

The high amplitude anomaly accounts for high magnetic susceptibility while the low amplitude accounts for low magnetic susceptibility in the area. Thus, the analytical signal method demarcates the area into amplitude zones based on the magnetization contrast produced by varying mineralogy composition (Okpoli, 2019). The amplitude of the analytical signals centered on the peak of the magnetic sources (contact) regardless of the direction of magnetization.

Use of Source Parameter Imaging (SPI) in Estimating Magnetic Source Depth of Gboko Area

SPI is a modern automatic method of calculating the depth to potential field sources using the relationship between source depth and the local wavenumber (k) of the analytic signal of the observed field and is based on Thurston and Smith (1997) method. The local wavenumber equation is as follows:

$$\kappa = \frac{h}{h^2 + x^2}$$

where h is the depth to the top of the contact and κ is the local wavenumber. $x = 0$, directly over the edges and at this peak locations, local depth is calculated using this equation:

$$h = \frac{1}{\kappa}.$$

Maxima of the local wavenumber are independent of the magnetization direction (Thurston and Smith, 1997). The Source Parameter Imaging (SPI) function is a quick, easy and powerful method for calculating the depth of magnetic sources (Kamba and Ahmed, 2017). SPI is a complex analytical signal technique that uses the magnitude of the analytical signal and also the phase. SPI uses the local wave signal to calculate depth to magnetic rocks and it does not require moving window difficulty (Li, 2003). The depth to the magnetic by SPI calculated is shown in a grid in Figure 10.

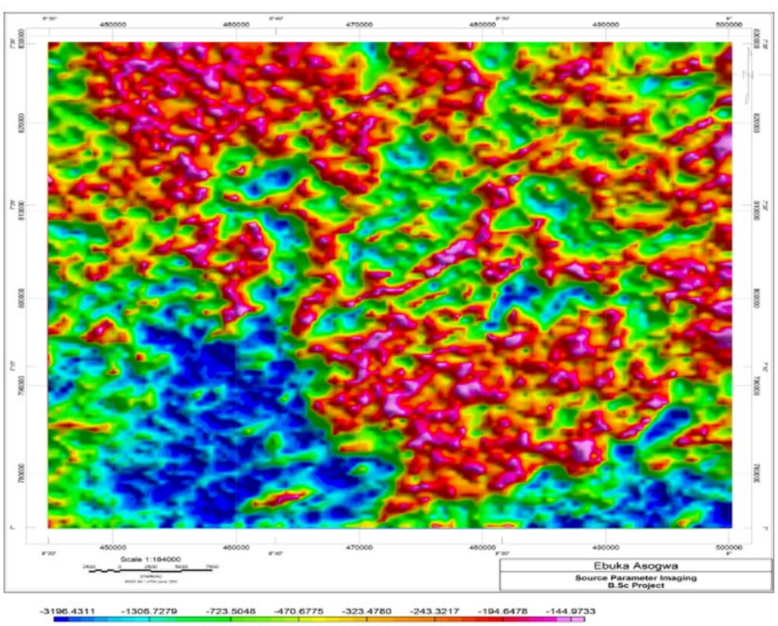

Figure 10: Source Parameter Imaging (SPI) map.

The readings from the legend indicate that the areas with green, pink, and red colors are areas of shallow magnetic bodies while the areas with blue color indicates areas of deep lying magnetic bodies or thicker sediments (Eze, *et al.*, 2017).

The shallow bodies could be magnetic intrusion within the sediment in the area. These shallow magnetic source bodies can be found at the north-western (NW), south-eastern (SE), and north-eastern (NE) parts of the study area while the deep magnetic bodies are found at south-western edge of the study area. South-western (SW) region shows high depth to basement rocks because of the deeper source bodies in the area which is represented by light blue to deep blue color. The generated SPI grid image and SPI legend has a minimum depth of 144.9733 m and a maximum depth of 3196.4311m. If all conditions for hydrocarbon generation are met, basement depth of 3196.4311m would be favorable for the commencement of hydrocarbon formation from marine organic remain (Wright, 1985; Nwosu, *et al.*, 2015).

The work of Oha, *et al.* (2016), Nwosu, *et al.* (2015) and Ozebo and Nwodo (2017) who worked in the same basin fairly agree with our work. The maximum depth to basement value for SPI is 4.85km (Oha, *et al.*, 2016). The area with maximum depth is possibly the magnetic basement depth while the areas with minimum depth are possibly the magnetic/igneous intrusions intruded into the sedimentary basin in the area. The intrusion is responsible for the lead-zinc mineralization in the area.

This method basically assumed that the inverse depth is defined by the peaks of the local wave number. The SPI therefore assumes a step-type source model. For this model the following formula holds:

$$Depth = \frac{1}{K_{MAX}} = \frac{1}{\left(\sqrt{\left(\partial Tilt/\partial x\right)^2 + \left(\partial Tilt/\partial y\right)^2}\right)_{MAX}}$$

$$Tilt = \arctan\left(\frac{\partial T/\partial Z}{\left(\partial T/\partial x\right)^2 + \left(\partial T/\partial Y\right)^2}\right) = \arctan\left(\frac{\partial T/\partial z}{HGRAD}\right)$$

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 is the horizontal derivative in the x-direction

∂y is the horizontal derivative in the y-direction

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

Trend Analysis Technique

The composite rose plot is a diagram that shows the circular distribution of directional data (Figure 10). Horizontal derivative derived lineaments map are shown in Figure 8 with its corresponding rose diagram in Figure 11. The result of Figures 10 and 11 show that the lineament directions were oriented along E-W, NW-SE, ENE-WSW, NNE-SSW, and NNW-SSE with three prominent structural trends, NE-SW, E-W, and NW-SE as the major trends.

The NNE–SSW, and NE–SW bodies are the continental extensions of the pre-Cretaceous Chain and Charcot fracture zones oriented parallel to the axis of the basin. These orientations and positions are congruent with the common tectonic features of Benue trough in the region. The lineaments are representative of subsurface faults, contacts, and tectonic structures (Eldosouky, *et al.*, 2022).

The epirogenesis of these lineaments has been associated with the stress regime associated with the pre-pan African and Pan African tectonic events (Anudu, *et al.*, 2014). This gives further evidence of the extent of deformation that occurred within the belt during the Pan African Orogeny. The lineaments trend predominantly in the NE-SW with subordinate E-W trend and this is an attribute of the Pan-African Orogeny (Nwosu, *et al.*, 2015). Abundance of trended anomaly variations along the study area clearly identifies that the area is influenced by many tectonic regimes.

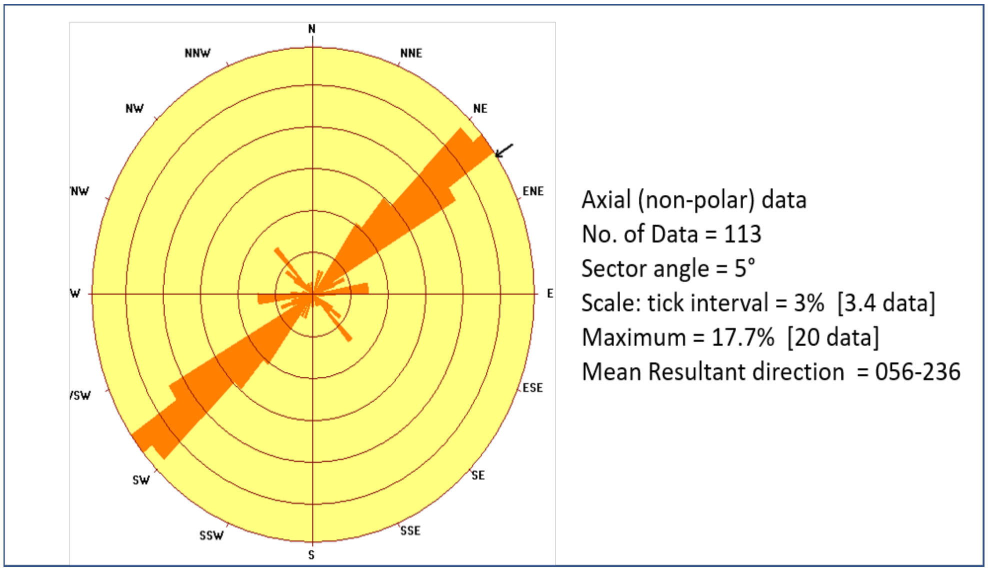

Figure 11: Rose Plot for the Lineament Maps.

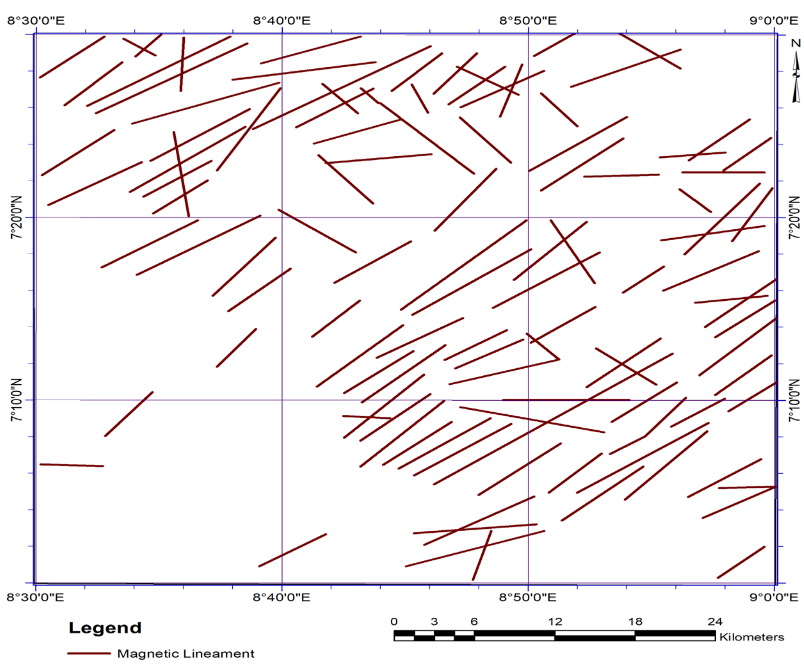

Figure 12: Magnetic Lineament Map.

CONCLUSION

The aeromagnetic data over Gboko area and environs has been processed and interpreted qualitatively and quantitatively using vertical derivatives, horizontal derivative, analytical signal, regional-residual separation, and source parameter imaging techniques. From the result of source parameter imaging, statistics show a minimum depth of 144.9733m for shallower source and a maximum depth of 3196.4311m for deeper source.

This study reveals that the area has been affected mainly by three significant tectonic trends, namely: NE-SW, NW-SE, and E-W. The result from the analytical signal shows that the amplitude ranging from 0.0031nT/Km to 0.1923nT/Km represents the susceptibility contrast of magnetic rocks.

The rate of change in magnetic susceptibility in the X and Y directions has been calculated using horizontal derivative. The first vertical derivative delineated the shallow magnetic sources, and the second vertical derivative further pursues this effect. The analytical signal method demarcates the area into amplitude zones based on the magnetization contrast produced by varying mineralogical composition.

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