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Structural Analysis and Interpretation of High Resolution Aeromagnetic data over the Southern Bida basin, North Central, Nigeria

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Abstract:

This study focuses on the analysis and interpretation of high resolution aeromagnetic data over the southern part of Bida basin. The study covers an area of 24,200 km^2 located between latitude 8^0 30′N and 9^0 30′N and longitudes 5^0 00′E and 7^0 00′E. Aeromagnetic data in grid format containing eight sheets in 1/2^o by 1/2^o (55 x 55 km) were analyzed and interpreted. This study employed several magnetic filtering methods to investigate lineaments and other structural features. The filtering methods used are: reduction to the magnetic equator, horizontal derivatives, vertical derivatives, analytical signal, and Centre for exploration targeting grid analysis. The reduced to magnetic equator shows variation in magnetic signatures ranging from-58.65nT-131.44nT. The results from first vertical derivative, second vertical derivative, horizontal derivatives and center for exploration targeting maps reveal that the major structures delineated, trend in NE –SW and NW-SE direction. Since minerals are structurally controlled, these structures delineated might host the economic mineralsin the study area. The second vertical derivative shows a major fault line cutting the area into two parts which is an extension of the Romanche fault. The CET grid analysis map reveals the geologic boundaries and fault lines within the basement rock.

Keywords: Aeromagnetic data, Analytical signal, center for Exploration Targeting, magnetic gradient.

Introduction

The study of the earth's magnetism is the oldest branch of geophysics. It has been known for more than three centuries that the earth behaves as a large and somewhat irregular magnet(Telford, et al., 1990). The aim of a magnetic survey is to investigate subsurface Geology on the basis of anomalies in the Earth's magnetic field resulting from the magnetic properties of the underlying rocks. Magnetic surveys can be performed on land, at sea and in the air. Consequently, the technique is widely employed, and the speed of operation of airborne surveys makes the method very attractive in the search for ore deposits that contain magnetic minerals.

Magnetic prospecting is used to explore for oil, minerals, and even archaeological artefacts. In prospecting for oil, it gives information from which one can determine the depth to basement rocks and thus locate and define the extent of sedimentary basins. Aeromagnetic surveys have traditionally been applied at the early stage of petroleum exploration to determine depth and major structure crystalline basement rocks underlying sedimentary basins. The methodology for acquiring and compiling data appears to be keeping pace with modern technology so that presently the magnetic method is by far the most widely used of all geophysical methods; both in terms of line-kilometres surveyed annually and in total line-kilometer(Peterson & Reeves, 1985). Thus compared to other geophysical methods, the aeromagnetic data are always readily available and so it is important to explore the potentialities of these data.

This work focuses on the analysis and interpretation of the aeromagnetic data over some parts of Bida Basin, central Nigeria. The outcome of the analysis is expected to throw more light on the structures (lineaments) within the study area which might host some potential minerals in the study area.

Location and Extent of the Study Area

The study area (Figure 1 and 2) is located between latitude 8^0 30’N to 9^0 30′N and longitudes 5^0 00′E to 7^0 00′E covering an area of 24,200 km^2, is a part of the entire Bida Basin otherwise known as the Mid-Niger Basin or the Nupe Basin. Eight aeromagnetic sheets cover the study area. It is a sedimentary basin extending from Kontagora in Niger State to areas slightly beyond Lokoja in the south.

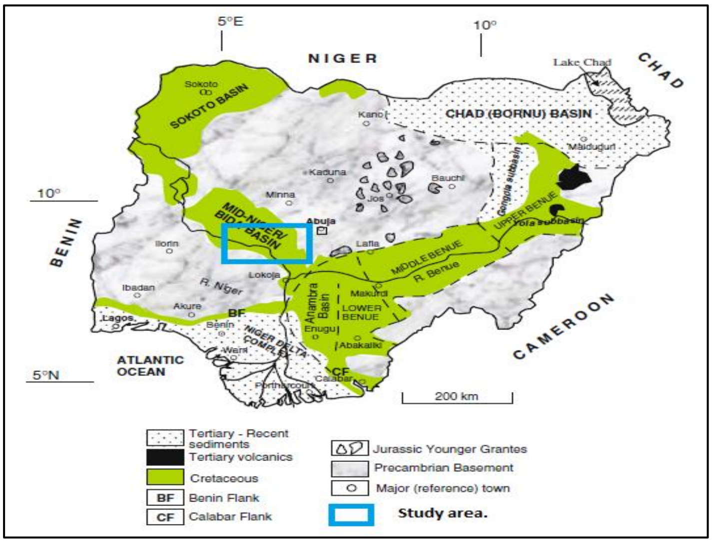

Figure 1: Geology and Location of the study area after Obaje, (2009).

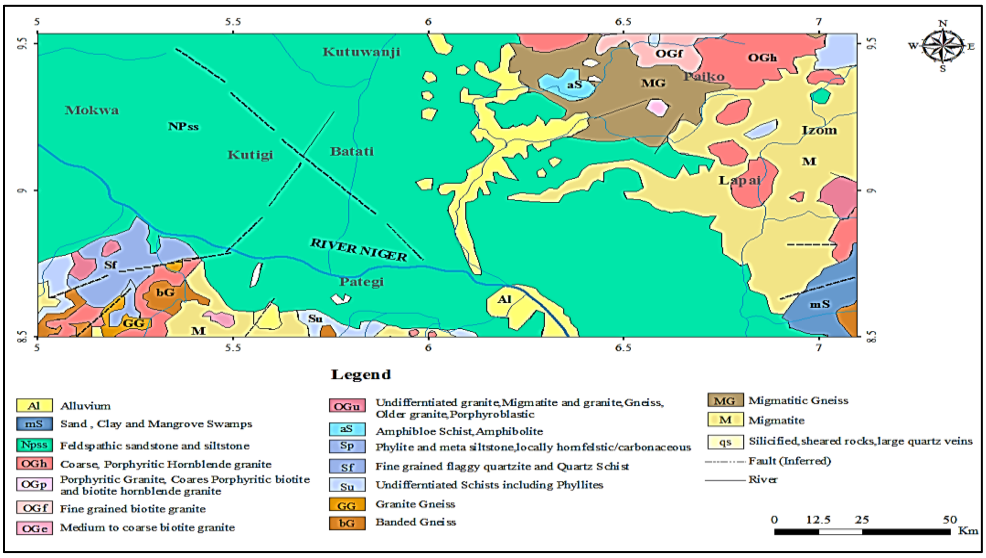

Figure 2: Geological Map of the study area

Geology of the Study Area

The Mid-Niger Basin otherwise known as the Bida Basin or the Nupe Basin is a NW–SE trending intracratonic sedimentary basin extending from Kontagora in Niger State of Nigeria to areas slightly beyond Lokoja in the south. It is delimited in the northeast and southwest by the basement complex while it merges with Anambra and Sokoto basins in sedimentary fill comprising post orogenic molasse facies and a few thin unfolded marine sediments (Obaje, 2009). The entire basin is bounded bylatitude 8^0 00′N to 10^0 30′N and longitudes 4^0 30′E to 7^0 30′E. It covers an area of about 90,760 km^2. The basin is a gentle down-warped shallow trough filled with Campanian-Maastrichtian marine to fluviatle strata believed to be more than 300 m thick(Bemsen, et al., 2013). The Basin might be regarded as north-western extension of Anambra basin, which is found in the southeast, both of which were major depocenters during the second major sedimentary cycle of southern Nigeria in the Upper Cretaceous time (Obaje, 2009).Although the hydrocarbon potential of the basin has not been fully tested with seismic data and the basin remains undrilled, both ground and aeromagnetic studies by several workers have outlined the basin's configuration(Udensi & Osazuwa, 2004). Often, experts working in the area have divided the basin geographically into northern and southern Bida basins probably due to rapid facies changes across the basins. The northern and southern Bida basins comprise of about 3 km thick Campanian to Maastrichtian continental to shallow marine sediments. The southern Bida Basin comprises of the basal Campanian Lokoja Formation (mainly conglomerate and sandstone), Maastrichtian Patti Formation (shale, claystone and sandstone) and the youngest Agbaja Formation (Ironstone). Their lateral stratigraphic equivalents in the northern Bida Basin consist of the basal Bida Formation (conglomerate, sandstone), Enagi Formation (siltstone, claystone and sandstone) and Batati Formation (Ironstone) (Ojo, et al., 2011).

Source of aeromagnetic data

The data for the analysis were obtained from the Nigerian Geological Survey Agency (NGSA) in digital/grid format. A high resolution Airborne Geophysical Survey involving magnetic, radiometric and limited electromagnetic surveys aimed at assisting and promoting mineral exploration were carried out in Nigeria between 2003 and 2009. The programme began with a pilot scheme in Ogun state in 2003. Following the success of the pilot scheme, the rest of the country was divided into project areas referred to as Phases I & II. Phase I covered 44% and Phase II covered 56% of the country. The surveys for these two phases were carried out from 2004 to 2009. Fugro Airborne Survey Limited, Johannesburg carried out the flying for data collection in all projects as well as for the interpretation of Ogun state and Phase I programmes. The interpretation of Phase II was carried out by Patterson Grant and West (PGW) consultants of Canada.

Technical details of the survey: Flight Parameters;

Total line kilometres: 36,500 km (Ogun state), 1,930,174 km (Phases I & II)

Flight line spacing: 500 metres

Terrain clearance: 100 m (Ogun state), 80 m (Phases I & II)

Flight direction: NW – SE

Tie lines spacing: 2 km

Tie lines direction: NE – SW

Measured Parameters: Magnetic gradient and Multi-channel radiometric

Materials and Method

The data for this interpretation which range in values from -1204.29 nT to 838.65 nT which are mostly of residual origin were subjected to:

1. Regional residual separation using polynomial fitting method to establish the regional trend within the field
2. Reduction to the equator to observe if there is any shift in anomaly position as a result of removal of data dependence on the angle of inclination.
3. Horizontal derivatives $\Delta x, \Delta y, \Delta z$ to observe the relative changes in the direction of major anomaly trending and as an input value for other analysis.
4. First and second Vertical Derivatives to delineate the major structures and lineament in the study area
5. Analytical Signal helped in delineating the area into regions of outcrop, intermediate structures and basement under the influence of thick sedimentation.
6. Centre for Exploration Targeting (CET) grid analysis to establish the structural features within the study area.

Theory of method

Vertical Derivative Filters

The vertical derivative is commonly applied to total magnetic field data to enhance the most shallow geological source and can be calculated either in space or frequency domain. The enhancement sharpens anomalies over bodies and tends to reduce anomaly complexity, allowing a clearer imaging of a causing structure. The transformation can be noisy since it will amplify short wavelength noise.

First vertical derivative data have become almost a basic necessity in magnetic interpretation projects. The second vertical derivatives has more resolving power than the first vertical derivatives (Milligan & Gunn, 1997). Derivatives quantify the spatial rate of change of magnetic field in vertical and horizontal directions. The expression for the magnetic F(r) is obtained from coulomb's law for magnetic poles m_1 and m_2 separated by a distance r as

$$\vec{F}(r) = \frac{m_1 m_2}{\mu r^3}\vec{r} \qquad (1)$$

The pole are somewhat of fiction, since they cannot exist isolated, but only in pairs: if we assume two very long bar magnets with two poles close together and the other two far apart, the situation is fulfilled in practice. The value μ is the permeability of the medium surrounding the magnetics field strength $\vec{H}(r)$ is expressed as

$$\vec{F}(r) = (\frac{m}{\mu r^3})\vec{r} \qquad (2)$$

And the magnetic induction $\vec{B}(r) = \mu\vec{H}(r), the\ magnetic\ field\ \vec{B}(r)$ can be derived from a scalar potential function $A(r)$ as

$$\vec{B}(r) = -\vec{\nabla}A(r) \qquad (3)$$

This potential may be defined as the work done in moving a unit pole against the magnetic field as

$$A(r) = -\int_{\infty}^{r}\vec{B}(r).\overrightarrow{dr} = m/\mu r \qquad (4)$$

Though a single magnetic pole is a pure fiction, the scalar potential is somewhat complex, more details can be found from (Telford, et al., 1990).

The first and the second vertical component of the field $\vec{B}$ are the derivatives of the potential in the direction of the vertical axis. They are respectively

$$\frac{\partial B}{\partial z} = -\frac{\partial^2 A}{\partial z^2} \quad and \quad \frac{\partial^2 B}{\partial z^2} = -\frac{\partial^3 A}{\partial z^3} \qquad (5)$$

Note that the magnetic potential A, like gravity potential satisfies the Laplace's equation:

$\nabla^2 A = 0$, for a homogeneous region outside the volume v of the magnetic body. Similarly the magnetic potential everywhere within a region containing magnetic material satisfies the Poisson equation.

$$\nabla^2 A = 4\pi\nabla \ . \vec{M}(r) \qquad (6)$$

Where the magnetic body is a continuous distribution of dipoles resulting in a vector dipole moment per unit volume, $\vec{M}(r)$

Many modern methods for edge detection and depth-to-source estimation rely on horizontal and vertical derivatives (Nabighian, et al., 2005). Derivatives essentially enhance high frequency anomalies relative to low frequency anomalies.

Analytical Signal

Analytical signal is the square root of the sum of squares of the derivatives in x, y and z directions:

$$Asig = sqrt(dx * dx + dy * dy + dz * dz) \qquad (7)$$

While this function is not a measurable parameter, it is extremely interesting in the context of interpretation, as it is completely independent of the direction of magnetisation and the direction of the field. This means that all bodies with the same geometry have the same analytical signal(Milligan & Gunn, 1997). The analytical signal, although often more discontinuous than the simple horizontal gradient, has the property that it generates a maximum directly over discrete as well as their edges. The analytical signal is useful in locating the edges of magnetic source bodies, particularly where remanence and/or low magnetic latitude complicate interpretation.

The Centre for Exploration Targeting (CET)

Stating with **Standard deviation,** which provides an estimate of the local variation in the data. At each location in the grid, it calculates the standard deviation of the data values within the local neighbourhood. Features of significance often exhibit high variability with respect to the background signal. For a window containing N cells, whose mean value is μ, the standard deviation σ of the cell values x_i is given by:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(x_i - \mu\right)^2} \qquad (8)$$

When interpreting the output, values which approach zero indicate very little variation, whereas large values indicate high variation (Kovesi, 1991). The next stage is to apply **Phase Symmetry;** this property is useful in detecting line-like features through identifying axes of symmetry. It is also known that the symmetry of a signal is closely related to the periodicity of its spatial frequency. Consequently, it is natural to utilize a frequency-based approach to detect axes of symmetry. In the one-dimensional case (1D), a point of symmetry in the spatial domain corresponds with a point where local frequency components are at either a minimum or a maximum. To identify points of symmetry in two-dimensional (2D) data we first break the data into 1D profile and analyze these over multiple orientations at varying scales. For example, a line-like feature will produce strong symmetry responses from the 1D profiles sampled from all orientations except for those parallel to the line.

The result from phase symmetry is passed through **Amplitude Thresholding,** in conjunction with non-maximal suppression (NMS). The NMS is useful for finding ridges since low values are suppressed whilst points of local maxima are preserved, it also takes into account the local feature orientation so that the continuity of features is maximized and can be used to remove noise and highlight linear features. A description of the NMS algorithm is given below. For each cell in the grid, it examines the values at a distance, *r*, in the directions perpendicular to the local feature orientation - the local feature orientation is typically the direction in which a ridge or valley is running. If the cell has a value greater than those on either side of it, the cell is kept since it is a local maximum; otherwise it is set to zero. The Amplitude Thresholding plug-in applies the above algorithm followed by a thresholding step. Thresholding marks cells in grid as either 'foreground' or 'background' cells depending on whether the cell value is greater or less than a specified threshold value respectively. Thus, thresholding will reduce a grid to a binary grid of only two distinct cells values: 1 for regions of interest and a dummy value for background. In this suite of tools, Amplitude Thresholding is useful for reducing phase symmetry or phase congruency output to a grid depicting only trend lines(Kovesi, 1997).

Finally, **Skeleton to Vectors** is applied. The Skeleton to Vectors plug-in is for vectorising the skeletonised structures from the skeletonisation plug-in via a line fitting method described below. This vectorised data can then be used as input to the structural complexity map plug-ins. For each structure in the grid, a line is formed between its start and end points. If the structure deviates from this line by more than a specified tolerance the structure is divided into two at the point of maximum deviation and the line fitting process is repeated on these two new structure segments. This process is continued recursively until no structure segment deviates from its corresponding line segment by more than the specified tolerance. These line segments form the vectorised representation of the structures within the grid(Kovesi, 1991).

Results and Discussion

Total magnetic Intensity (TMI) map

The total aeromagnetic field map of the study area (southern part of Bida basin), Nigeria after IGRF removal of 33,000 nT is displayed in (Figure 3). The map is produced in a colour aggregate, with pink to red colour depicting positive anomalies while green to blue depicts negative anomalies. The Total Magnetic Intensity map of the study area exhibits both positive and negative anomalies ranging from 31,796 nT to 33,839 nT. The southwestern and the Northeastern part of the study area are predominantly of high magnetic signature which corresponds to crystalline rocks (Migmatitic gneiss (MG), Granite gneiss, and Migmatite) while from the central portion to the Northwestern part of the study area is dominated by negative (low) magnetic anomalies which also corresponds to sedimentary rocks (Alluvium deposition, Sandstone, Siltstone)

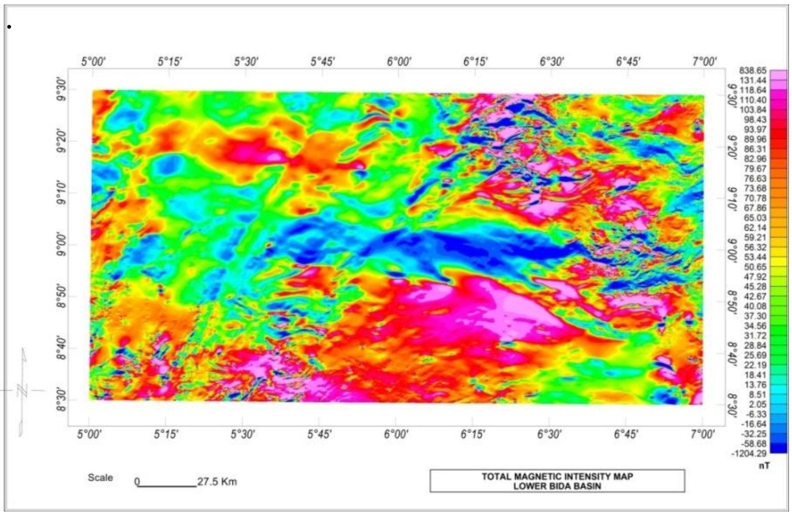

Figure 3: IGRF filtered Total Magnetic Intensity Map of the study area. (Actual values are obtained by adding 33,000 nT to the values shown in the key)

Results of Vertical Derivative Filters

The first vertical derivative filter enhances shallow geologic sources like structural lineaments and igneous intrusions that could be associated with mineralization systems in the area. The filter has aided in revealing near surface magnetic lineaments that trends NE-SW and NW - SE. The first vertical derivative (Fig. 4a) consists of basement and sedimentary region; the basement takes up the Southwestern and the Northeastern part of the study area. While the sedimentary region occupies the northwestern to the central part of the study area. This map agrees with Figure 2.

The entire area can be demarcated into basement and sedimentary regions as mapped in Figure 4b, the basement rocks around north-eastern and south-western corners can clearly be seen while the sedimentary parts are purely sedimentary regions. Figure 4b finds good correlation with the geological map of the study area (Figure 2), other fractured zones marked as F-F's, some coinciding with linearly high susceptibility features which can be identified as veins of mineralization. Most of these fractures and linear magnetic highs are trending in the NW-SE direction, same as regional fields.

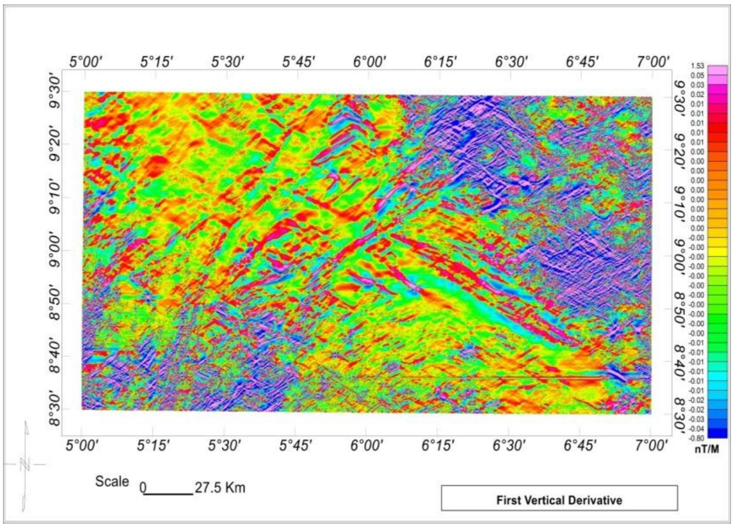

Figure 4a: First vertical Derivative (1VD) Map of the Study area.

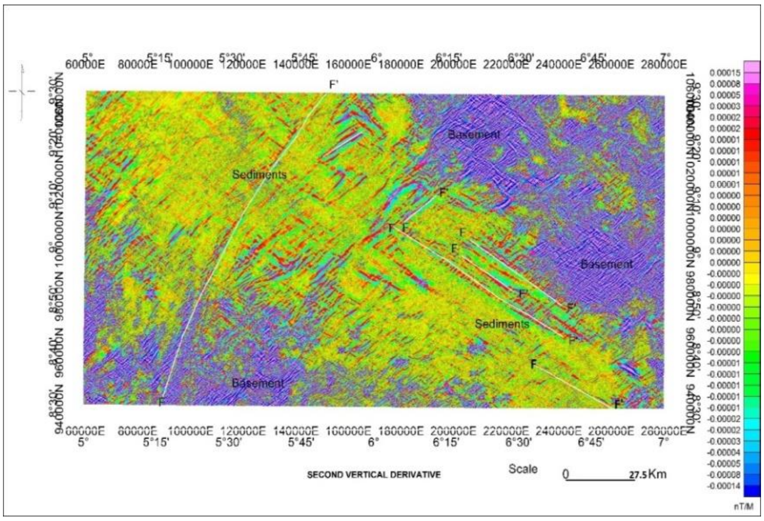

Figure 4b: Second Vertical Derivative (2VD) Map of the Study area showing Magnetic Lineaments.

Results of Analytical Signal

In using the analytical signal techniques, the Horizontal derivatives in x, y and z directions were computed and used as input grids. Analytical signal filter simplifies the magnetic signatures for easier interpretation. Analytical map helps in delineating the area into regions of outcrop, intermediate structures and basement under the influence of thick sedimentation. Two major regions can easily be observed (Figure 5); regions whose amplitude responses range from 0.07 to 0.28 which are predominantly basement outcrops with varying degree of deformations and regions whose amplitude ranges from zero (0) to 0.052, which depicts regions with relatively good sedimentation. Isolated intrusive bodies can also be identified whose amplitude varies between 0.066 and 0.1.

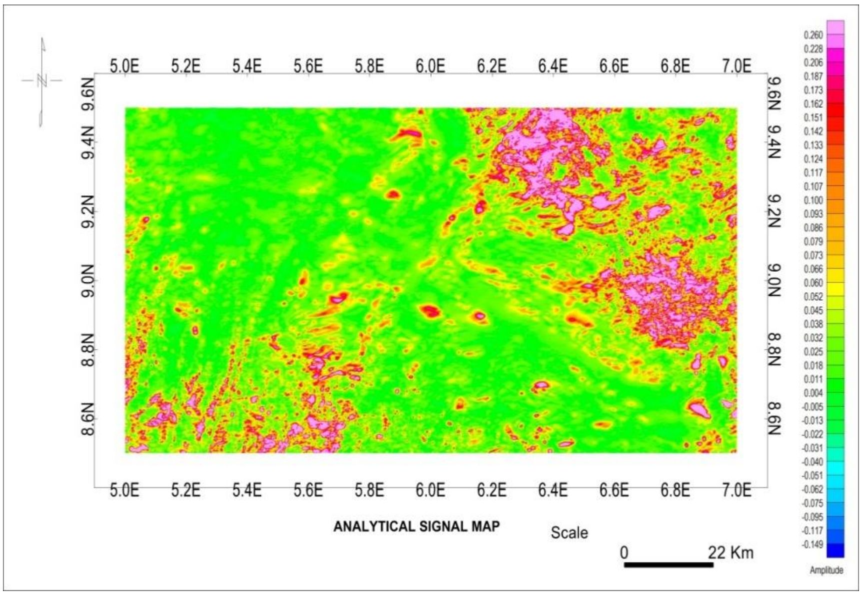

Figure 5: Analytical Signal map of the Study Area.

Centre for Exploration Targeting (CET) Grid Analysis

A set of mathematical modules starting from standard deviation was applied to a sample window size within the dataset. The maximum values of the magnetic susceptibility were picked within the data. These set of maximum were vectorised and trended. Data of maximum value that trend in a particular direction were then lineated, suppressing values of lower susceptibility within the same window. A set of two maps were obtained from this analysis. The first map demarcates the geologic boundary within the basement rock as thick bands and also illustrates basement features; regions of outcrop intrusive bodies into the basement and sedimentary formation (Fig. 6a). The second map (Fig. 6b) reveals fault lines within the basement rocks, these fault lines at the basement are shown as thin fault linear structures and actually have no reference on the shallow features. These fractures on the basement are generally trending in the NE-SW, E-W, NW-SE and N-S directions which agrees with Fig. 3 and Fig. 4. The NE-SW trending indicates the direction of shear force during the separation of American plates from African plate.

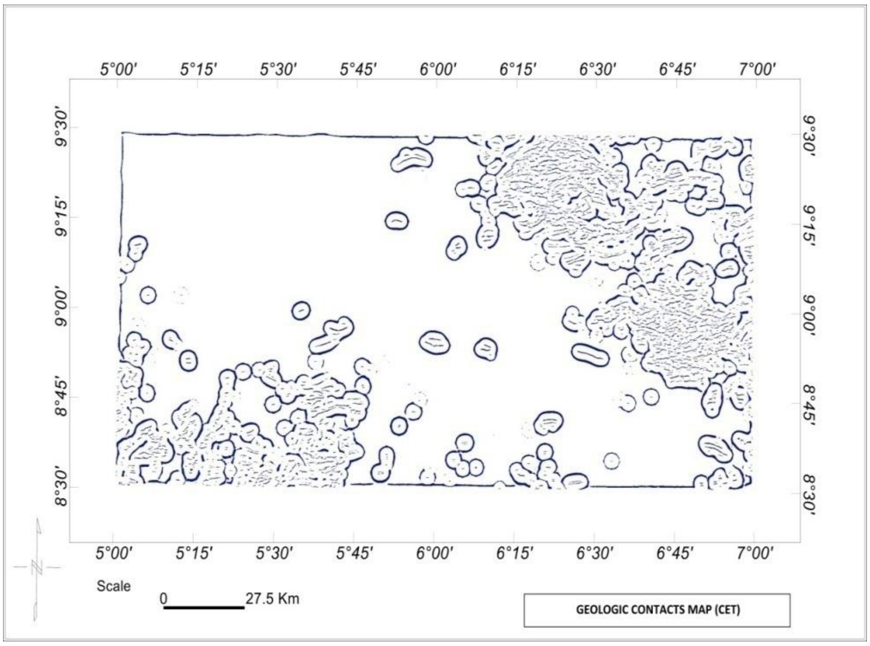

Figure 6a: Geologic Contacts Map (CET)

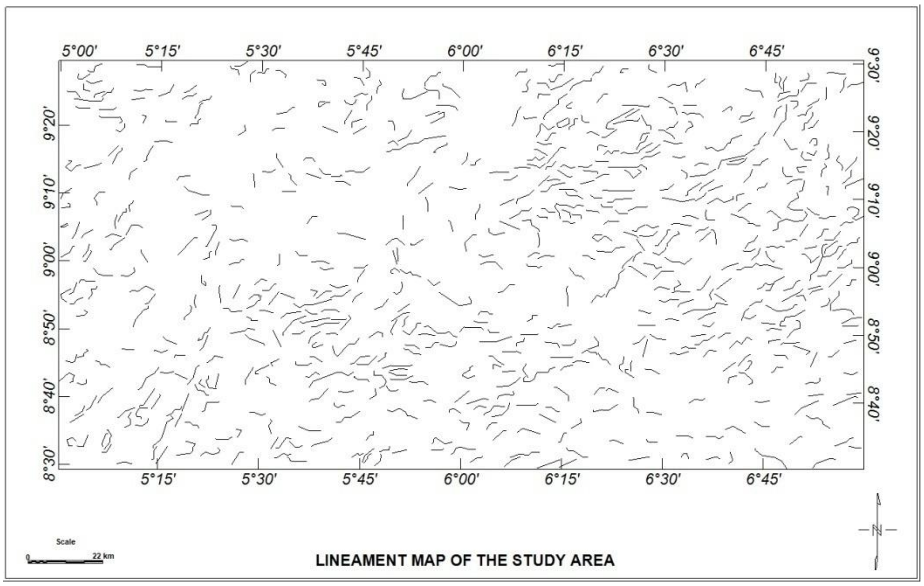

Figure 6b: Lineament Map (CET)

Conclusion

A qualitative interpretation of the total magnetic intensity map over the southern part of the Bida basin reveals that the lower part of the area is predominantly of positive anomaly while the middle portion is dominated by negative (low) magnetic anomalies. The North-eastern corner down to the eastern flank is dominated by mixtures of both high and low short wavelength closures which are high in frequency of occurrence made up of crystalline rocks. The regional fields of the study area have a trend of NW-SE which is attributed to long period of marked thermo-tectonic subsidence within the pan African rifts of cretaceous basement rocks.

The first and second derivative map reveals a major fault line cutting the study area into two and other fractured zones. Most of these fractures are trending in the NW-SE and NE-SW direction, same as regional fields. Analytical signal delineates the area two major regions: regions whose amplitude responses range from 0.07 to 0.28 which are predominantly basement outcrops with varying degree of deformations and regions whose amplitude ranges from zero (0) to 0.052 which depicts regions with relatively good sedimentation. The Centre for Exploration Targeting (CET) grid analysis maps show how the geologic boundary is demarcated and the fault lines within the basement rock.

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