



Delineation of Magnetic Lineaments within some parts of Nigeria's Bida Basin using Aeromagnetic Data

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ABSTRACT

Aeromagnetic data over some parts of Bida Basin, Nigeria was acquired from the Geological Survey Agency of Nigeria and interpreted, using Oasis Montaj software, with the aim of delineating magnetic lineaments in the area. The study area is situated within latitude 8⁰⁰'N - 10⁰⁰'N and longitude 4³⁰'E - 7⁰⁰'E and covered by 10 aeromagnetic data sheets which were digitized and assembled to produce a combined aeromagnetic data file for the area. The data was reduced to pole and then subjected to vertical, horizontal and generalised derivatives as well as CET grid analysis. The result of first vertical derivative revealed some organized trends that could be recognised as regions of linear highs or lows and on these regions, nine magnetic lineaments were delineated. The horizontal derivatives also highlighted features with known strikes in the x- y- and z- directions while the generalised derivative of TMI showed a sharp and enhanced map that has succinctly revealed the major structures in 3D. The result of application of the CET phase symmetry grid analysis to the TMI data, on the other hand, revealed the line-like regions of discontinuity and lineaments within the study area. These lineament features could serve as migration and depositional environments for minerals, hydrocarbon accumulation and hydrological considerations.

Keywords: Vertical, horizontal and generalised derivatives, grid analysis, mineralization, hydrocarbon accumulation

INTRODUCTION

Magnetic survey is aimed at investigating subsurface structures on the basis of the anomalies in the earth's magnetic field. The variation in magnetic field intensity of rocks varies according to the type of rocks, susceptibility, thickness of overburden and elevation, with susceptibility playing the key role. Anomalies in the earth's magnetic field are caused by the differences in the magnetisation of rocks in the Earth's crust and could be of remanent or induced nature. According to Mariita, (2009), sedimentary rocks generally have a very small magnetic susceptibility compared to igneous or metamorphic rocks, which tend to have much higher magnetite content. Hence, most magnetic studies are planned to map the geologic structures in the basement rocks which are the crystalline rocks that lie beneath the sedimentary layers or to detect magnetic minerals directly.

Nigeria has enormous mineral resources that are fairly distributed and if genuinely utilized

could boost the economy. One of the ways of achieving this task is to harness these abundant natural resources. The depleting nature of the existing petroleum reservoir and hence the products derived from it is also a point of concern, as there is the possibility that the existing quantity may be exhausted in the nearest future. There is, therefore, the need to explore for more reserves of hydrocarbon to complement and supplement the existing quantity. Consequently, a proper geophysical prospecting which would be aimed at ascertaining the presence of these minerals and the associated geomagnetic features and determining whether or not they are in commercial quantities, and subsequent exploitation is of paramount interest. The research therefore, aims at carrying out a geophysical interpretation of the total

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magnetic intensity over some parts of the Northern Bida Basin of Nigeria with a view to evaluating the lineament structures within the study area and their extent for informed deductions.

The basin is bordered in the NE and SW by the basement complex and merges with the Anambra and Sokoto basin to the SE and NW respectively. It is located between latitudes 7.30° N and 10.00° N; and longitude 4.00° E and 7.00° E (Obi, 2015). Figure 1 is the geology and location map of the basin. The basin is endowed with abundant mineral resources and there is also the likelihood of hydrocarbon and hence petroleum occurrence in it (Obaje, 2009).

Other geophysical works conducted in the basin using magnetic and other methods include: Udensi, and Osazuwa, (2004) who used statistical analysis to estimate the average depth to basement to be 3.39km, Ojo, and Ajakaiye, (1989) who delineated the presence of a positive gravity residual centre in the basin and attributed this to the presence of a shallow metamorphic basement of high density and intermediate composition which they deduced was probably of schist; and negative anomalies which were ascribed to relatively great thicknesses of sediments; Ojo, (1990) who investigated a major east-west magnetic low whose deep seated structures dominated the southern part of the basin.

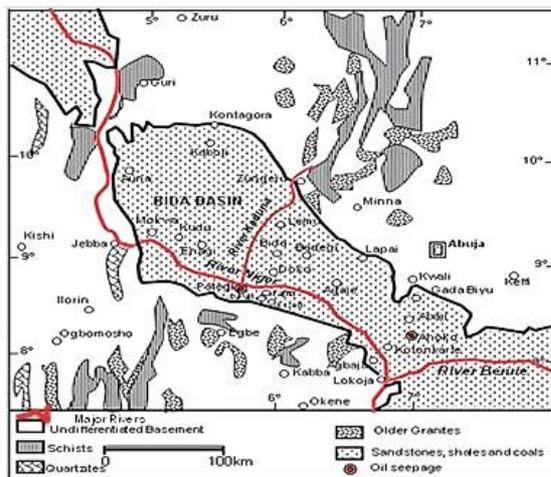


Figure 1: Geology and Location Map of Bida Basin and its Surroundings (Obaje, 2013)

Udensi, (2001) also identified the landward prolongation of St. Paul and Romanche fracture zones as lineaments passing through

the northern and southern parts of Bida basin. In the spectral determination of depths to magnetic rocks in the Bida Basin, Udensi and Osazuwa (2004) corroborated the findings of Ojo (1984) and Ojo and Ajakaiye (1989) who outlined the basin as being bounded by a system of linear faults. Ofor *et al.*, (2014) carried out a study of Pategi and Egbako areas of the lower Bida basin and revealed two prominent layers; with average values of 0.59km and 3.1km. Megwara, and Udensi, (2014) also carried out structural analysis using aeromagnetic data over parts of southern Bida basin and the surrounding basement rocks to highlight trend characteristics of magnetic lineaments.

Geology Of The Study Area

The Bida basin comprise the Bida Sandstone and Lokoja formation which were produced during the Campanian, and the Sakpe, Enagi, Batati, Patti and Agbaja formations which were created during the Maastrichtian. The Bida Formation is divided into the Doko and Jima Members. Adeleye (1974) reported that the Doko Member is about 183m thick showing localized development of cross-stratification with the Jima Member being about 90m thick and predominantly sandy. The Doko Member, located 16km south of Bida is the basal unit and consists of 80m of massive and flat bedded arkoses and coarse to medium sandstone with breccia horizons (Olaniyan *et al.*, 2012). Adeleye (1989) and Obaje (2009) also viewed the member as having fairly to poorly sorted and exposed pebbly, sub-arkoses and quartzose sandstones with granular to sub-granular grains which are thought to have been deposited in a braided alluvial fan setting. The sandstones of the Jima Member (Jima Sandstone subfacies), according to Adeleye (1989), are dominantly quartzose, non-arkosic and brownish. Thin intercalations of poorly sorted, hard, whitish, argillaceous sandstones are locally present in the lower parts of the Jima subfacies. The colours of the quartz grains are also similar to those of the underlying subfacies. Shiny, blackish ferruginous mineral, possibly goethite/haematite, form the cement and some weak to strong concentric growth shells are displayed.

The Sakpe Formation comprises mainly oolitic and pisolitic ironstones with sandy claystones

locally, at the base, followed by dominantly oolitic ironstone which exhibits rapid facies changes across the basin at the top (Adeleye, 1973). The Enagi Formation as described by Obaje (2009), on the other hand, consists mainly of siltstones and correlates with the Patti Formation in the Lokoja sub-basin. Other subsidiary lithologies include sandstone-siltstone with some claystones. Fossil leaf impressions and rootlets have been found within the formation. The formation ranges in thickness between 30m and 60m. Mineral assemblage consists mainly of quartz, feldspars and clay. The Batati formation constitutes the uppermost units in the sedimentary sequence of the Bida Basin. It consists, according to Obaje *et al.* (2013), of argillaceous, oolitic and goethitic ironstones with ferruginous claystone and siltstone intercalations and shaly beds which occur in minor proportions some of which have yielded near shore shallow marine to fresh water fauna.

The Lithologic units in Lokoja Formation according to Akande *et al.*, (2005) consists of sandstones, siltstones, claystones and shales interbedded with bioturbated ironstones with the argillaceous units predominating in the central parts of the basin. The Agbaja Formation consists of sandstones and claystones interbedded with oolitic, concretionary and massive ironstone beds in this region.

METHODOLOGY

IGRF corrected data was acquired from Nigerian Geological Survey Agency which serves as the custodian of geosciences data in Nigeria, through the IBBU hydrocarbon Research Group, digitized and then reduced to pole using Oasis montaj software. To identify the subsurface structures in the area, the First Vertical Derivative and the Horizontal Derivatives methods were used to delineate linear structures while the Centre for Exploration Targeting (CET) Phase Symmetry Grid Analysis was used to examine the texture of the image to detect any laterally continuous line-like regions of discontinuity such as lineaments along ridges and edges; and areas of structural complexity employing standard deviation to locate deposit occurrence favourability.

The first vertical derivative sharpened anomalies over bodies and reduced anomaly complexity thereby allowing a clearer imaging of the causative structures (Olaniyan *et al.*, 2012). The vertical derivative map is much more responsive to local influences than to broad or regional effects and therefore tends to give sharper picture than the map of the total field intensity. Thus the smaller anomalies were more readily apparent in areas of strong regional disturbances.

The Horizontal Derivatives are other enhancement techniques designed to reveal faults and contact features. They were used to complement the first vertical derivative but generally produced a more exact location than the former. In a sedimentary formation, like the Bida Basin, the derivatives enhance the surface to near surface features while suppressing features due to deeper sources. The generalised derivative was used to bring out small details concealed by larger amplitude anomalies normally to the general geological structure. It is similar to the horizontal derivative filter, with the additional benefit that the angle of the filter is specified in 3D, through an Azimuth and a Dip angle. The curvature of the potential field response is a useful attribute that enhanced the signal along a specified 3D direction.

RESULTS

Result of Reduction to Magnetic Pole (RTP).

Reduction to the pole (RTP) operation transforms a magnetic anomaly caused by an arbitrary source into the anomaly that the same source would produce if it were located at the magnetic pole and magnetized by induction only. RTP also helps in interpretation of magnetic data by removing the influence of magnetic latitude on the anomalies. Reducing the magnetic data to pole from Oasis Montaj software directly was not achievable as the method introduces drags at the edges of the anomalies, thus complicating the problem of symmetry which results from the dipolar nature of the magnetic data. The problem of drag results because the study area is closer to the equator than the pole. Hence, to achieve TMI reduced to pole, the inverse of the values of IGRF corrected TMI reduced to equator was computed using Oasis Montaj software

and the result is shown in Figure 2. From the map, a negative broad and deep seated magnetic anomaly could be observed around areas bounded by latitudes $8^{\circ}45' \text{ N} - 9^{\circ}00' \text{ N}$ and longitudes $5^{\circ}30' \text{ E} - 6^{\circ}50' \text{ E}$. This region is shown in blue colour on the RTP map and corresponds to areas around south of Patigi, Baro and north of Gulu. Sandwiching this region are broad and deep seated positive magnetic anomalies covering areas around latitudes $8^{\circ}00' \text{ N}$ to $8^{\circ}15' \text{ N}$ and longitudes $6^{\circ}00' \text{ E}$ to $7^{\circ}00' \text{ E}$ below and situated on magnetic sheets covering areas around the southern parts of Kotonkarfe and Kirri; and latitude $9^{\circ}00' \text{ N}$ to $9^{\circ}15' \text{ N}$ and longitude $5^{\circ}15' \text{ E}$ to $6^{\circ}30' \text{ E}$ above covering areas around the extreme north of Baro, Gulu and Patigi as well as southern Egbako. There are also some deep pockets of negative and positive anomalies scattered around the region which could be attributed to the nature of the region which is known to be dominated by sandstones and siltstones which are nonmagnetic, and ironstones which are magnetic in nature. The yellow bands represent the transition between these regions and clearly show the edges of the shapes of the anomalies.

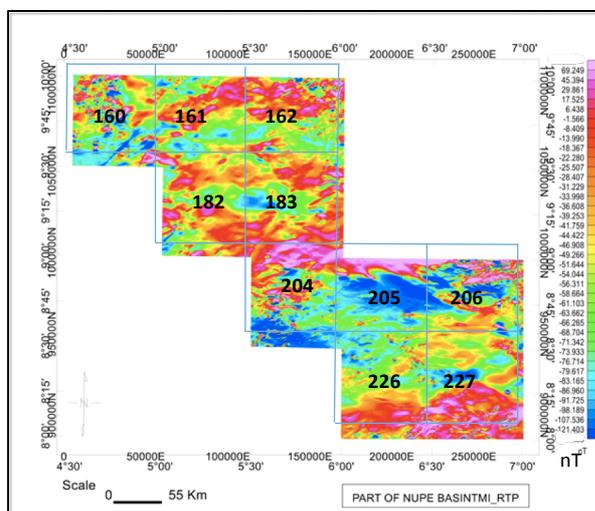


Figure 2: 2009 IGRF Corrected TMI data of Parts of Bida/Nupe Basin Reduced to Pole.

The First Vertical Derivative Result

The first vertical derivative is an enhancement that sharpens anomalies over bodies and tends to reduce anomaly complexity, thereby allowing a clearer imaging of the causative structures (Olaniyan *et al.*, 2012). Since the transformation amplifies short wavelength noise, it can sometimes be noisy; however, the

causative structures can easily be identified. The first vertical derivative was applied on the RTP IGRF corrected TMI data using Oasis Montaj and the resultant data then gridded and used to produce a colour aggregate map shown in Figure 3. The map clearly shows regions where magnetic signatures are distorted, which can be identified by the various colour contrasts within the region as indicated on the map. Within the distortions, however, some organized trends can be recognized as regions of linear magnetic highs or lows. On these regions, lineaments could be identified and nine of such magnetic structures were delineated and labeled F1 to F9 as shown in Figure 3.

Whereas F1, F2, F3, F4, F5 and F6 were observed to have a NE - SW trending, F7 and F8 have a NW - SE trending while F9 trends NW - SE. These are areas of different resolutions in the magnetic data grid which could be interpreted to mean fractures, dykes or fault lines.

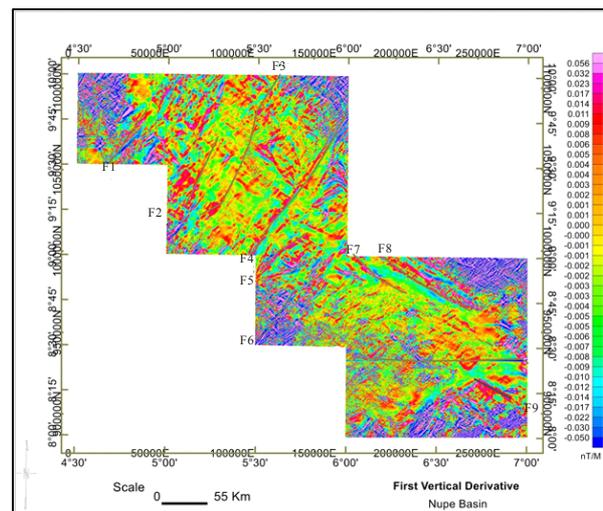


Figure 3: First Vertical Derivative of TMI showing interpreted Structures

The Horizontal Derivatives Result

The horizontal derivatives are other enhancement techniques designed to reveal faults and contact features. They are used to complement the first vertical derivative by generally producing a more exact location in X-, Y- and Z- directions. In a sedimentary formation, like the Bida Basin, the derivatives enhance the surface to near surface features while suppressing features due to very deep sources.

The Oasis Montaj Software was used to generate the specific directional horizontal derivatives to highlight features with known strikes in X (Fig. 4), Y (Fig. 5) and Z (Fig. 6) directions respectively. The TMI data was used as input channel with the x or y direction as the coordinate in the Universal Transverse Mercator (UTM) geographic coordinate system. From Figures 4 and 5 it is observed that some of the structures delineated in Figure 3 (F1- F8) have resurfaced except F9 which has been overshadowed by the predominant surface features in the derivative filters. The trending of the surviving structures is also similar to those obtained from vertical derivative map. F9 has however, resurfaced in the Z-direction in Figure 6, maintaining its orientation.

It can also be observed that the derivatives in x - direction enhanced the features trending in y - direction while the derivatives in y - direction accentuated the structural features trending in the x - direction. It can be further noted that the regions observed in Figure 2 as having negative or positive broad and deep seated magnetic anomalies have vanished from the derivatives maps, an indication that they were actually signatures from deeply seated structures. The predominantly blue regions, therefore, show characteristics that can be attributed to surface and near surface intrusions of magnetic rocks which could be biotite or/and undifferentiated granite.

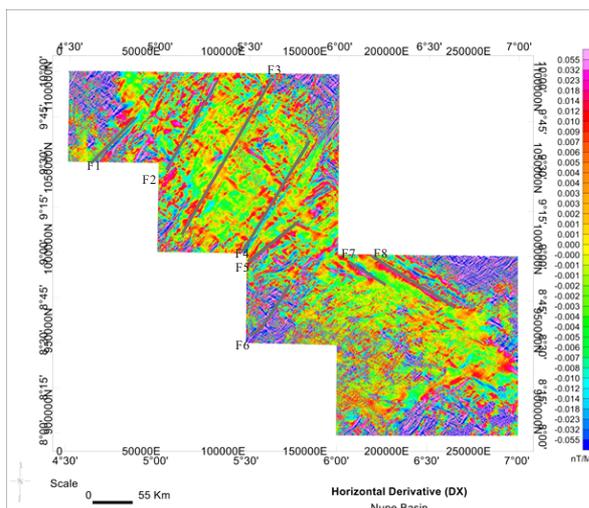


Figure 4. Horizontal Derivative of TMI showing interpreted Structures in X-direction.

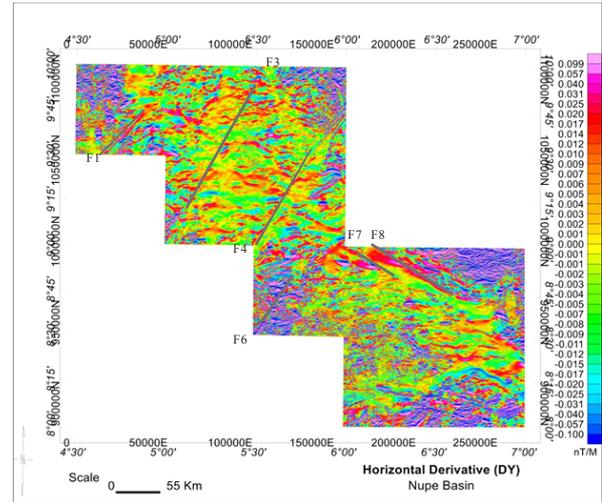


Figure 5: Horizontal Derivative of TMI showing interpreted Structures in Y-direction.

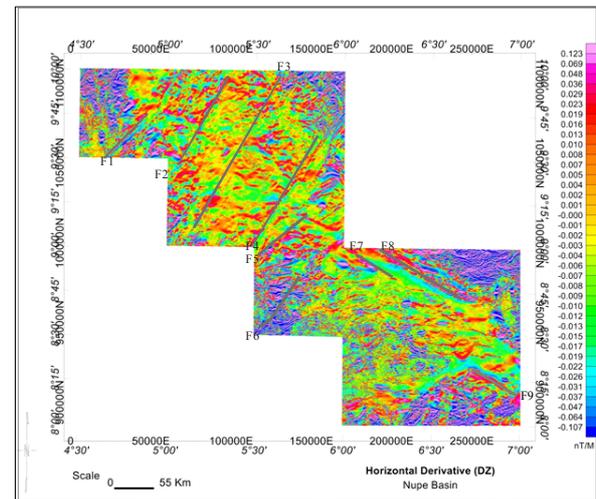


Figure 6: Horizontal Derivative of TMI showing interpreted Structures in Z-direction

Result of the Generalised Derivative

The generalized derivative filter is used to bring out small details concealed by larger amplitude anomalies normally to the general geological structure. It is similar to the horizontal derivative filters, with the additional benefit that the angle of the filter is specified in 3D, through an Azimuth and a Dip angle. The curvature of the potential field response is a useful attribute that is used to enhance the signal along a specified 3D direction. Figure 7 shows the generalized derivative of the TMI data showing a sharp and enhanced map that has succinctly revealed the four major surviving structures in 3D which are F1, F4, F7, F8 and F9. These structures are similar to those revealed by the first vertical derivative

as well as the x -, y - and z - derivatives, except that some of the structures in Figure 3, namely F2, F3, F5 and F6 are suppressed. This could be that these structures were not due to major geological activities or since the angle of the filter is specified in 3D through an azimuth and a dip angle, they cannot be visualized in 3D. While F1 and F4 trend in a NE – SW direction, F7, F8 and F9 have a NW – SE trending.

Apart from exposing major features, the generalized derivative has also helped in revealing, very unambiguously, regions which show some deep pockets as represented by the blue colouration on the legend in Figure 7. These are regions of high negative anomalies with a maximum value of -0.985nT. Areas with positive anomalies are also shown in purple to red colours on the legend, with the highest positive value being 0.972nT, while the yellow colour shows a transition between the magnetic highs and lows.

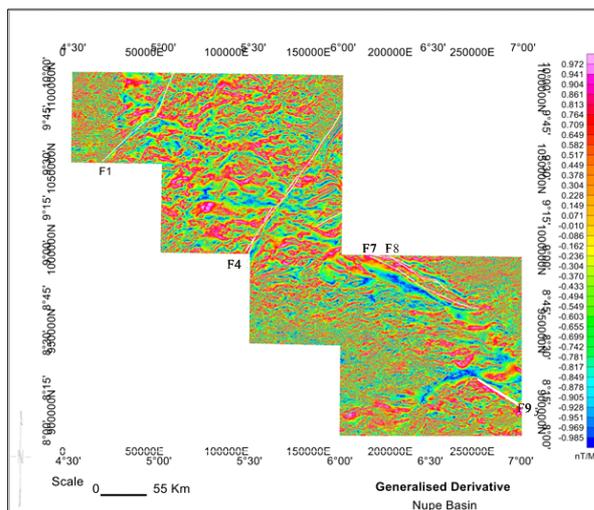


Figure 7: Generalised derivative of TMI showing interpreted Structures

Result of Centre for Exploration Targeting (CET) Phase Symmetry Grid Analysis.

CET Grid Analyses system examines the texture of an image to detect any laterally continuous line-like regions of discontinuity such as lineaments along ridges and edges as well as areas of structural complexity using standard deviation to locate deposit occurrence favourability. Since magnetic field data delineate geologic structures relatively well, the method is applied to the pole reduced data so that anomalies are shifted over their

causative structures. Figure 8 shows the result of the application of the CET phase symmetry grid analysis to the TMI data which has revealed the line-like regions of discontinuity and lineaments within the study area as seen in Figure 8. From the Figure, it is obvious that the areas shown in blue colouration and representing areas with very low amplitudes are the most favourable areas for occurrence of mineral deposits. This region is observed to follow a NW- SE trend. If a search for hydrocarbon deposits is to be conducted, these areas are the most favourable. The areas depicted by purple colour, on the other hand, are shallow depths arising, most likely, due to intrusions from the basement at different depths. These areas are observed predominantly in the vicinity of Kirri, Gulu north, southern parts of Kotonkarfe and Patigi as well as Kainji east and Akere west.

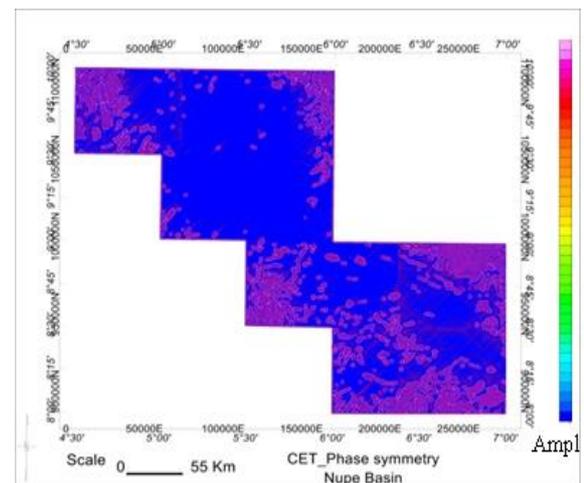


Figure 8: Phase Symmetry showing areas of discontinuity and lineaments.

DISCUSSION

The TMI was subjected to vertical derivative as well as the x -, y -, and z - horizontal derivatives to produce a better visualization of the data, revealing enhanced lineaments and shallow structures with the trend of such structures clearly revealed. These derivatives also clearly brought out the demarcation between the areas with shallow basement and those with deeply seated basement in the study area. This was identified by characteristic distortions of the magnetic field lines at the boundaries of the formations. On the maps of the vertical derivative, the x -, y -, and z -horizontal derivatives as well as the

generalized 3D derivative as shown in Figures 3, 4, 5, 6 and 7 respectively, the major lineament features and fault zones are clearly indicated and labeled as F1 to F9, with their trends conspicuously shown on the maps.

The anomalies with short wavelengths which are usually associated with shallow basement structures were observed around the Kainji magnetic sheet as well as the southern parts of Kirri and Kotonkarfi sheets. Similar features were also noticed around the northern part of the Gulu sheet, the south western Patigi and north-eastern Akere sheets. The Fashe, Mokwa, Egbako, Baro, the southern parts of Gulu and Akere as well as northern parts of Kirri and Kotonkarfi sheets are revealed to have longer wavelengths, indicating that these sheets have deep seated magnetic basement. The major lineament features are identified with lines within these blocks and labeled as F1 – F9 as shown in Figures 3, 4, 5 and 6. The NE – SW lineaments represented by F1, F2, F3, F4, F5 and F6 are similar those identified and described by Udensi (2001) and Megwara and Udensi (2013) as being typical of St. Paul and Romanche fracture zones while the NW-SE magnetic lineaments (F7, F8 and F9) are similar to those observed by Ojo (1984) as being associated with a system of linear faults. This is an indication that the study area might have undergone intense tectonic activities as suggested by Adepelumi *et al.* (2008). Features such as dykes, fractures, shear zones and/or faults are visible expressions of residual forces produced after rocks have been subjected to deformation and they also serve as confirmation of occurrence of tectonic events in the past within the area. These areas may have been heavily fractured, jointed and/or sheared and may contain grabens with sediment fills similar to those reported by Oga and Mamah (2014).

The CET phase symmetry map (Figure 8) has clearly revealed the low amplitude regions associated with deeper magnetic sources as indicated in blue colour and the relatively high amplitude areas shown in pink colour, which are associated with shallow magnetic sources. The CET plug-in uses various mathematical algorithms to analyse TMI data with the purpose of revealing the basement at the bottom of a sedimentary basin. The application of this plug-in resulted in the delineation of a

NW to SE trend of deep magnetic sources which is clearly discerned on the map with succinct demarcations between the shallow and deeper geological formations.

Conclusion

The IGRF corrected aeromagnetic data of some areas within the Bida/Nupe Basin of Nigeria were acquired from the Geological Survey Agency of Nigeria and analysed using the Oasis montaj Software from Geosoft, South Africa for the purpose of mapping the magnetic lineaments and their extents within the Bida basin. The total magnetic field intensity data was first reduced to pole to show how the anomalies would have been if the data was collected at the magnetic pole and then subjected to First vertical derivative, horizontal derivatives in x -, y- and z- directions as well as the generalised derivative to reveal the enhanced structures while the Centre for Exploration Targeting (CET) phase symmetry grid analysis was applied to the TMI data to reveal the line-like regions of discontinuity and lineaments within the study area. The lineaments corroborated those identified by Udensi, (2001) as landward prolongation of St. Paul and Romanche fracture zones passing through the northern and southern parts of the basin. The lineaments could serve as aquifers or migration and reservoirs for hydrocarbon and hence can further be studied for hydrocarbon deposits.

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