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Full Length Research Article

ESTIMATION OF MAGNETIC DEPTH TO SOURCE USING HIGH RESOLUTION OF AEROMAGNETIC DATA OF PARTS OF UPPER BENUE TROUGH, NORTH EASTERN NIGERIA

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ABSTRACT

A detailed quantitative interpretation of high resolution aeromagnetic data covering latitude 9.0°N – 10.0°N and longitude 11.0°E – 12.0°E with a total area of 12,100km^2 which corresponds to parts of upper Benue Trough (Kaltungo, Guyok, Lau and Dong) Northeast, Nigeria has been carried out using Source Parameter Imaging (SPI) and Standard Euler Deconvolution methods for the purpose of estimating the sedimentary thickness of the study area for hydrocarbon maturation or accumulation. The polynomial fitting with order one method was applied in the regional–residual separation. Further analysis was conducted on the residual map. The SPI results revealed a maximum sedimentary thickness of 4908.178m while Standard Euler Deconvolution results also revealed a depth of 4050.1 m. Therefore, the highest sedimentary thickness of the study was found around Wafango, Dong and Lau region of the study area with shallow thickness of 741.108m to 1162.154m around Biliri, Tula and Kaltungo down to Lankoviri in Southern region of the study area. Consequently, the highest sedimentary thickness of about 4908.17 m from SPI and 4050.1 m from Standard Euler deconvolution is sufficient enough for hydrocarbon maturation or accumulation. These areas with maximum sedimentary thickness may be subjected for further geophysical investigation like seismic reflection/refraction, so as to affirm its hydrocarbon potential.

Keywords: Aeromagnetic data, Hydrocarbon, Euler deconvolution, Maturation, Sedimentary thickness

INTRODUCTION

The Upper Benue Trough and Gongola Basin in particular is one of those basins being presumed to have high hydrocarbon potential, besides other economic mineral deposits concentration (Abubakar *et al,* 2010). The Benue Trough of Nigeria is an elongated trough of subsidence which trend north east to attain an approximate length of 800km. it has a width of 130-150km and it is filled with Cretaceous sediments whose ages ranges from middle Albian to Maestrichtian, (Ofoegbu, 1984). Aeromagnetic methods are widely used to infer subsurface geologic features by observing variations in the Earth's magnetic field arising from contrasts in total magnetization of the crust.

This study aims at using high resolution aeromagnetic data to estimate the sedimentary thickness of parts of Upper Benue trough. This has implication on the on-going petroleum exploration in the Nigerian basins with the aim of increasing our oil/gas reserve, boost our economy, provide suitable environment for business opportunity and consequently, eradicate unemployment and poverty from the country.

Just of recent the Nigerian National Petroleum Corporation (NNPC) disclosed the intention of Indonesia a South East Asian country, indicating their interest to buy more crude oil from Nigeria above the current 18 percent they used to buy. As a result of this demand which is a welcome development to the country economy, it is of necessity to explore other sedimentary basins in Nigeria presume to be rich in hydrocarbon like the upper Benue trough, as this will boast the economy of the nation and pave way for business opportunities in the country.

This study is on basis of reconnaissance survey and thickness of the sedimentary basin is an important factor in hydrocarbon exploration. Two depth estimating methods was adopted in this study to estimate the sedimentary thickness of the study area; Source Parameter Imaging and Standard Euler deconvolution. One of the importance of these methods is that they show the image of the depth.

Location and the Geology of the Study Area

This study area is bounded by latitudes 9.00'N to 10.00'N and longitudes 11.00'E to 12.00'E located within the Upper Benue Trough and Gongola Basin, Northeast, Nigeria. The study area covers parts of Taraba, Gombe and Adamawa States, North East Nigeria (Figure 1). It is approximately 12,100 km^2. All the rocks in the area belong either to the Upper Cretaceous or to the Precambrian. All the above mentioned units have already been described in detail by various workers Eborall (1976), and Bowden and Turner (1974)). The sandstones of the Upper Benue Trough and the lower part of the Bornu Basin belong to the Upper Cretaceous and they are underlain by the Precambrian rocks of the Basement Complex. The Upper Benue Trough comprises the area extending from the Bashar-Mutum Biyu line as far north as the "Dumbulwa-Bage high" of Zaborski *et al.* (1998), which separates it from the Bornu Basin. Early studies of the Upper Benue Trough and Southern Bornu Basin were carried out by Raeburn and Jones (1934) and Barber (1965).

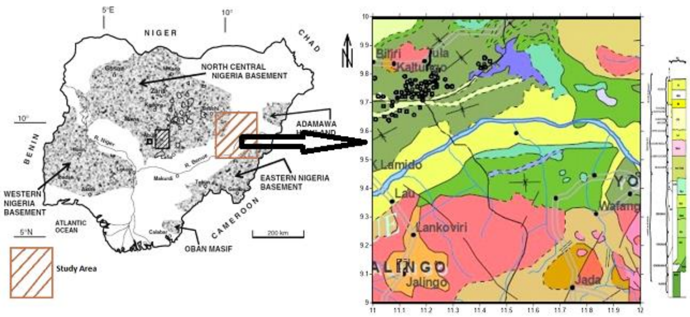

Figure 1: Geological Map of the Study Area

MATERIALS AND METHODS

Four aeromagnetic maps (HRAM) with sheet numbers 173, 174, 194 and 195 and their respective locations; Kaltungo, Guyok, Lau and Dong were acquired, assembled and interpreted. These maps were obtained as part of the nationwide airborne survey carried out by Fugro and sponsored by the Nigerian Geological Survey Agency in the year 2009. The data were obtained at an altitude of 100 m along a flight line spacing of 500 m oriented in NW-SE and a tie line spacing of 2000 m. The maps are on a scale of 1:100,000 and half-degree sheets contoured mostly at 10nT intervals. The geomagnetic gradient was removed from the data using the International geomagnetic Reference Field (IGRF). The total area covered was about 12,100 km^2. The actual magnetic intensity value of 33,000 nT which was reduced for handling purpose must be added so as to get the actual value of the magnetic intensity at any point.

The four maps covering the study area were assemble and merged. The next step was to re-gridded the maps using Oasis Montaj software to produce the total magnetic intensity map (TMI) of the study area (Fig.2). The magnetic intensity of the study area ranges from -19.1 nT to 144.5 nT after 33000 nT have been removed. The TMI was subjected to regional/residual separation using polynomial fitting with order one for further processing to achieve the target. The pre-processed grids from residual map (Figure 3) dx, dy and dz was used to calculate the source parameter imaging.

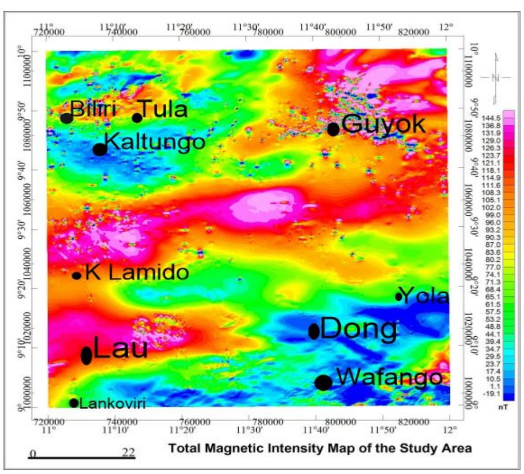

Figure 2: Total magnetic Intensity Map of the study Area (33,000 nT must be added to get the actual magnetic value at any point)

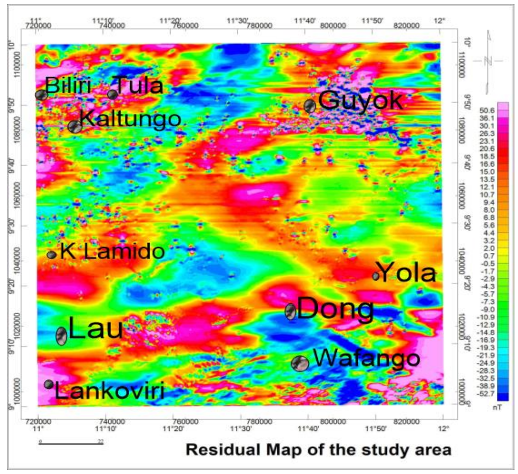

Figure 3: Residual Map of the Study Area

Source Parameter Imaging (SPI)

The Source Parameter Imaging was carried out on the residual data for the purpose of investigating the sedimentary thickness beneath the surface. The pre-processed grids, from the residual grid, used as input grids for SPI are dx, dy and dz.

The Source Parameter Imaging TM (SPITM) function is a quick, easy and powerful method for calculating the depth of magnetic sources. Its accuracy has been shown to be ± 20% in test on real data sets with drill hole control. This accuracy is similar to that of Euler deconvolution, However SPI has the advantage of producing a more complete set of coherent solution points. The SPI method by Thurston and Smith (1997) estimates the depth from the local wave number of the analytic signal. The analytic signal A1(x, z) is defined by (Nabighian, 1972) as:

$$A_1(x,z) = \frac{\partial M(x,z)}{\partial x} - j\frac{\partial M(x,z)}{\partial z}, \qquad (1)$$

Where M(x,y) is the magnitude of the anomalous total magnetic field, j is the imaginary number, z and are Cartesian coordinates for the vertical direction and horizontal direction respectively. Nabighian (1972) reveal that horizontal and vertical derivatives comprising the real and imaginary parts of the 2D analytical signal are related as follows:

$$\frac{\partial M(x,z)}{\partial x} \Leftrightarrow \frac{\partial M(x,z)}{\partial z}, \qquad (2)$$

Where ⇔ denotes a Hilbert transformation pair. The local wave number k_1 is defined by Thurston and Smith (1997) to be

$$k_1 = \frac{\partial}{\partial x}\tan^{-1}\left[\frac{\partial M}{\partial z}\Big/\frac{\partial M}{\partial x}\right], \qquad (3)$$

The concept of an analytic signal comprising second-order derivatives of the total field, if used in a way similar to that used by Hsu et al. (1996), the Hilbert transform and the vertical-derivative operators are linear, so the vertical derivative of (2) of will give the Hilbert transform pair,

$$\frac{\partial^2 M(x,z)}{\partial z\,\partial x} - \frac{\partial^2 M(x,z)}{\partial^2 z}, \qquad (4)$$

Thus the analytic signal could be defined based on second-order derivatives, $A_2(x,z)$, where

$$A_2(x,z) = \frac{\partial^2 M(x,z)}{\partial z\,\partial x} - j\frac{\partial^2 M(x,z)}{\partial^2 z} \qquad (5)$$

This gives rise to a second-order local wave number k_2, where

$$k_2 = \frac{\partial}{\partial x}\tan^{-1}\left[\frac{\partial^2 M}{\partial^2 z}\Big/\frac{\partial^2 M}{\partial z\,\partial x}\right], \quad (6)$$

The first and second order local wave numbers are used to determine the most appropriate model and a depth estimate independent of any assumptions about a model.

The first and second order local wave numbers are used to determine the most appropriate model and a depth estimate independent of any assumptions about a model.

Nabigbian (1972) gives the expression for the vertical and horizontal gradient of a sloping contact model as:

$$\frac{\partial M}{\partial x} = 2KFcsin\,d\,\frac{h_c\cos(2I-d-90)+xsin(2I-d-90)}{{h_c}^2+x^2}, \quad (7)$$

$$\frac{\partial M}{\partial z} = 2KFcsin\,d\,\frac{x\cos(2I-d-90)+h_c sin(2I-d-90)}{{h_c}^2+x^2}, \quad (8)$$

where K is the susceptibility contrast at the contact, F is the magnitude of the earth's magnetic field (the inducing field),$c = 1 - cos^2 isin^2\alpha$,$\alpha$is the angle between the positive x-axis and magnetic north, *i* is the ambient-field inclination, $tanI = sini/cos\alpha$d is the dip (measured from the positive x-axis), *hc* is the depth to the top of the contact and all trigonometric arguments are in degrees. The coordinate system has been defined such that the origin of the profile line (x = 0) is directly over the edge.

The expression for the magnetic-field anomaly due to a dipping thin sheet is

$$M(x,z) = 2KF_{cw}\frac{h_1\sin(2I-d)+xcos(2I-d)}{{h_c}^2+x^2}, \quad (9)$$

Reford (1964), where w is the thickness and h_1 the depth to the top of the thin sheet. The expression for the magnetic-field anomaly due to a long horizontal cylinder is

$$M(x,z) = 2KFS\frac{sini}{sinr}\frac{({h_h}^2-x^2)\cos(2I-180)+2xh_h\sin(2I-180)}{({h_c}^2+x^2)^2}, \quad (10)$$

Murthy and Mishra, S is the cross-sectional area and h_h is the depth to the centre of the horizontal cylinder.

Substituting (7), (8), (9) and (10) into the first- and second- order (i.e. (3) and (6) respectively) local wavenumbers, we obtain, after some simplification, a remarkable result as:

$$k_1 = \frac{(n_k+1)h_k}{{h_k}^2+x^2}, \quad (11)$$

and

$$k_2 = \frac{(n_k+2)h_k}{{h_k}^2+x^2}, \quad (12)$$

Where n_k is the SPI structural index (subscript k = c, t or h), and n_c =0 n_t = 1 and n_h = 2 for the contact, thin sheet and horizontal cylinder models, respectively. From (11) and (12) above, it is evident that the first- and second- order local wave number are independent of the susceptibility contrast, the dip of the source and the inclination, declination, and the strength of the earth's magnetic field.

The contact, thin sheet and horizontal cylinder are all two-dimensional models (infinite strike extent), so it is an implicit assumption of the SPI method that the geology is two dimensional. If the body is two-dimensional and there is no interference from nearby bodies, the depth estimate will be reasonable and the structural index should be constant over the entire area for which the response is anomalous.

Standard Euler Devolution

The Standard Euler deconvolution which uses the analytical signal in the calculation of depth to basement of the magnetic anomaly was employed. The anomaly profile selected was perpendicular to the geological structure generating the field. The Euler deconvolution assumes the source bodies are either dikes or contacts with infinite depth extent and uses a least-squares approach to solve for the source body parameters in a series of moving windows along the profile (Ku & Sharp, 1983). Solutions derived from the total field profile are designated "Dike" solutions and solutions derived from the horizontal gradient are designated "Contact" solutions.

Each Euler deconvolution calculation operates on a segment of the anomaly profile referred to as a window, and produces a single solution at each window. Several parameters which controls the number of solutions generated by Euler deconvolution was set accurately to generate the desired solution. The Window Expansion Increment which determines the number and size of steps between the minimum and maximum length was set to 500. The distance which the Standard Euler operator moves along the profile between calculations was set to 200 in other to restrain the number of solutions generated. Solutions caused by noise in the input profile were eliminated by setting an amplitude threshold for the anomalies (setting the "Residual cut-off" to 0.1). The calculated solutions are saved in an Oasis montaj database (GDB), allowing for viewing in profiles or 2D plots.

A formulation of Euler's homogeneity relationship given by Reid *et al.* (1990) shows that:

$$(x-x_0)\frac{\delta T}{\delta x} + (y-y_0)\frac{\delta T}{\delta x} + (z-z_0)\frac{\delta T}{\delta z} = N(B-T) \quad (13)$$

where *(x_o,y_o and zo)* are the positions of the magnetic source whose total magnetic intensity field T is detected at *(x,y,z).*

RESULTS AND DISCUSSION

The pre-processed grids *dx, dy and dy* from residual grid (Fig. 3) was used as an input grid to calculate the source parameter imaging (Fig. 3). This process was carried out using the algorithm in the Oasis Montaj software. SPI method makes the task of interpreting magnetic data significantly easier as shown by the SP images generated from residual field data of the studied area (Fig. 4). Different magnetic depths and susceptibilities contrast within the study area are indicated by the gridded SPI depth map and legend. The negative values shown in the SPI legend depicts the depths of buried magnetic bodies, which may be deep seated basement rocks or near surface intrusive while the positive values depicts outcropping magnetic bodies. The pink colour generally indicates areas occupied by shallow magnetic bodies, while the blue colour depicts areas of deep lying magnetic bodies ranging from -438.216 to -4908.178m. SPI depth result generally ranges from 315.373m (outcropping and shallow magnetic bodies) to -4908.178m (deep lying magnetic bodies). The highest sedimentary thickness found in the study area corresponds to Wafango and Dong. The SPI results agree with result obtained in (Salako *et al.,* 2013).

The Standard Euler deconvolution method for depth estimation is an automatic technique used for locating source of potential field based on amplitudes and gradients; it windows the area and locates structures and evaluate the depth to which those structures exist by writing equations for the structures. Its degree of accuracy depends on the structures having a perfect shape and that the structure or anomaly falls on the center of the window. Figures 5 represent the maps for the Euler depth. The Standard Euler Depth map shows two depth source; maximum depth of -4050.1 m and minimum depth of 856.2 m.

Comparing the results obtained in this work with the results obtained by other researchers in the Benue Trough, (Onwuemesi, 1997) evaluated the depth to the basement (sedimentary thickness) in the Anambra Basin to vary from 0.9 to 5.6 km. His depth is slightly higher than the depths obtained from this study. (Igwesi & Umego 2013) obtained a two layer source model with depth for deeper magnetic source ranging from 1.16 to 6.13 km with average of 3.03 km and depth to the shallower magnetic source ranging from 0.016 to 0.37 km with average of 0.22 km. Their estimated depth agrees with the depth estimated from this study especially within the shallow source. (Onuba *et al*., 2012) estimated that the depths to the magnetic source bodies in the lower Benue Trough and some adjoining areas vary from 0.518 to 8.65 km with a mean depth of 3.513 km (for deeper magnetic source bodies) and 0.235 to 3.91 km with a mean depth of 1.389 km (for shallower magnetic source bodies), which are greater than the depth estimated from this work. (Onuba *et al*., 2012) estimated the depth to basement over Okigwe areas and established two depth models varying from 2.18 to 4.91 km for deeper sources while the shallower sources vary from 0.55 to 1.82 km. However, they did not recommend hydrocarbon exploration in the area since the area has low thickness of sediments on the average. (Adetona & Abu 2013) estimated the thickness of sedimentation within the Lower Benue Basin and Upper Anambra Basin by employing spectral depth analysis and obtained a depth of 7.3 km and source parameter imaging to obtain a depth of 9.847 km. This result is also greater than our result. (Ezema *et al.*, 2014) estimated maximum depths of 4.96 to 9.8 km and minimum depths of 0.12 to 0.17 km over Abakaliki area. Their estimated depth agrees with our depth for the shallow source. The results of some of these works agree with the results of the present study especially within the shallow source. It should be noted that none of these works were carried out in Kaltungo, Guyok, Lau and Dong sheets, but in other parts of Upper Benue Trough.

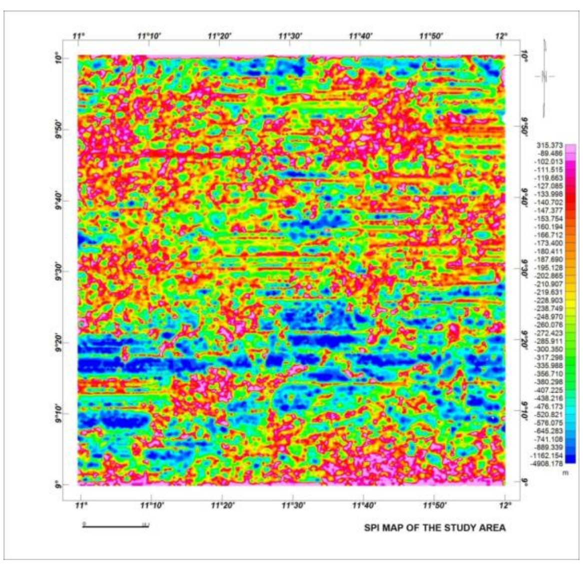

Figure 4: Source Parameter Imaging from the study Area

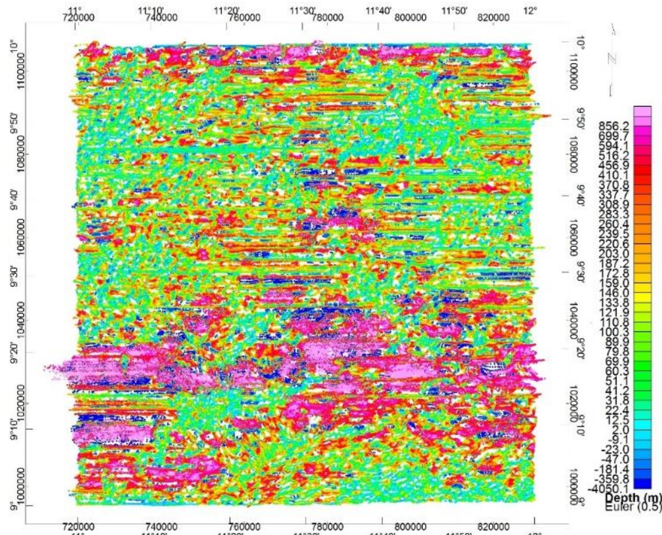

Figure 5: Standard Euler deconvolution produced from the Study Area

Conclusion

The depth estimation results from the two depth estimating methods; Source parameter imaging and Standard Euler deconvolution shows a good indications of the region in the study area harboring hydrocarbon potential by possessing a sedimentary thickness of over 3km. the sedimentary thickness of over 3 km from the study is sufficient enough for hydrocarbon maturation or accumulation.

Consequently, further geophysical survey like seismic reflection could be carried out in the areas with high sedimentary thickness of over 3 km to affirm the existent of the presumed hydrocarbon potential since this present study is bases on a reconnaissance survey.

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