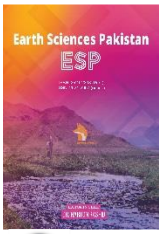
Earth Sciences Pakistan (ESP)

DOI: http://doi.org/10.26480/esp.01.2021.07.11

ZIBELINE INTERNATIONAL PUBLISHING

ISSN: 2521-2893 (Print)
ISSN: 2521-2907 (Online)
CODEN: ESPADC



CrossMark

RESEARCH ARTICLE

ESTIMATION OF SEDIMENTARY THICKNESS FOR HYDROCARBON POTENTIAL OVER PART OF ADAMAWA TROUGH, NE NIGERIA USING MAGNETIC METHOD

Ajala S.A[a]., Salako K. A[a], Rafiu A. A[a], Alahassan U. D[b], Adewumi T[a*], Sanusi Y.A[c]

[a] Department of Physics, School of Physical Science, Federal University of Technology.
[b] Department of Physics, Faculty of Science, Federal University Lafia, Nasarawa State, Nigeria.
[c] Department of Physics, Faculty of Science, Usmanu Danfodiyo University.
****Corresponding Author Email: taiwo.adewumi@science.fulafia.edu.ng***

ARTICLE DETAILS

Article History:

Received 18 January 2021
Accepted 21 February 2021
Available online 12 March 2021

ABSTRACT

This study presents the results of the analysis and interpretation of aeromagnetic data over part of Adamawa trough with the aim of investigating the hydrocarbon potential of the study area. The study area is located between latitude 8.50oN and 9.50oN and longitudes 11.50oE and 12.50oE. The Total magnetic intensity map of the study area was subjected to regional/residual separation. Three depth estimating techniques applied on the residual map to determine the thickness of sediments in the study area were Source parameter imaging, Euler deconvolution and spectral method. The results of these methods corroborate; the SPI, Euler Deconvolution and Spectral method shows a thick sedimentation of 4.42 km, 4.20 km and 4.17 km at the north-eastern part of the study area respectively. The SPI, Euler deconvolution and the Spectral method reveal shallow depth of 0.06 km, 0.10 km and 0.42 km at the southeast, southern and southwest part of the study area respectively. The maximum sedimentary thickness of above 4 km obtained in this study at the north-eastern part of the study area which corresponds to Numal might be sufficient for hydrocarbon maturation and accumulation. The study area was found to have a good prospect for hydrocarbon exploration.

KEYWORDS

Aeromagnetic data, Analysis, Euler deconvolution, SPI, Spectral method.

1. INTRODUCTION

The exploration for solid minerals, oil and gas across the Benue trough and its adjoining areas has increased tremendously with the aim of increasing the nation's hydrocarbon reserve and alternative means of generating more revenues for nation so as to curb the menace caused by poverty in the country. The interest in sedimentary basins born out from the fact that they are the usual potential host rocks for oil and gas. The discovery and harnessing of hydrocarbon in the study area will expand Nigeria's oil and gas holds, boost quantities of the hydrocarbon potentials of the Nigerian inland basins, in this way, give opportunities, help the economy of the nation and also provide many new employments to lessen unemployment drastically in Nigeria.

Recently, the Nigerian National Petroleum Corporation (NNPC), the national oil company which is in the forefront of the drilling in the northern part of the country announced the discovery of commercial quantity of crude oil and gas in the upper Benue trough (Gongola Basin) to boost the hydrocarbon reserved of the nation since the substantial part of the Nigerian economy depend mainly on the export of crude oil and gas whereupon more than 180 million teeming populace depends on upon.

The present study attempts to use the quantitative interpretation of aeromagnetic data over part of Adamawa trough (within the Yola arm subbasin of the Upper Benue trough) on a reconnaissance basis to examine the subsurface structures of the study area for possible hydrocarbon maturation and accumulation within the area using some depth estimating techniques such as; Source parameter imaging, Euler deconvolution and Spectral method. It also involves analysing and interpreting the high airborne magnetic data set obtained at 500 m flight line spacing by Fugro Airborne Survey and supervised by Nigerian Geological Survey Agency (NGSA). This is an improvement on the old magnetic data collected at flight line spacing of 2 km in 1972. This improvement in data quality will provide a better understanding and thickness of sedimentation of the basin (Ogunmola et al., 2016).

1.1 Location and Geology Settings of the Study Area

The study area covers an area of approximately 12,100 sq.km in the north-eastern part of Nigeria and bounded by latitudes 8.5 ^{0}00'N to 9.5^{0}00'N and longitudes 11.5^{0}00′E to 12.5^{0}00′E. The study area (Adamawa trough) is located within the upper Benue trough (Yola subbasin) in the North Eastern part of Nigeria and covering Dong, Numal, Monkin and Jada (Figure 1). The Basin is born out from the rifting of the Central West African basement during cretaceous (Obaje et al., 2009). The trough is covered with sediments of cretaceous within the geologic age off Albian –

Quick Response Code	Access this article online	
	Website: www.earthsciencespakistan.com	**DOI:** 10.26480/esp.01.2021.07.11

Maastrichtian; comprises of sandstones, shales and limestone which are source rock for petroleum. Geologically, the study area is made of crystalline basement and sedimentary deposition. Alluvium deposition at the extreme northern to north-eastern part of the study area; shale, standy clay, calcaneous sandstone, shale and limestone beneath the alluvium deposition somewhere at the northern part of the study area; Porphyritic granite deposition occupies the western and south-eastern part of the study area; pronounced deposition of migmatite at the southwestern to the central part of the study area and medium-coarse grained feldspartic sandstone at the central part of the study area (Figure 2).

Several authors have carried out geophysical studies in the Benue trough including the lower, middle and upper benue trough with aim of assessing the economic importance of the basin. Ofoegbu and Onuoha estimated the sedimentary thickness of part of the Benue trough and came up with depth range of 1.2 km and 2.5 km using the acquired old aeromagnetic data of 1979 (2 km flight line spacing) (Ofoegbu and Onuoha, 1999). Their result suggested that the thickness of sediment obtained is not enough for hydrocarbon maturation and accumulation. Igwesi and Umego used spectral analysis of the high resolution aeromagnetic data of part of lower Benue trough to estimate the depth to top of magnetic basement and depth of 3.0 km was obtained which is a good indicator for hydrocarbon prospectivity in the area (Igwesi and Umego, 2013). Salako and Udensi recorded thickness of sediment of part of Upper Benue trough to be 3.35 km using spectral analysis of aeromagnetic data (Salako and Udensi, 2013). Adetona and Abu obtained a maximum sedimentary thickness at the lower Benue trough using high resolution aeromagnetic data (Adetona and Abu, 2013). A group researchers carried out structural-depth analysis of aeromagnetic data of Yola Arm of Upper Benue rough and obtained depth range of 1 km to about 4.3 km which is a good indicator for hydrocarbon maturation and accumulation in that area (Ogunmola et al., 2016).

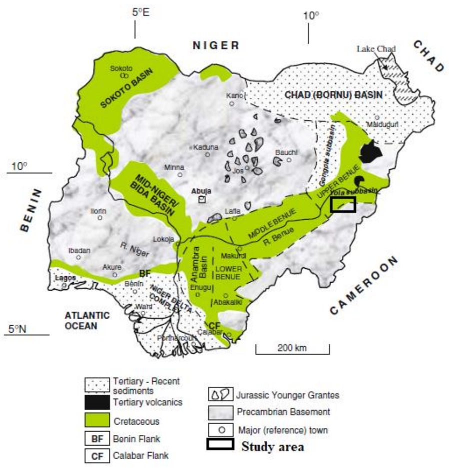


Figure 1: Geologic map of Nigeria showing the study area in outline (Obaje, 2009)

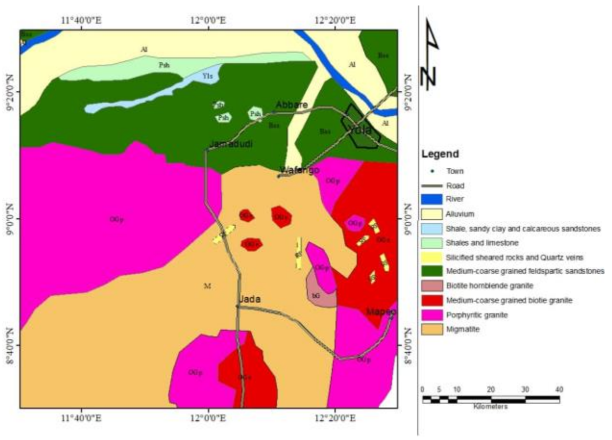


Figure 2: Geologic map of the study area

2. Materials and Methods

The following procedures were adopted in this present study; (i) production of Total magnetic field map of the study area using Oasis montaj software (V. 8.3), (ii) subjected the TMI to regional/residual separation using polynomial fitting order one, (iii) divide the residual map into nine overlapping blocks of 55 x 55 km^2 for spectral depth estimation within the study area and lastly, (iv) evaluate the depth to top of magnetic source using Source Parameter Imaging (SPI) and Euler deconvolution.

2.1 Data Source

Four sheets of airborne magnetic data used for this study were acquired from Nigeria Geological Survey Agency. This data was part of the data acquired during nationwide airborne survey between years 2005 – 2009 by Fugro Airborne Survey and supervised by the aforementioned agency. The four aeromagnetic data sheets acquired are 195 (Dong), 196 (Numal), 216 (Monkin) and 217 (Jada) which correspond to area covered by latitude 8.5^{0}N to 9.5^{0}N and longitude 11.5^{0}E to 12.5^{0}E. Each 1:100,000 topographical sheet covers an area of about 3025 km^2 (i.e. 55 km x 55 km) totalling a superficial area of 12, 100 km^2. Below are the technical details of the survey/ flight parameters:

Flight line spacing: 500 m

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

Flight direction: NW - SE

Tie lines spacing: 2 km

Tie lines direction: NE -SW

2.2 Spectral Depth Estimation Method

It is a depth estimating method used in geophysics for investigating the thermal frame work via aeromagnetic studies. Spectral depth analysis based on statistical models has been employed in numerous geophysical works, as in the determination of average depth to the top of magnetic basement and in the computation of crustal thickness. The Fourier transform of the potential filed due to a prismatic body has a broad spectrum whose peak location is a function of the depth to the top and bottom surfaces and whose amplitude is determined by its density or magnetization (Adetona and Abu, 2013). The expression below shows the relation of the peak wavenumber to the geometry body (Spector and Grant, 1970):

$$\omega' = \frac{(h_b/h_t)}{h_b - h_t} \tag{1}$$

where ⍰' is the peak in wavenumber in radian or ground unit, h_t and h_b is the depth to the top and depth to the bottom in meters or kilometres respectively. For a bottomless prism, the spectrum peak at the zero wavenumber is according to the expression:

$$f(\omega) = \ell^{-h\omega} \tag{2}$$

where ⍰ is the angular wavenumber in radians/ground-unit and h is the depth to top of the prism in meters or kilometres. When considering a line that is long enough to include many sources, you can use the log spectrum of these data to determine the depth to the top of a statistical ensemble of sources using the relationship:

$$\text{Log } E(k) = 4\pi hk, \tag{3}$$

where h is the depth in ground-units and k is the wavenumber in cycles/ground-unit. You can determine the depth of an "ensemble" source can be determined by measuring the slope (m) of the energy (power) spectrum and dividing by 4π. i.e.

$$h = m/4\pi, \tag{4}$$

A typical energy spectrum for magnetic data may exhibit three parts—a deep source component, a shallow source component, and a noise component. The thickness of sediments of the study area for hydrocarbon maturation and accumulation would be estimated from the spectral analysis of the aeromagnetic data of the study area.

2.3 Source Parameter Imaging (SPI)

The Source Parameter Imaging (SPI) is a technique using an extension of the complex analytical signal to evaluate magnetic depths. The Source Parameter Imaging (SPI) function is a fast, simple, and capable method for computing the depth of magnetic sources. Its accuracy has been demonstrated to be +/- 20% in tests on real data sets with drill hole control. This accuracy is analogous to that of Euler deconvolution, however SPI has the advantage of delivering a more complete set of coherent solution points and it is easier to use (Salako, 2014). One merit of the SPI technique is that the depth can be visualised in a raster format and the true thickness can be determined for each anomaly. The Source Parameter Imaging (SPI) of aeromagnetic fields over the area would differentiate and characterise regions of sedimentary thickening from those of uplifted or shallow basement and also to determine the depths to the magnetic sources. SPI is a procedure for automatic calculation of source depths from gridded magnetic data (Thurston and Smith, 1997). The results could be used to suggest whether or not the study area has the potential for oil/gas and mineral deposits concentration.

SPI assumes a step-type source model. For a step, the following formula holds:

$$Depth = {}^{1}\!/_{K_{\max}} \qquad (5)$$

where K_{max} is the peak value of the local wavenumber K over the step source.

$$K = \sqrt{\left(\frac{dA}{dx}\right)^2 + \left(\frac{dA}{dy}\right)^2 + \left(\frac{dA}{dz}\right)^2} \qquad (6)$$

$$\text{Tilt derivative } A = \tan^{-1}\left(\frac{\frac{dT}{dz}}{\sqrt{\left(\frac{dT}{dx}\right)^2 + \left(\frac{dT}{dy}\right)^2}}\right) \qquad (7)$$

T = the total magnetic field anomaly grid

2.4 Euler Deconvolution

Euler deconvolution is a method to estimate the depth of subsurface magnetic anomalies and can be applied to any homogeneous field, such as the analytical signal of magnetic data. It is particularly good at delineating the subsurface contacts. It has been observed that the depth estimates from magnetic data are more accurate if the pole-reduced magnetic field is used, than when using the magnetic data themselves. Euler deconvolution was originally developed in exploration geophysics for rapidly estimating the location of and depth to magnetic or gravity sources. It is based on the fact that the potential field produced by many simple sources obeys Euler's homogeneity equation (Hood, 1965). If a given component of the magnetic anomalous field $\Delta T(x, y, z)$ satisfies the following equation:

$$\Delta T(x, y, z) = \text{tn}\, \Delta T(x, y, z) \qquad (8)$$

where n is the degree of homogeneity, then differentiating Equation 8 with respect to t gives Equation 9:

$$x\frac{\partial \Delta T}{\partial x} + y\frac{\partial \Delta T}{\partial y} + z\frac{\partial \Delta T}{\partial z} = n\Delta T \qquad (9)$$

where x, y, and z are the coordinates of the field observation points and assumed to be at the origin.

According to Thompson, (1982), considering the potential field data, Euler's deconvolution equation can be expressed as

$$(x - x_0)\frac{\partial \Delta T}{\partial x} + (y - y_0)\frac{\partial \Delta T}{\partial y} + (z - z_0)\frac{\partial \Delta T}{\partial z} = N(B - T) \qquad (10)$$

where ($x0$, $y0$, $z0$) is the position of a magnetic source whose total magnetic field T is measured at (x, y, z). The total field has a regional value B, and N is the degree of homogeneity (structural index), which is equivalent to n in Equation (9). The unknown coordinates (x_0, y_0, z_0) are estimated by solving a determined system of linear equations using a prescribed value for N with the least squares method. And a solution with a minimum standard deviation is found through using different tentative values for N. In this study, the Euler deconvolution was used to determine the thickness of sediment for hydrocarbon potential of the study area.

3. Results and Discussion

The total magnetic intensity map (Figure 3) of the study area (part of Adamawa trough) after IGRF removal of 33,000 nT for the purpose of handling was produced in colour aggregates; with pink to red colour portraying positive (high) anomalies while green to blue depicts negative (low) anomalies. The Total Magnetic Intensity map of the study area exhibits both positive and negative anomalies ranging from -80.7 nT to 139.6 nT. The extreme northern part of the area is predominantly positive (high) anomaly and it also appear in some part of the study area. The presence of the high magnetic anomaly at the north-eastern part of the study area might be as a result of basement intrusion into the sediment since the study area is majorly sedimentary basin. While the southeastern portion of the study area is dominated by negative (low) magnetic anomalies. The central part of the study area is dominated by mixtures of both high and low short wavelength closures which are high in frequency of occurrence. Major structures delineated trends NE-SW, NW-SE and E-W. This map shows some correlation with the geologic map of the study area (Figure 2).

Figure 4 is the residual map of the study area produced after the residual/regional separation. The regional was removed from the total magnetic intensity map (Figure 3) using polynomial fitting order of Oasis Montaj and the result produced the residual map. The residual map emphasis the short wavelength anomalies after the separation and show variations in magnetic signature ranging from magnetic value of -87.4 nT and 78.9 nT. Major structures delineated on this map trend NW-SE, NE-SW and E-W which agrees with the structures identified on Figure 3. The residual map was further subjected to quantitative analysis to estimate the depth to magnetic source for hydrocarbon maturation and accumulation.

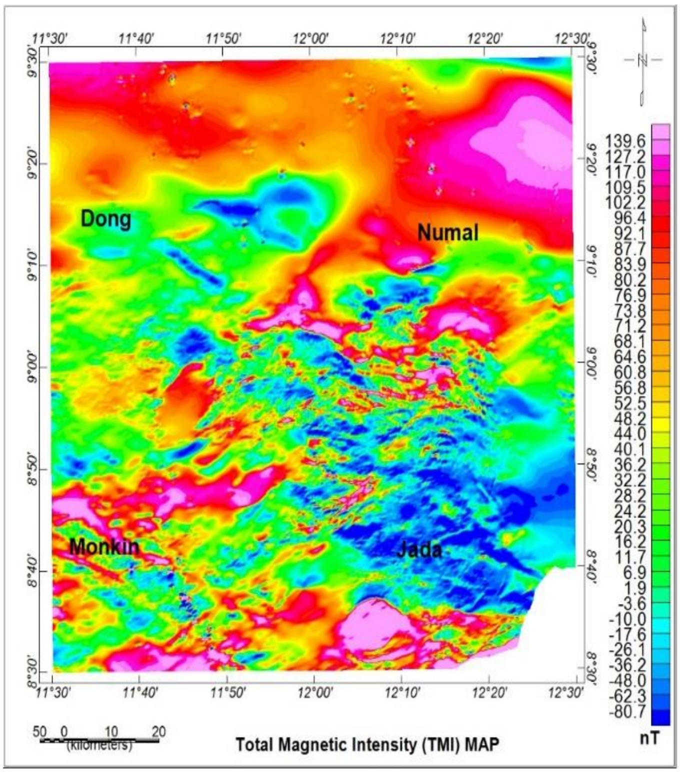


Figure 3: Total magnetic intensity map of the study area (The sum of 33,000 nT IGRF removed for the purpose of handling must be added to get the actual value at any point)

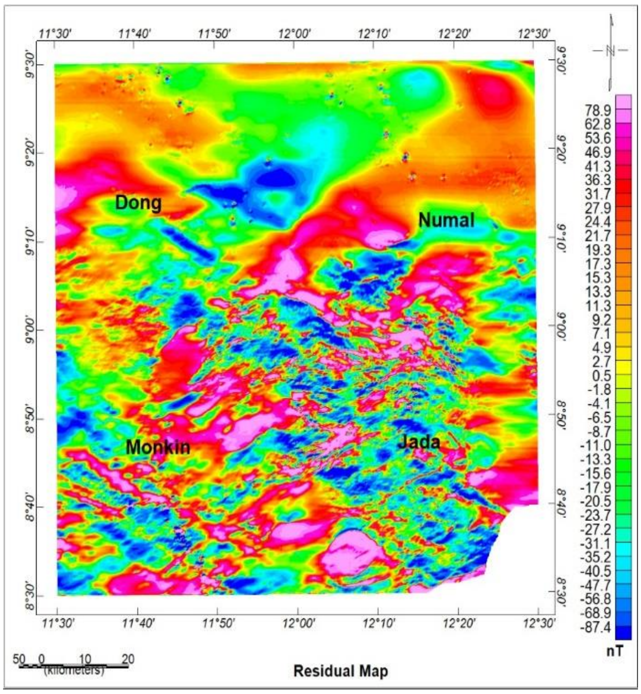


Figure 4: Residual map of the study area

3.1 Results from the Spectral Analysis

This method was used in this present study determine the depth to top of magnetic basement based on a moving data window by selecting the sharpest and therefore deepest straight-line segment of the power spectrum. A depth solution was calculated for the power spectrum derived from each grid sub-set located at the centre of the window. Overlapping the windows creates a regular, comprehensive set of depth estimates. The residual map (Figure 4) of the study area was divided into twelve (12) overlapping spectral blocks (A-L) of 55 x 55 km^2. Spectral analysis was performed on each block and a plot of spectrum energy against wavenumber was carried out using a program designed with Matlab software (Figure 5). The gradient from the plots give two depths; deeper and shallow depth and the results depth estimated are displayed on Table 1. The deeper depth obtained ranges from 1.48 km to 4.17 km with the maximum depth of 4.17 km found at the north-eastern part of the study area (Figure 6a). While the shallow depth ranges 0.42 km to 0.82 km and the shallowest depth could be found at the south-western part of the study area (Figure 6b).

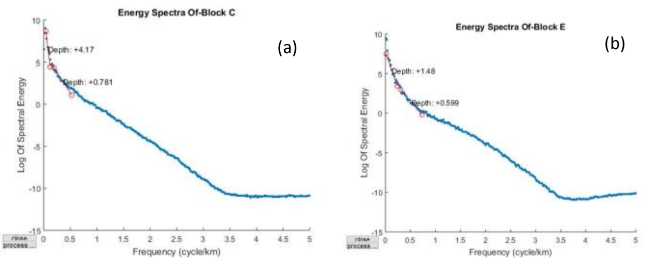


Figure 5: (a) Spectral plots for block C showing the maximum depth, (b) block E showing the minimum depth.

Table 1: Spectral table of deeper and shallow depth (km) of the study area

Blocks	Long. (Deg.)	Lat (Deg.)	Deeper depth Z_1(km)	Shallow depth Z_2 (km)
A	11.75	9.25	2.08	0.53
B	11.92	9.25	2.05	0.82
C	12.08	9.25	4.17	0.78
D	12.25	9.25	3.37	0.6
E	11.75	9.08	1.48	0.59
F	11.92	9.08	3.02	0.58
G	12.08	9.08	1.58	0.65
H	12.25	9.08	2.43	0.56
I	11.75	8.75	1.65	0.54
J	11.92	8.75	1.99	0.49
K	12.08	8.75	1.75	0.75
L	12.25	8.75	2.38	0.54

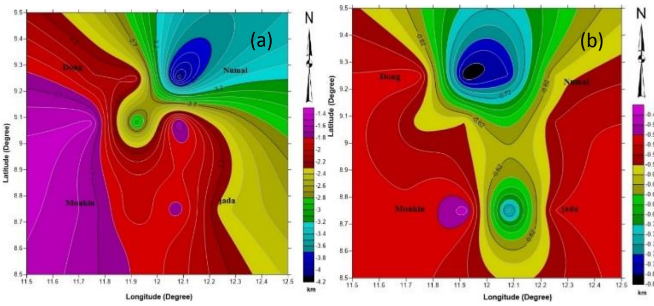


Figure 6: (a) Contour map of the deeper depth of the Study area, (b) Contour map of the shallow depth of the study area

3.2 Results of Source Parameter Imaging (SPI)

The depth to top of magnetic basement of the study area was estimated using source parameter imaging (SPI). SPI gives a conspicuous image of the anomalies with respect to their depth. Figure 7 is the Source parameter imaging map and was produced in aggregates of colours; red to pink depicting shallow depth; green colour depicting intermediary depth and blue colour depicting thick sediments. Shallow and deeper depths were obtained from the results of the SPI; the shallow depths ranging from 64.9 m to 174.6 m at the southern to the central part of the study area which corresponds to Jada while maximum depth ranges from 1075.0 m to 4420.7 m at the north-eastern part of the study area which corresponds to Numal. Since the maximum depth of 3 km and above in a rift basin is sufficient for hydrocarbon maturation and accumulation (Adewumi et al., 2017). Hence, the maximum sedimentary thickness of 4420.7 m obtained from the study area (Adamawa trough) is sufficient for hydrocarbon maturation and accumulation and a good pointer for petroleum exploration.

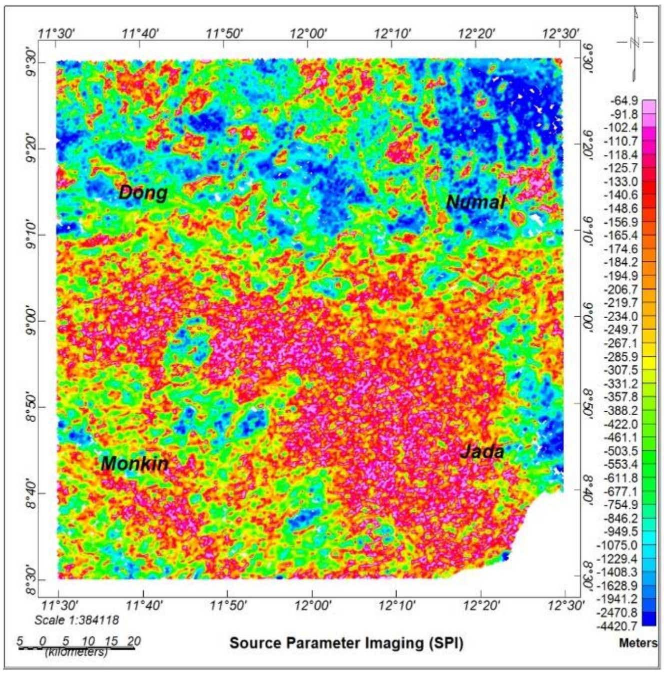


Figure 7: Source Parameter Imaging (SPI) Map of the Study Area

3.3 Results of 3D Euler Deconvolution

Figure 8 presents the result of the Euler deconvolution map produced from the study area. The pre-processed grids of the residual map (dx, dy and dz) were used to calculate the Euler depth with structural index 1. The Euler Depth map shows that the depth to magnetic sources (anomalies) ranges from 104.2 m to 4208.3 m. The Euler depth map agrees with the SPI map (Figure 7) (Ogunmola et al., 2016). The regions of shallow depth on the Euler depth map corresponds to the regions of shallow depth on Figure 7. While the region of deeper depth (thick sediments) on the Euler depth map corresponds to the regions of thick sediments on the Figure 7. The maximum depth of 4208.3 m obtained at the north-eastern part of the study area from the Euler solutions is sufficient for hydrocarbon maturation and accumulation and a good indicator for petroleum exploration in the Adamawa trough.

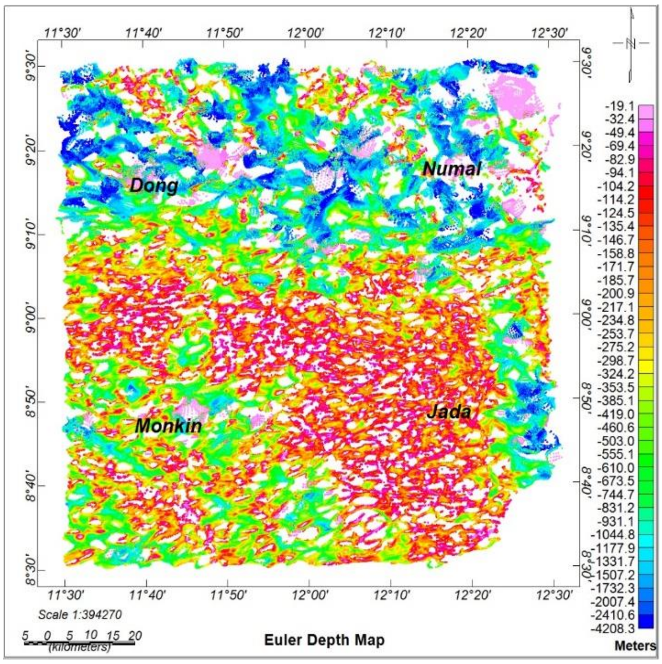


Figure 8: Euler depth map of the study area

4. Conclusion

The high-resolution aeromagnetic data of Adamawa trough (Upper Benue trough) has been analysed and interpreted quantitatively using three depth estimating techniques; Source parameter imaging, Euler deconvolution and spectral method to estimate the thickness of sedimentation for hydrocarbon maturation and accumulation for petroleum exploration in the study area. It is an established fact by several researchers around the globe that hydrocarbon maturation and accumulation are controlled by some factors such as; source rock, thickness of sediments, and thermal gradients. The residual map was subjected to quantitative analysis to estimate the depth to magnetic source for hydrocarbon maturation and accumulation. The spectral method, SPI and Euler deconvolution shows a maximum sedimentary thickness of 4.17 km, 4.420 km and 4.208 km at north-eastern part of the study area which corresponds to Numal respectively. The results from the three depth estimating techniques used in this study agrees and correlate with the previous work carried out in that area. It can therefore be inferred from this study that, the thickness of sedimentation obtained is sufficient might for hydrocarbon maturation and accumulation.

Recommendation

The outcome of this present research can further be investigated using more sophisticating geophysical method such as seismic reflection technique capable of imaging the subsurface structures for hydrocarbon exploration. Especially regions of thick sediments of 4 km and above.

References

Adetona, A.A., and Abu, M., 2013. Estimating the thickness of sedimentation within Lower Benue Basin and Upper Anambra Basin, Nigeria, using both spectral depth determination and source parameter imaging. ISRN Geophysics, Pp. 1-10.

Adewumi, T., Salako, K.A., Salami, M.K., Mohammed, M.A., Udensi, E.E., 2017. Estimation of Sedimentary Thickness Using Spectral Analysis of Aeromagnetic Data over Part of Bornu Basin, Northeast, Nigeria. Asian Journal of Physical and Chemical Sciences, Pp. 1-8.

Hood, P., 1965. Gradient measurements in aeromagnetic surveying. Geophysics, 30 (5), Pp. 891-902.

Igwesi, I.D., Umego, M.N., 2013. Interpretation of aeromagnetic anomalies over some parts of lower Benue Trough using spectral analysis technique. Int. J. Sci. Technol. Res., 2 (8), Pp. 153-165.

Obaje, N.G., 2009. The Benue Trough. In Geology and Mineral Resources of Nigeria, Pp. 57-68). Springer, Berlin, Heidelberg.

Ofoegbu, C.O., Onuoha, K.M., 1990. A review of geophysical investigations in the Benue Trough. Friedr: Vieweg and Sohn., Pp. 170.

Ogunmola, J.K., Ayolabi, E.A., Olobaniyi, S.B., 2016. Structural-depth analysis of the Yola Arm of the Upper Benue Trough of Nigeria using high resolution aeromagnetic data. Journal of African Earth Sciences, 124, Pp. 32-43.

Salako, K.A., 2014. Depth to basement determination using Source Parameter Imaging (SPI) of aeromagnetic data: An application to upper Benue Trough and Borno Basin, Northeast, Nigeria. Academic Research International, 5 (3), Pp. 74.

Spector, A., Grant, F.S., 1970. Statistical models for interpreting aeromagnetic data. Geophysics, 35 (2), Pp. 293-302.

Thompson, D.T., 1982. EULDPH: A new technique for making computer-assisted depth estimates from magnetic data. Geophysics, 47 (1), Pp. 31-37.

Thurston, J.B., Smith, R.S., 1997. Automatic conversion of magnetic data to depth, dip, and susceptibility contrast using the SPI (TM) method. Geophysics, 62 (3), Pp. 807-813.