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Interpretation of Aeromagnetic Anomalies of Degema and Oloibiri area of Niger Delta, Nigeria, Using Qualitative Approach

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Authors' contributions

This work was carried out in collaboration between all authors. Author CCO designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors GE and ASE managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Qualitative interpretation of high resolution aeromagnetic data spanning Oloibiri and Degema area of Southern Niger Delta, Nigeria was undertaken in order to interpret anomalies that could (1) delineate structural features with low and high anomalous values within the area and (2) determine if there is any structural relationship between the offshore Niger Delta region and the onshore region. Regional-residual separation was applied to the digitized data covering Long. 6º0'0'' E - 7º0'0'' E and Lat. 4º30' N - 5º0'0'' N with a first order polynomial fitting using the X utility module of Oasis Montaj software. This filtering action gave rise to the regional and residual maps depicting anomalies relating to the low and high frequency components. The high frequency components/anomalies (or the residuals) emanate from shallow seated geologic bodies while the low frequency components/anomalies originate from the basement. The anomalies emanating from the deeply and shallow seated structural features have NE-SW, NW-SE, E-W and N-S directional trends.

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Keywords: Anomalies; residuals; colour variations; qualitative approach; X Y channel; NE-SW; NW-SE.

1. INTRODUCTION

No source of energy is required during the acquisition of magnetic data. Thus, the magnetic technique is termed to be passive. This technique can be performed on the land, in the air or under the sea. When performed on land, it is called land survey while when carried out in the air and under the sea, it is called aero and marine survey respectively. The aeromagnetic survey, when compared to other types of magnetic survey, has an advantage of covering inaccessible areas. Depending on the survey specifications, a high or low resolution aeromagnetic data can be obtained. The resolution of the data is also partly dependent on the nature of corrections applied on the data acquired.

The use of aeromagnetic studies as a reconnaissance tool has proven to be apt in delineating structures features like lineaments, folds, faults, dykes and seals over the past few decades. According to [1] the aeromagnetic survey has proven consequential in revealing the distribution and abundance of magnetic and non-magnetic anomalous sources within and around the basement complex and sedimentary section.

[2] delineated basement fracture and fault zones expressed as lineaments and then inferred the influence of such lineaments on the tectonic history and oil and gas bearing potential of some parts of offshore Niger Delta through aeromagnetic studies. To achieve the purpose the aeromagnetic data were analysed qualitatively using WingLink software. Their result showed northeast-southwest (NE-SW), northwest-southeast (NW-SE), north-south (N-S) and south-west (S-W) trends which probably was the result of faulting, fracturing, downwarp and epeirogenic warping within the study area.

[3] (2013) discriminated the regional from residual structures within the study area through aeromagnetic study. This was done in order to define thicker sedimentary section by subjecting the data to various geophysical techniques like tilt depth, Euler Deconvolution, Analytic signal, derivatives and 2D derivatives. Tectonic trends with strike direction of NE-SW, NW-SE and E-W directions were observed.

In order to examine the relationship between deep basement shape and size and the hydrocarbon target [4] used airborne magnetic data covering Niger Delta area. to investigate the relationship between deep basement architecture and hydrocarbon target. Varying basement structures which would have significant control on oil and gas within the Tertiary strata of the Niger Delta were established.

Aeromagnetic data covering parts of Imo River was used by [5] in identifying basement features associated with the basin and then deduced the influence of the basement features in hydrocarbon exploration by subjecting the data to various filtering actions. This art revealed tectonic features trending in the NE-SW direction.

In many sedimentary basins, magnetic anomalies from secondary mineralization along fault planes which are revealed on aeromagnetic maps as surface linear features. This research will thus delineate the structural features associated with the study area.

One of the basins with high hydrocarbon potential is the Niger Delta sedimentary basin. The basin is believed to be ranked among the world's major hydrocarbon province [6]. Several directional tectonic trends found within the basin do form an oil and gas rich belt [7,8]. The directional trends of NW-SE forming this belt extend from the northwest offshore to the onshore region according to [8]. This research is then undertaken in order to investigate the possibility of locating the NW-SE tectonic trend within the onshore part of the study area. By so doing, this study will help us to understand if there is any structural relationship between the offshore Niger Delta region and the onshore region.

1.1 Location and Geology of the Study Area

The study area is bounded eastwards by Port Harcourt, westwards by the Penington River, southwards by Bille and Bonny and Northwards by Patani and Ahoada. Geographically, the study area spans 6º0'0" E - $7^0$0'0" E and 4º30' N - 5º0'0" N. Basically, the area under review is about 6050 $km^{2.}$. The geologic map, (Fig 1), which falls within Oloibiri and Degema, reveals the area to be swampy and shows the Creeks, with the Benin

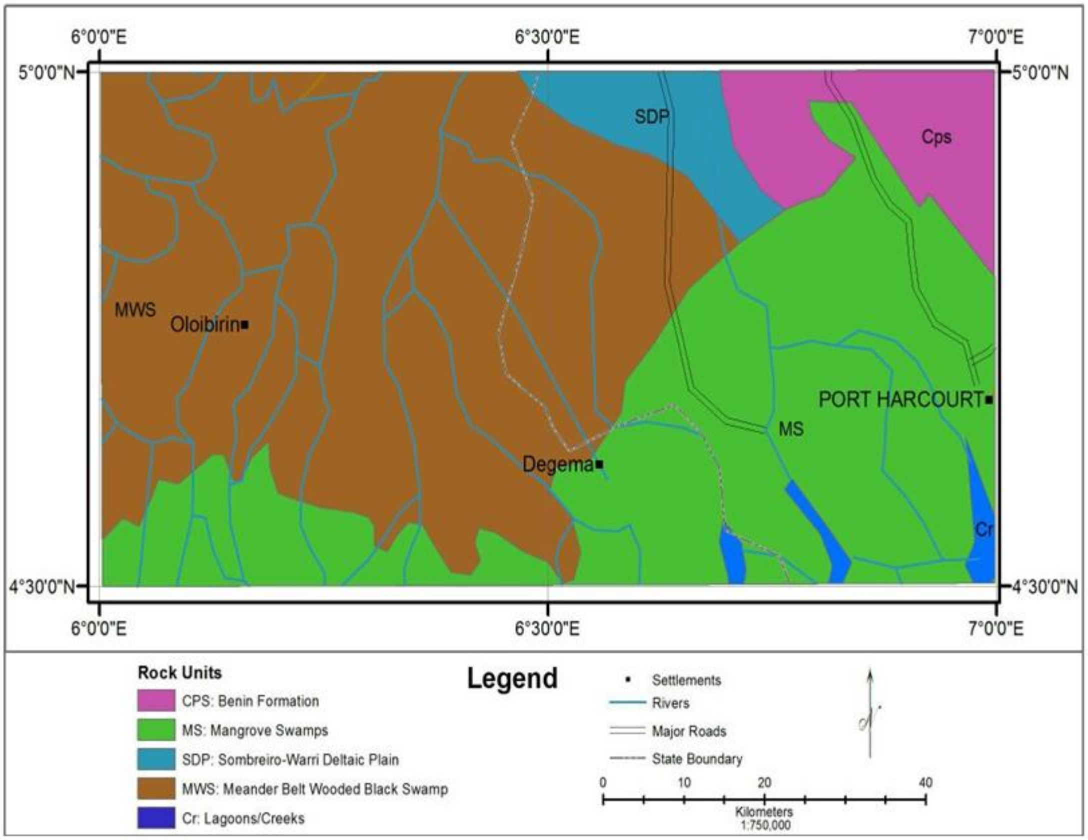

Fig. 1. Geological map of the study area
(Courtsey: The Nigerian Geological Survey Agency, NGSA, Abuja)

Formation and Sombreiro Warri Deltaic Plain sands.

2. MATERIALS AND METHODS

Two sheets of digitized aeromagnetic data covering parts of Oloibiri and Degema area of onshore southern Niger Delta (Fig. 2) were used for this study. The aeromagnetic datasets with sheet numbers 327 and 328 were acquired in 2009 by Fugro Airborne Service on behalf of the Nigerian Geological Survey Agency. The aeromagnetic data were obtained from the Nigerian Geological Survey Agency, NGSA, in half degree sheet and in Geosoft file format. The aeromagnetic data are of high resolution in that they were acquired at a terrain clearance of about 100 m, flight line pattern of NE-SW and tie line spacing of 500 m. The Oasis Montaj Modeling was used for the processing, analysis and interpretation of the aeromagnetic datasets.

For the purpose of this research, a principal method (Fig. 3) of data interpretation and analysis was adopted, namely: the qualitative approach of data analysis and interpretation. Qualitative data interpretation and analysis were implemented on the acquired aeromagnetic data with the aid of Oasis Montaj Software by digitizing the geosoft grid file formats into X, Y and Z channels using the gridding tool. For the coordinate channels (X, Y) and the principal channel (Z) to be created, the gridded aeromagnetic datasets were saved to a database which was created before the importation of the datasets. Regional-residual filtering actions using X utility module were then performed on the principal Z channel and consequently the regional and residual channels were generated. Further filtering actions like the first vertical derivative, first horizontal derivative, second horizontal derivative, second vertical derivative, upward continuation at 5 km and downward continuation at 5 km were performed on the residual channel and this gave rise to other qualitative channels corresponding to the first vertical derivative, first horizontal derivative, second horizontal derivative, second vertical derivative, upward continuation and downward continuation filtering actions. From each of the channels, qualitative grid maps were generated. Thereafter, visual inspection of the raster (image) maps done before they are then transformed into its contour formats. Tectonics of the study area was examined by analyzing the structural trends of the contoured maps. Analyses was performed on the contoured maps on the basis of amplitude, shape and size of the anomalies and identification of anomalous boundaries, volcanic zones, lineaments, folds, faults, dykes, seals, and other regional structures that could be akin to those that are believed to exist within offshore Niger Delta.

The first vertical derivative map transformational technique was applied to the residual data so as to make more apparent the shallow related magnetic bodies. This filtering or transformational technique accentuated the high wavenumber component at the expense of the low wave number component. According to [9], this technique is based on the expression:

$$Ƒ\left[\frac{d^n Ø}{dZ^n}\right] = K^n Ƒ(Ø) \quad (3.1)$$

Where,

n = 1, the nth order vertical derivative
Ø = the potential of the magnetic field
Ƒ = the Fourier transform of the magnetic field

Like the first vertical derivative, the second vertical derivative highlights near surface anomalous effect at the expense of the effects that are of deep origin. This study necessitated the application of the second vertical derivative (SVD) on the residual data so as to make conspicuous some shallow effects that were not accentuated by the first vertical derivative. The second vertical derivative filtering method is based on equation 3.1 with n = 2

The upward continuation applied on the residual transformed the observed magnetic field to a higher level. When this transformation was applied, the deep seated causative sources were discriminated from the shallow causative sources. For this research work, the aeromagnetic residual field data set was upward continued at 5 km and 40 km. The residual was upward continued at 5 km. [10] stated that the upward continuation filter measured on a level $\boldsymbol{z = z_o}$ at point $\boldsymbol{P = (x, y, z_o - \Delta z)}$ is governed by the equation:

$$U(x, y, z_o - \Delta z) = \frac{\Delta z}{2\pi}\iint_{-\infty}^{\infty} \frac{U(x^I, y^I, z_o)}{[(x-x^I)^2+(y-y^I)^2+\Delta z]^{\frac{3}{2}}} dx^I dy^I, \quad (3.2)$$

$Where$

$\Delta z > 0$

Applying Fourier convolution to equation 3.2, we obtained

$$Ƒ[U_u] = Ƒ[U]Ƒ[\psi_u] \quad (3.3)$$

Where,

U_u = Upward continuation at the initial level
ψ_u = Upward continuation at a new level and can be expressed as

$$\psi_u(x, y, \Delta z) = \frac{\Delta z}{2\pi(x^2+y^2+\Delta z^2)^{\frac{3}{2}}} \quad (3.3a)$$

Equation 3.3a which is the analytical expression of $Ƒ[\psi_u]$ and $Ƒ[U_u]$ is the Fourier transform of the upward continued field and is given by:

$$Ƒ[U_u] = e^{-\Delta z|k|} \quad (3.3b)$$

$where$

$$\Delta z > 0 \quad (3.4)$$

Downward continuation filtering was applied on the residual field data so as to transform the observed causative fields to a lower level near the source. This processing technique highlighted the shallow related features to the detriment of the deep seated bodies. [11] stated that the downward continuation is governed by:

$$D_c = \frac{R}{4\pi(\mathrm{R+H_i})}\sum_j K_{ij}\Delta g_j^g + F_{\Delta g} \quad (3.5)$$

Where,

g = the geoid
i and j = the respective computation and integration points
Hi = height of a computation point
Kij = the kernel coefficients
$F_{\Delta g}$ = the contribution outside the chosen near-zone cap called the far-zone contribution.

First horizontal derivative which enhances low frequency component of underground causative sources was applied to the residual data. This technique has the capability of producing anomaly peaks located over the edges of wide bodies. Thus by applying this filtering technique, there is an increase in the definition of body edges located at a shallower depth.

[9] believes that, in Fourier domain, the horizontal derivatives of a smoothly scalar quantity Ø(x, y), in x and y directions are given by:

$$\mathrm{F}\left[\frac{d^n Ø}{dx^n}\right] = (\boldsymbol{ik_x})^{\boldsymbol{n}}\mathrm{F}(Ø) \quad (3.7)$$

and

$$\mathrm{F}\left[\frac{d^n Ø}{dy^n}\right] = (\boldsymbol{ik_y})^{\boldsymbol{n}}\mathrm{F}(Ø) \quad (3.8)$$

Where the factors $(\boldsymbol{ik_x})^{\boldsymbol{n}}$ and $(\boldsymbol{ik_y})^{\boldsymbol{n}}$ are operators which transforms a function into nth order derivatives with respect to x and y, respectively [10]

3. RESULTS AND DISCUSSION

The aeromagnetic data used for this study is presented in contour format (Fig.2). The contoured aeromagnetic data give an insight about the subsurface geology and also highlight the architectural framework of the study area. The result of regional-residual separation undertaken on the contoured aeromagnetic data is given in Fig. 3. and Fig. 4. On Fig. 3. further enhancement techniques like first vertical derivative, second vertical derivative, first horizontal derivative, second horizontal derivative, upward and downward continuation were applied and consequently Fig. 5, Fig. 6, Fig. 7, Fig. 8, Fig. 9 and Fig. 10 were generated. This was done in order to accentuate the subtlest anomalies within the area. The regional-residual and the enhancement techniques analysis performed on the aeromagnetic data enhanced greatly the understanding of shallow and deep seated anomalous sources. The analysis performed on the aeromagnetic data sets discriminated anomalies of interest from aomalies that are not of interest. The anomalies of interest are shallowly related (or the residuals) while the anomalies that are not of interest are of deeper origin.

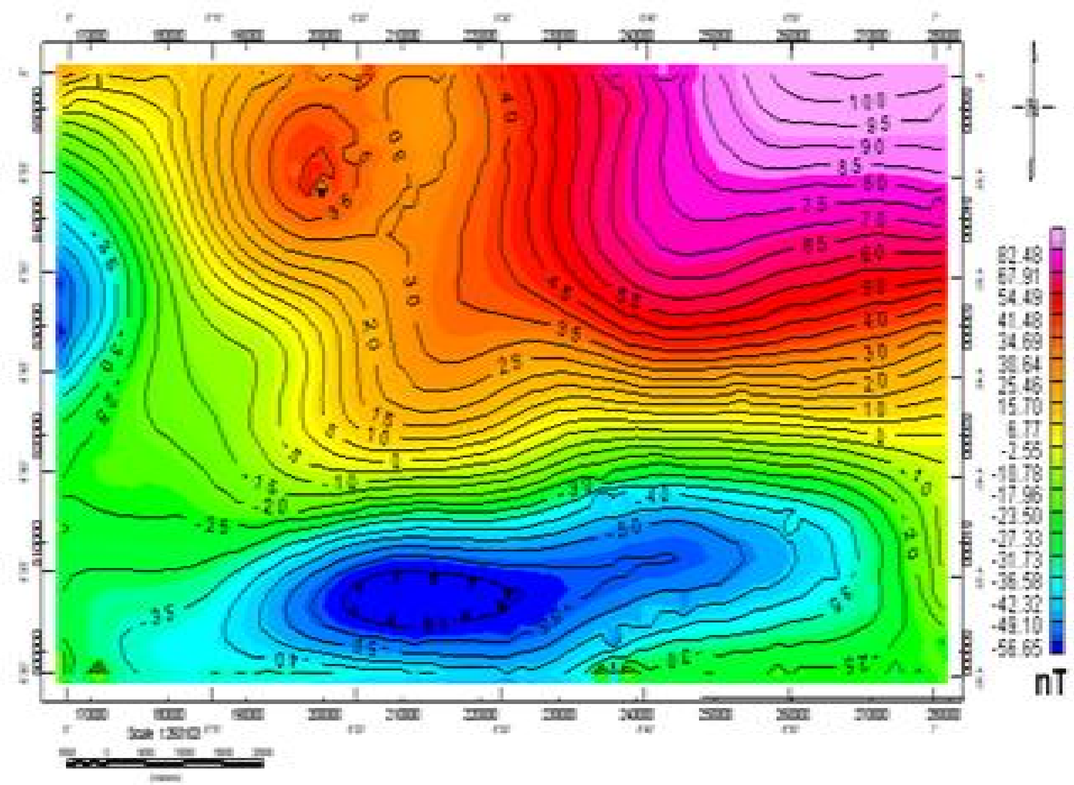

Fig. 2. Contoured aeromagnetic data covering Degema and Ololhiri

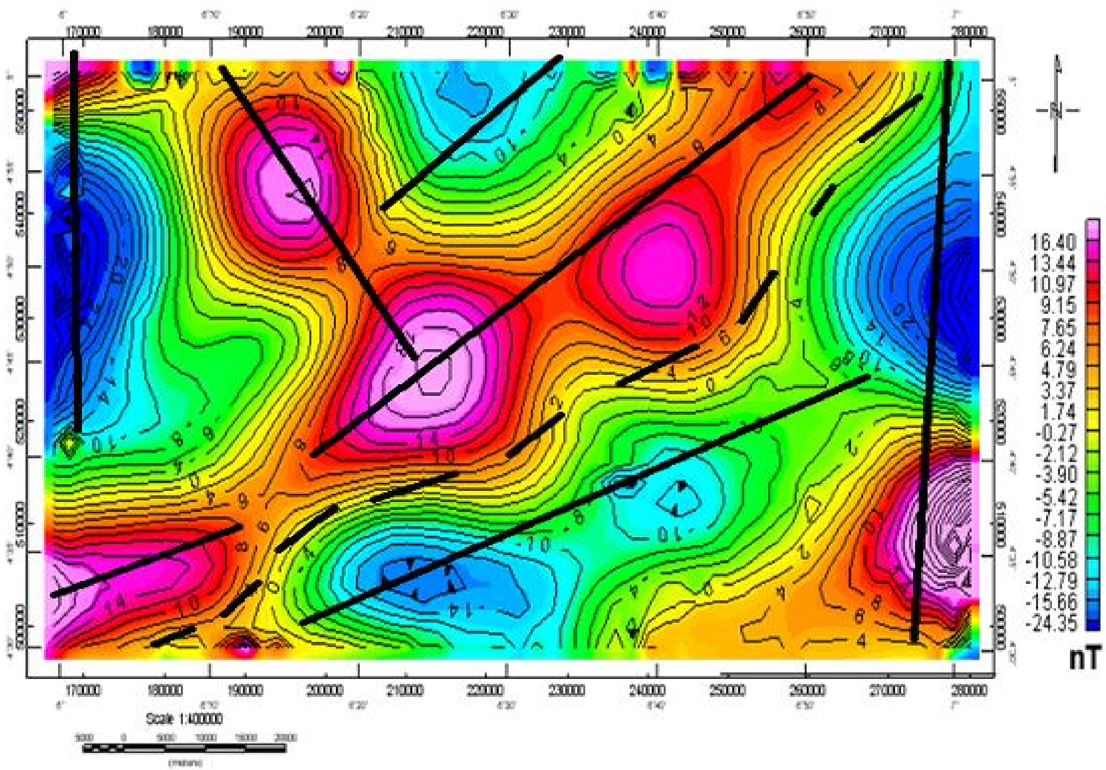

Fig. 3. Aeromagnetic residual map of the study area in contour format (nT)

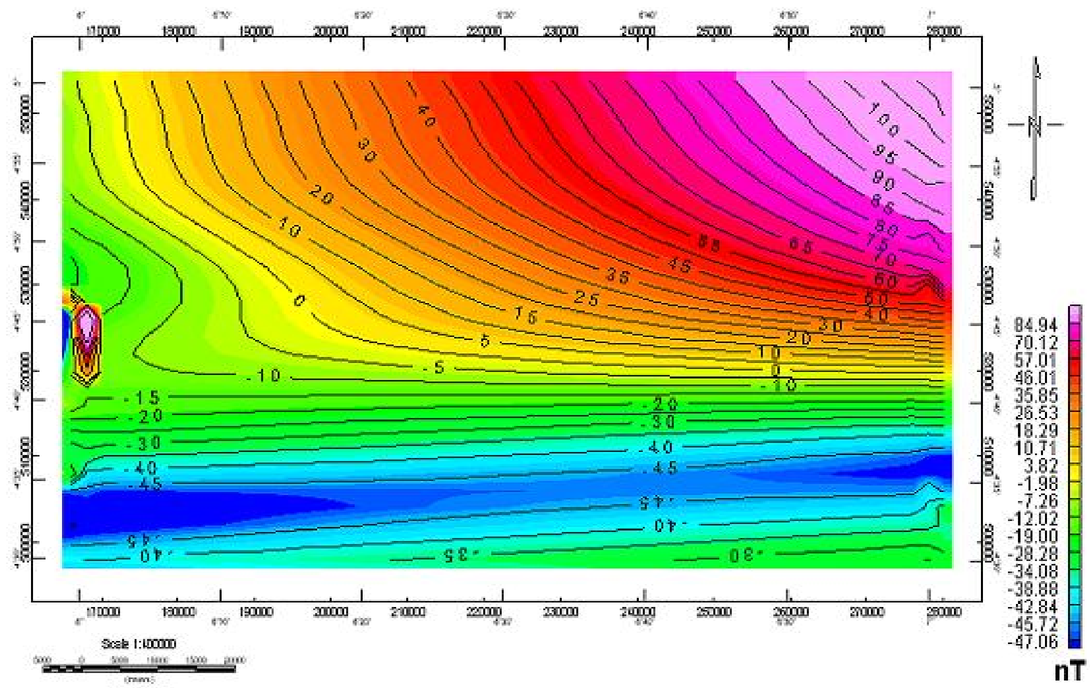

Fig. 4. Regional .4eromagnetic alap of the study area in contour format (nT)

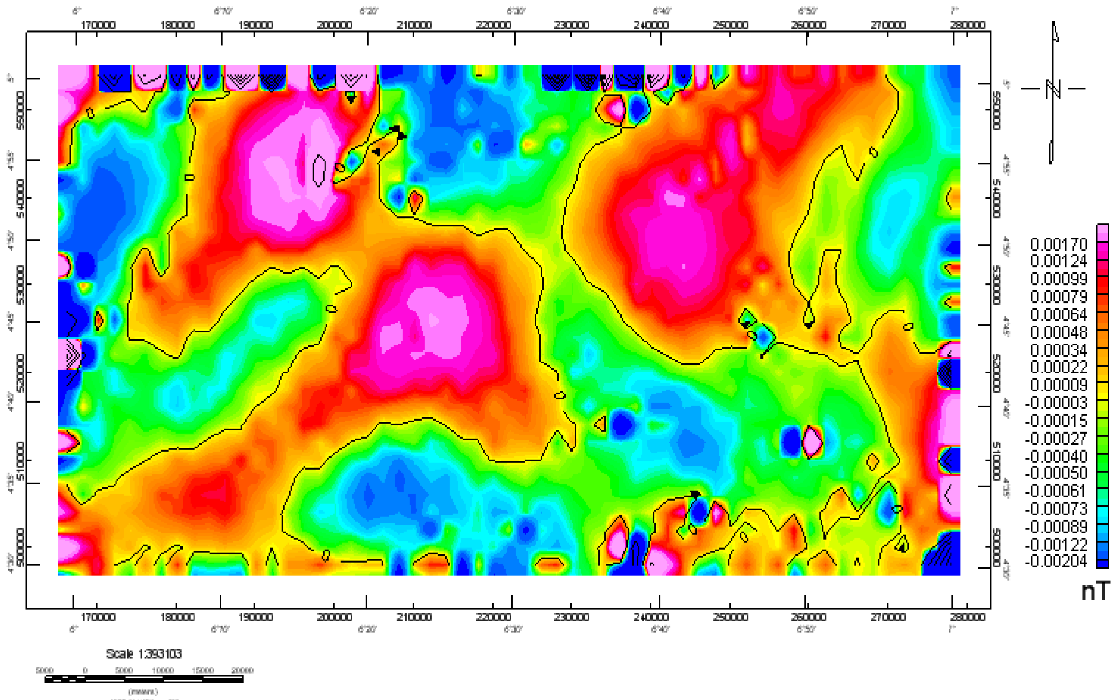

Fig. 5. First vertical aeromagnetic derivative map (nT)

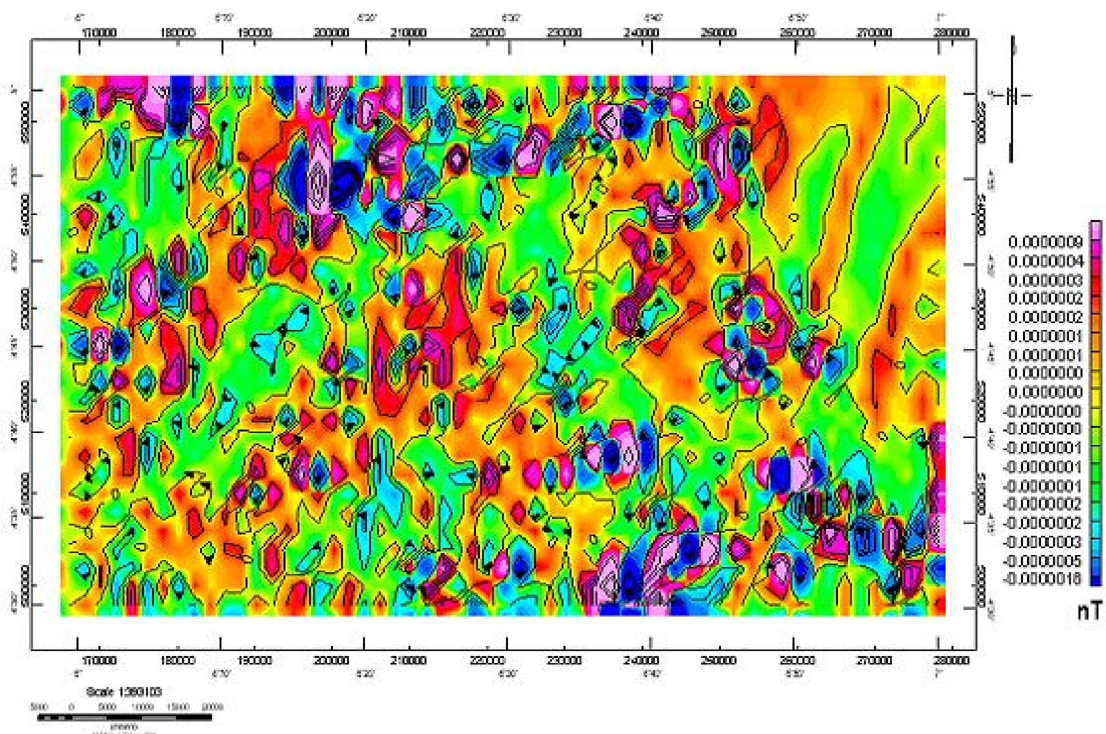

Fig. 6. Aeromagnetic second vertical derivative map (nT)

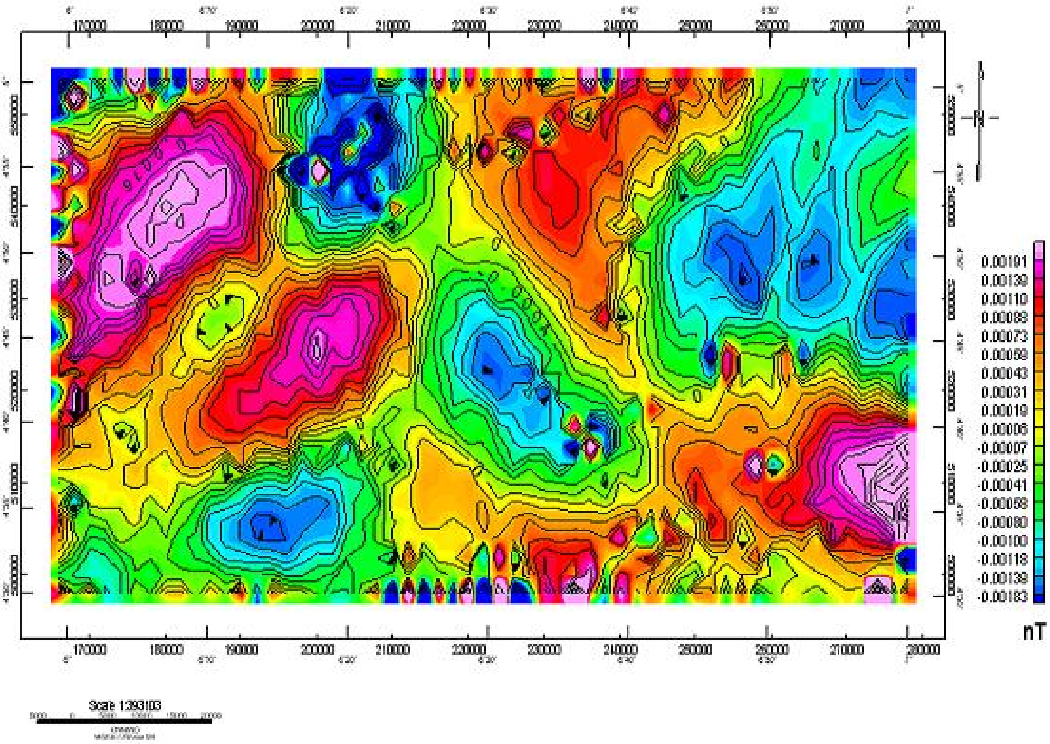

Fig. 7. First horizontal aerornasmeric derivative map (nT)

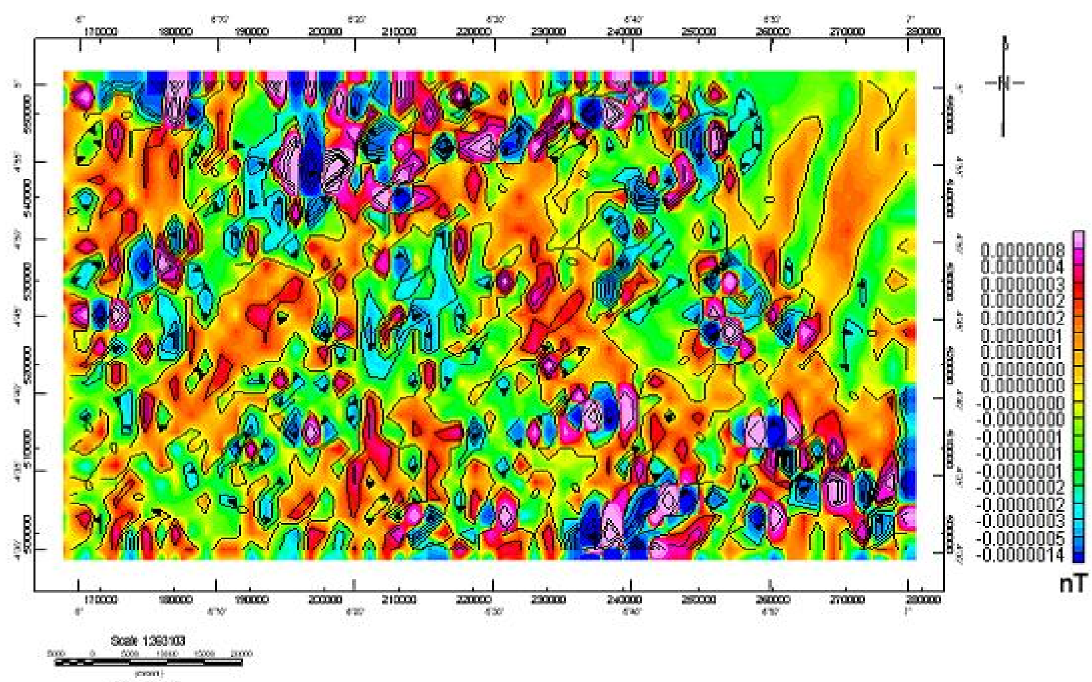

Fig. 8. Second horizontal derivative aeroniasnetic map (HT)

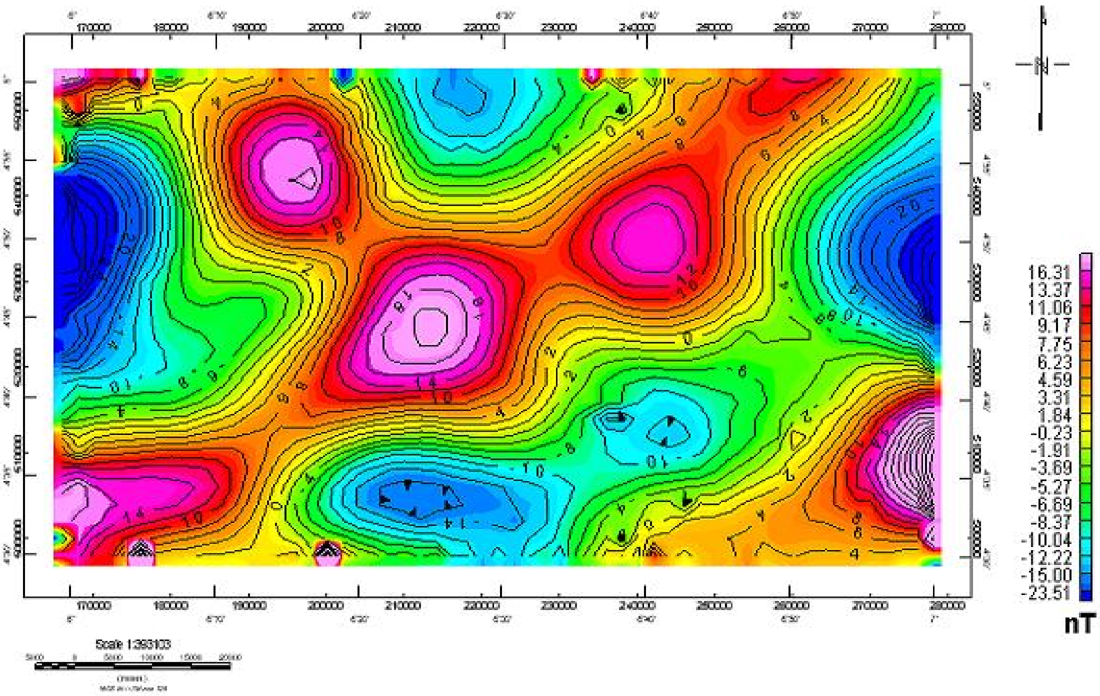

Fig. 9. Aeromagnetic data upward continued at 5 Ian (nT)

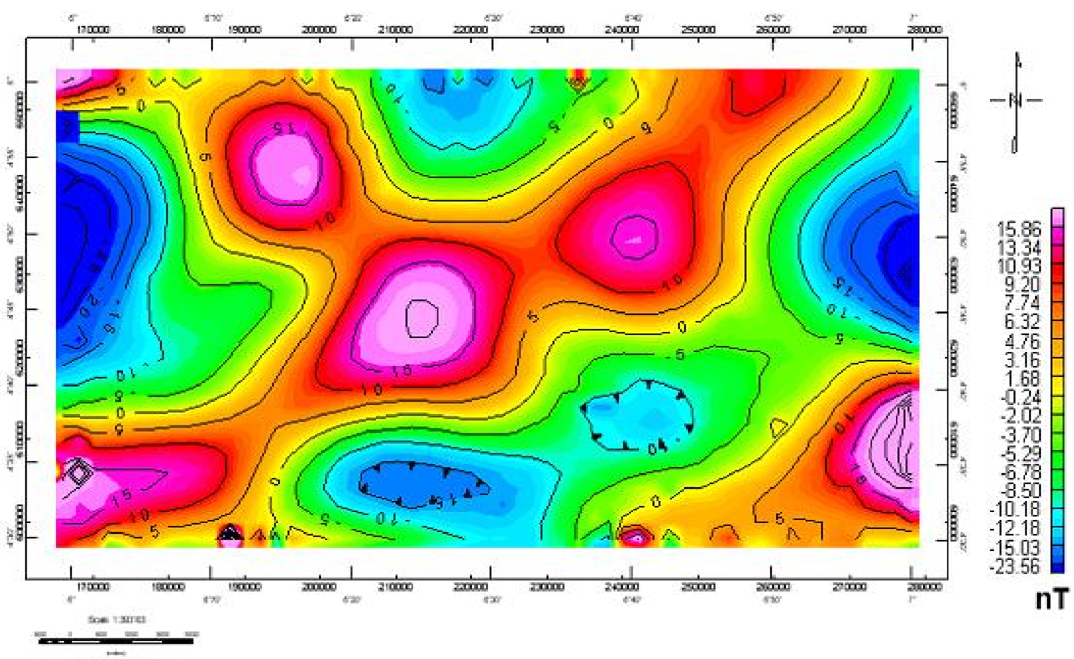

Fig. 10. Aeromagmetic data downward continued at 5 km (nT)

The study area is characterized by colour variations depicting total magnetic intensity values. Each of the colour has corresponding magnetic values shown with the aid of the legend attached to the aeromagnetic raster map. Accentuation of the magnetic field is enhanced by the aeromagnetic raster map. On the aeromagnetic map, zones of similar magnetic values are outlined and distinguished on the basis of colour variations. Two magnetic zones can be identified on the map, namely; the magnetic high (magenta, red and yellow colours) and the magnetic low (green and blue colours). High magnetic zones can be identified at the northern portion of the raster map while low magnetic zones are discernible at the western and southern parts of the map. Nevertheless, the magnetic intensity values decrease from the north to the south. Negative and positive aeromagnetic anomalies are distributed within the map. Anomalous zones with positives values show areas that have little or no mineral. These zones with high magnetic values can be labeled to be regions that are magnetically responsive. Basement or volcanic rocks are associated with such region. The negative values highlight areas that are magnetically subdued. Hence sediments can be inferred from such areas. The total magnetic intensity values, however, range between 56.65 nT and 82.48 nT. Maximum magnetic values which were recorded at the northern side of the map range from 6.77 nT to 82.48 nT while the minimum magnetic values occurring at the western and southern portions of the map range from -56.65 nT to 2.55 nT. In the southern corner of the map, an elliptical magnetic low with blue colouration is visible. This elliptical magnetic low feature is elongated. The elliptical shape of the magnetic low anomaly is a possible indication of a dyke like structure that fosters the entrapment of hydrocarbon within the study area. The elongated nature of the anomaly possibly implies that the anomaly is of regional extent. [11] suggested that such elongated anomaly with wide area extent is caused by wide contrasts in magnetic susceptibility. An almost circular magnetic low point can visibly be seen in the western portion of the map. According to [1] the isolated magnetic anomaly with hemispheric shape is an indication of a magnetic aureole occurring within the study area.

Various contour configurations are discernible on the total magnetic intensity contour map. The contour map is obtained by the transformation of the raster map into its contour format. The contours range from being linear, irregular to being circular and broad. Stretched E-W elliptical contours highlighting magnetic low zone are noticeable at the southern side of the map. The relative closeness of the magnetic signatures characteristically shows that the magnetic source bodies causing the disturbance are at or very near to the ground surface. Immediately above the elongated and elliptical signatures are extended linear belt depicting probable fault zone within the area. The linear belt of magnetic highs (yellow contour lines) and lows (green contour lines) could be partly attributed to metasedimentary and mainly due to sedimentary related structures respectively. According to [4] such type of fault zone occurring on the map is synonymous with the fault zone found within offshore Niger Delta area of Nigeria. They also stated that the E-W trending direction is a reflection of the Cameroon volcanic line within the study area. From the central to the northwestern portion of the map, this area is magnetically characterized mainly by NW-SE lineation with high amplitude. The lineations are true reflection of the trends produced by the causative masses generating the anomalies. Regular and similar pattern of magnetic anomalous contours can be observed at the north-eastern part. The similar type of signatures can be attributed to the location of the anomalous sources at the same depth. Deeper magnetic bodies can be located at the south western portion of the map. This is evident by the contour spacing.

Smoothened magnetic anomalies are expressed on the residual aeromagnetic map. Colour contrasts indicating magnetic field changes are apparent on the map like the total magnetic intensity raster map. The magnetic field anomalies vary between -24.35 nT and 16.40 nT. Magnetic highs (red, yellow and magenta colours) whose values range from -0.25 nT to 16.40 nT occur at the central, north-west, north-east, north-east, south-eastern and south western portions of the map. Similarly, magnetic lows represented by the blue and green colours are apparent at the northern, eastern, western and southern portions of the map. The magnetic lows vary from -24.35 nT to 2.12 nT. The residual contour map shows contours of different form and magnitude. The map depicts series of closed and elliptical magnetic signatures. Closed signatures are found within the high magnetic zones while the elliptical signatures are associated with the magnetic low zones. Magnetic low contours or weak anomalies reflect the presence of a local relief on the basement. Embedded inside the high magnetic zones are higher magnetic units whose values are 13.44 nT and 16.40 nT. [1] asserted that the embedded magnetic unit is indicative of a distinct lithology from the surrounding or possibly a lava flow as evidenced by the inhomogeneity of the magnetic units. Immediately below the high circular contours located at the center of the map are few elongated linear and curved contours with long wavelength, high relief and high amplitude. These curved and elongated contours are believed to be deep seated foldings that are possible traps for economic fluids in the sedimentary section as they permeate through the overlying sedimentary cover. Various lineaments are indicated by the thick lines. The dash thick lines indicate the existent of folds within the area. Generally, NE-SW, NW-SE, E-W and N-S tectonic trends which are onward extension of oceanic fracture zones are seen clearly on the map but with the NE-SW and NW-SE trends becoming dominant. With the aid of the numerous elliptical structures coupled with the magnetically low and high which are cut by the Benin Formation, Mangrove swamps, Sombreiro Warri Deltaic Plain, and the Meander Belt Wooded Blank Swamp, it could, therefore, be inferred that the study area holds a promise for hydrocarbon exploration.

For this study, proper modeling of the study area began with the removal of the regional effect. [6] defined the regional as that effect which would exist if the anomalies of interest are absent. He further stated that the interpretation of regional may become quite subjective. Unraveled on the map are regional magnetic field values ranging from -47.06 nT to 84.94 nT. Negligible magnetic unit is obvious in the western portion of the map. [11] proposed that such type of anomaly is attributed to remnant magnetization. The magnetic values decrease from the northern to the southern part of the map. Long wavelength contours of regional extent are evident on the map. The regional contours trend in the E-W and NW-SE direction. The planar E-W trends correspond to the Cameroon volcanic line trend while the NW-SE tectonic trends highlight, probably, the Charcot fault and chain oceanic fracture zone which are believed to be extending continuously toward the offshore West African region.

Showed on the first vertical derivative map are shallow related anomalous features with anomalies ranging from 0.00204 nT to 0.00170 nT. Dominant on the map are magnetic highs which appear at the northern, central, south-eastern, south-western, north western and north eastern side of the map. The magnetic values for the magnetic highs fall within 0.00009 nT and 0.00170 nT while the magnetic lows lies within -0.0024 nT to -0.0003 nT. The magnetic highs are possible igneous intrusive that have intruded into the sedimentary section. The first vertical derivative contour map displays contours that have NE-SW and NW-SE tectonic trend. These contours are relatively spaced.

Magnetic units of shorter wavelength and sharper edges are obviously seen on the second vertical derivative map. These magnetic units with no relief and amplitude have field values falling in the range of -0.000016 nT and 0.0000009 nT. Within the map, magnetic highs range between 0.00001 nT and 0.0000009 nT while magnetic lows range from 0.0000016 nT to -0.0000001 nT.

Unlike the second vertical derivative map, the first horizontal derivative map reveals broad magnetic anomalies with protruding and sharp edges. Spatially distributed on the map are magnetic highs and lows but with the magnetic highs occurring more. The magnetic field values vary from 0.00008 nT to 0.00191 nT for the magnetic highs while the magnetic lows range between -0.00183 nT and 0.00006 nT. Generally, magnetic field values within the map vary from -0.00183 nT to 0.00191 nT. Unlike the residual map, more elliptical contours are discernible on the second vertical derivative map and they trend in the NE-SW and NW-SE directions.

Discrimination of shallow seated magnetic bodies against the deeply seated sources is noticeable on the second horizontal derivative map. This is justified by the localized magnetic units with short wavelengths. The second horizontal derivative map, like the first horizontal derivative accentuated shallow features (or short wavelength bodies) at the expense of the deep seated long wavelength regional effect. Magnetic highs and lows are spatially distributed on the map. Within the map, values ranging between -0.000014 nT and 0.0000008 nT exist. Nevertheless, the magnetic highs have values ranging from 0.0000001 nT to 0.0000008 nT while magnetic lows have values between –0.0000014 nT and 0.0000001 nT. Tiny and localized contours are evident on the map. The contours trend in the NE-SW, NW-SE, N-S and E-W directions.

Downward continuation map at 5 km reveals anomalies with magnetic values ranging from -23.56 nT to 15.86 nT. The anomaly pattern is similar to the anomalous pattern observed on the residual map. Circular and elliptical magnetic units are widely and visibly showing on the map. The smoothened magnetic signatures indicate that the anomalies are unrelated to noise that is usually associated with the shallow related structures. Identifiable on the contoured map are spaced magnetic contours. This indicates that the anomalous trending in the NE-SW and NW-SE are of deeper origin.

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The upward continuation map at 5 km enhanced the deep seated anomalous features. Colour contrasts similar to the residual and downward continuation at 5 km maps are visible on the upward continuation map at 5 km. Dominating NE-SW tectonic trend is recognized on the contoured map. Thus, NE-SW, NW-SE, E-W and N-S tectonic trends prevail within the study.

4. CONCLUSION

Lineaments, faults, fonds as well seals were revealed to exist within the study area. This is evidenced by the elliptical, circular and curve linear contours that were apparent when qualitative analysis was carried out on the aeromagnetic data. The lineaments expressed as elliptical, circular and curve linear contours have structural trend of NE-SW, NW-SE, E-W and N-S directions. These trends, however, represent onward extention of the active charcot and oceanic fracture zones from offshore West African to onshore Niger Delta region.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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