Determination of Sedimentary thickness over parts of Middle Benue Trough, North-East, Nigeria using Aeromagnetic Data

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Abstract

High resolution aeromagnetic data acquired by the Nigerian Geological Survey Agency which covers about 18,150 km^2 of some parts of middle Benue trough (that lies between Longitude 9ºE – 10ºE and Latitude 8ºN – 9.50ºN), was processed and interpreted with the goal of estimating the study area sedimentary thickness. Polynomial fitting of order one was used in regional-residual separation of the Total Magnetic Intensity map of the study area. Thereafter, analytical signal, source parameter imaging (SPI) and spectral depth analyses were applied on the residual data. Results from the analytical signal showed that the area is made up of highs and lows magnetic anomalies with varying amplitudes. The SPI result revealed a sedimentary thickness ranging between 101.8 m and 2550.0 m and the depth estimates from the spectral depth analysis showed that the sedimentary thickness of the study area ranges between 1.20 km and 3.20 km. The estimated depths from spectral analytical method were contoured to portray the basement isobaths for the study area. The highest sedimentary thickness from both depth analytic methods agreed in terms of location, this value can supports the hydrocarbon (gas) accumulation in the central and southern part of the study area.

Keywords: Aeromagnetic data, polynomial fitting, analytic signal, source parameter imaging, spectral depth analysis and sedimentary thickness.

1. INTRODUCTION

Exploration of earth's contents have been of major concern to human because it requires an innovative technique to unravel its complexity as a result, geophysical survey method has been adopted to map the structures and lithology of the subsurface. Magnetic method is one of the best geophysical techniques used in delineating or estimating sedimentary thickness and other subsurface structures. Recent interest in the inland basins in Nigeria for petroleum and mineral deposits necessitated the need to study one of the prominent basins in which Middle Benue Trough is one of them, high resolution aeromagnetic data over part of Middle Benue Trough was used to determine the sedimentary thickness in the study area for possible hydrocarbon accumulation. The Middel Benue Trough, Nigeria, is part of the Benue Trough of Nigeria which is the study area of this research, the study area is located between latitude 8ºN and 9.50ºN and longitude 9ºE and 10ºE in north central Nigeria It covers an area of 18,150 km^2, and covers farmlands, villages, towns, game reserves, and natural reserves. The area lies east of the Federal Capital, Abuja.

This present study is based on reconnaissance survey and two depth estimating methods were adopted to determine the sedimentary thickness over part of middle Benue Trough for possible hydrocarbon potential in the area. The methods are source parameter imaging and spectral depth analysis. The results from these two methods, that is, source parameter imaging and spectral depth analysis would be used to suggest areas with the presence of hydrocarbon potential.

2. LOCATION AND GEOLOGY

The study area is located in the Middle- Benue Trough Nigeria and it lies in the north eastern part of Nigeria and it lies within latitude 8^0.00' N and 9^0.50' N and longitudes 9^0.00′ E and 10^0.00’ E. Figure 1a shows the generalized geology map of Nigeria showing the study Area (Obaje, 2009). The Benue Trough in Nigeria comprises of a progression of rift basins that model a portion of the Central West African Rift System of the Niger, Cameroon, Chad and Benin Basement fracture, subsidence, block faulting and cracking.

Benkhelil (1982 and 1989),pointed out that the Benue Trough generally has been geographically and structurally subdivided into three parts erroneously termed as "lower Benue Trough", "middle Benue Trough" and an "Upper Benue Trough".

The study conducted by Offodile (1976) distinguishes six sedimentary Formations in the middle Benue trough which are Asu River Group, Keana Formation, Awe Formation, Ezeaku Formation, Awgu Formation, Lafia Formation. The work of Cratchley and Jones (1965), Burke *et al.* (1970), Offodile (1976 and 1984), Osazuwa *et al.* (1981) and Offoegbu (1985) and Patrick*et al.*, 2013) have more on the geology of the Benue Trough. Figure 1b shows the geological map of the study area (extracted from geology map of Nigeria, produced by the Nigeria Geological Survey Agency 1984).

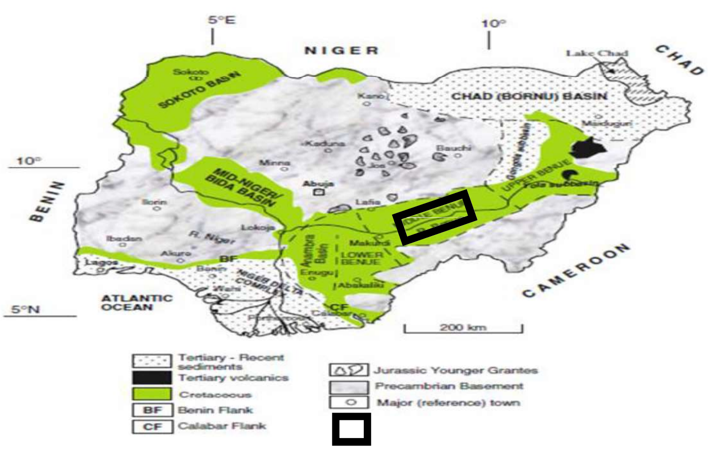

Figure 1a: Geological Map of Nigeria showing the study area in black outline (Source: Obaje, 2009)

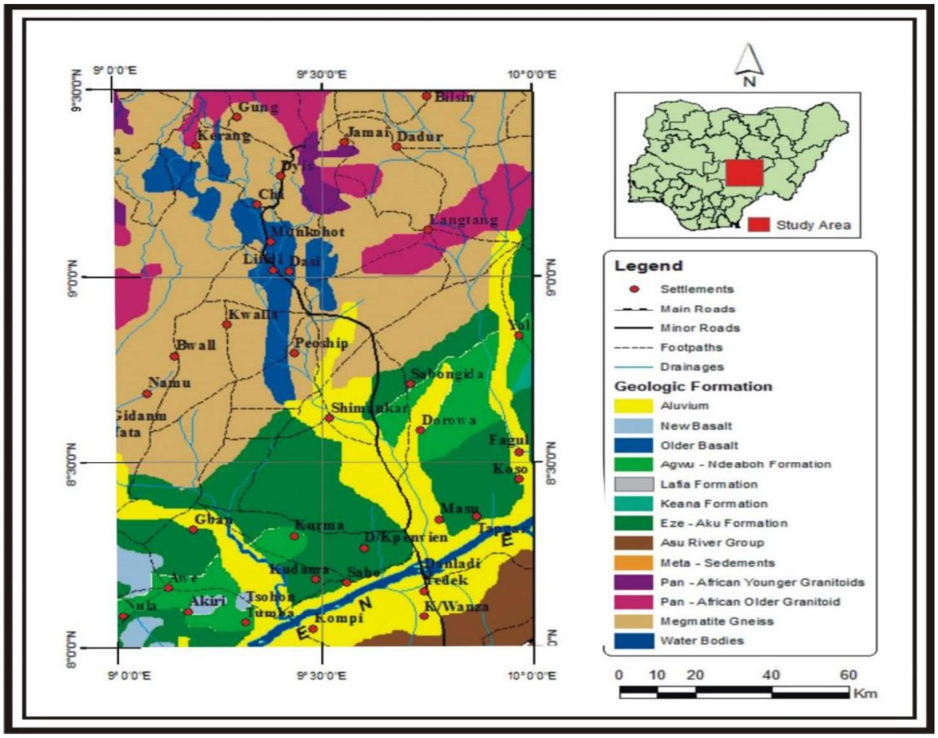

Figure 1b: Geological map of the middle Benue trough (Source: Geological Survey of Nigeria, 1984)

3.0 MATERIALS AND METHODS

For this work, six aeromagnetic maps with sheet numbers 190, 191, 211, 212, 231 and 232 covering the study area was acquired from the Nigerian Geological Survey Agency (NGSA) Abuja as a part of the across the nation aeromagnetic study carried out in 2009 by Fugro Airborne survey. The data was acquired using magnetometers. The survey was conducted along NW-SE flight lines and tie line along NE-SW direction with 500 m flight line spacing, Terrain clearance of 80 m and line spacing of 2 km were used. The magnetic data recording interval during the survey was 0.1 seconds. All grid data were saved and delivered in Oasis Montaj Geosoft raster file format. Each 1:100,000 topographical sheet covers an area of about 3,025 km^2 (i.e. 55 km x 55 km) totalling a superficial area of 18,150 km^2.

The TMI and even the aeromagnetic field sheets used in producing it are the entirety of the effect of all sources generating the magnetic anomaly. In applied geophysics, the issue is to dispose with or lessen to a minimum, the impacts of deep seated, non-profitable sources with minimum disturbance of the resultant anomaly as could reasonably be expected. Thus, this work begins with the separation of the long-wavelength anomalies of the regional field component which is attributed to deep and large scale sources from the shorter wavelength features constituting the residual field assumed to arise from shallow, small scale sources. In view of the simplicity in the trend of the magnetic field in the survey area, the regional field component was removed from the observed data using polynomial fitting method of order two.

The residual anomaly map was later subjected to three automated processing techniques to determine the depth to magnetic basement. The three automated processing techniques are (i) analytic signal, (ii) Source parameter imaging and (iii) spectral analysis

3.1 Analytic Signal method:

The analytic signal method is a notable method for establishing the edges of magnetic anomalies. The analytic signal is not dependent of magnetization direction and Earth's magnetic field direction. This implies that all bodies with similar geometry have the same analytical signal (Milligan and Gunn, 1997).
The function used in the analytic signal method is the analytic signal amplitude (absolute value) of the observed magnetic field at the location (x, y), defined by three orthogonal gradients of the total magnetic field using the expression:

$$|A(x,y)| = \sqrt{(\frac{\partial M}{\partial x})^2 + (\frac{\partial M}{\partial y})^2 + (\frac{\partial M}{\partial z})^2} \quad (3.1)$$

Where

A (x, y) = amplitude of the analytic signal at (x, y),

M = observed magnetic field at (x, y).

3.2 Source Parameter Imaging:

The Source Parameter Imaging (SPI^{TM}) is a technique using an extension of the complex analytical signal to assess magnetic depths. The Source Parameter Imaging TM (SPI^{TM}) function is a fast, simple, and powerful method for calculating the depth of magnetic sources. One merit of the SPI technique is that the depth can be visualized in a raster format and the true thickness determined for each anomaly (Salako 2014).
This approach developed by Thurston and Smith (1997) and Thurston et al. (1998, 1999) uses the connection between source depth and the local wave number (k) of the observed field, which can be calculated for any point within a grid of data through vertical and horizontal gradients Thurston and Smith, (1997). The depth is shown as an image. The basics are that for vertical contact, the peaks of the local wave number define the inverse of depth.

The SPI method (Thurston and Smith, 1997) estimates the depth parameter using the local wave number of the analytical signal (Salako 2014). The analytical signal A1(x, z) is defined by Nabighian (1972) as

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

Where

$A_1(x,z)$ = analytic signal

M(x,z) = magnitude of the anomalous total magnetic field,

Nabighian (1972) have demonstrated that the gradient change constitutes the real and imaginary parts of the 2D analytical signal are connected as follows:

$$\frac{\partial M(x,z)}{\partial x} \Leftrightarrow -j\frac{\partial M(x,z)}{\partial z} \quad (2)$$

Where

$\Leftrightarrow$ implies a Hilbert transform.

Thurston and Smith (1972) defined the local wave number k_1 to be:

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

Salako (2014) and Nwosu (2014) expressed that the marks illustrated by Thurston and Smith (1972) used Hilbert transformation pair expressed in (2). The Hilbert transform and the vertical derivative operators are linear, so the vertical derivative of (3) will give the Hilbert transform pair,

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

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

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

This gives rise to a second order local wave number κ_2 , where

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

This k_1 and k_2 are used to determine the most appropriate model and depth estimate of any assumption about a model.

3.3 Spectral analysis:

The method was pioneered by Bhattacharryya (1966) and developed by (Spector and Grant, 1970), it has been utilized widely in the interpretation of magnetic anomalies Onuoha *et al.* (1994), Nwogbo (1997)Eleta and Udensi (2012)Salako and Udensi (2013) Udensi E.E. (2000) Mishra and Naidu (1974). It depends on the expression of Power spectrum for the total magnetic field anomaly.

The approaches used involve Fourier transformation of the aeromagnetic data to compute the energy (or amplitude) spectrum. (Spector and Grant, 1970) demonstrated that the depth could be made using the equation

$$E(r) = \mathrm{e}^{-2\mathrm{hr}} \qquad (7)$$

where E(r) = spectral energy

r = frequency

h= depth

The energy or amplitude spectrum is plotted on the Logarithmic scale against frequency. The plot shows the straight line segments which decrease in slope with increasing frequency. The slopes of the segments yield estimates of depths to magnetic sources.

If h is the mean depth of a layer and the depth factor for the ensemble of anomalies is e^{-2rh} hence, a plot of the energy spectrum of a single ensemble of prism against angular frequency r would yield a straight line graph whose slope is directly proportional to the average source depth, h of that ensemble. That is, the logarithm plot of the radial would yield a straight line whose slope,

$$m = -2h$$

$$h = -\frac{m}{2} \qquad (8)$$

Equation (3.10) can be specifically applied if the frequency unit is in radian per unit distance (kilometer as it is in this research), if it is unit is in cycle per unit distance as it is in this work, the expression becomes

$$h = -\frac{m}{4\pi} \tag{9}$$

4 Discussion of Result

4.1 Total Magnetic Intensity (TMI)

The total magnetic intensity map (TMI) of the study area (Figure 2) shows variation of highs and lows in magnetic signature, ranging from -54.4nT to 153.5nT. The pink colouration depicts high magnetic signature while blue depicts low magnetic signature, greenish depicts alluvium deposition and yellow indicates intermediary. The high magnetic signature region denoted with **H** is well pronounced at the central part of the of the study area, trending East-West. Although the high magnetic signatures are scattered all round the study area while the low magnetic signature denoted with **L** is well pronounced in the northern part of the study area, though few lows could also be found at Southern part of the study area trending NE-SW.

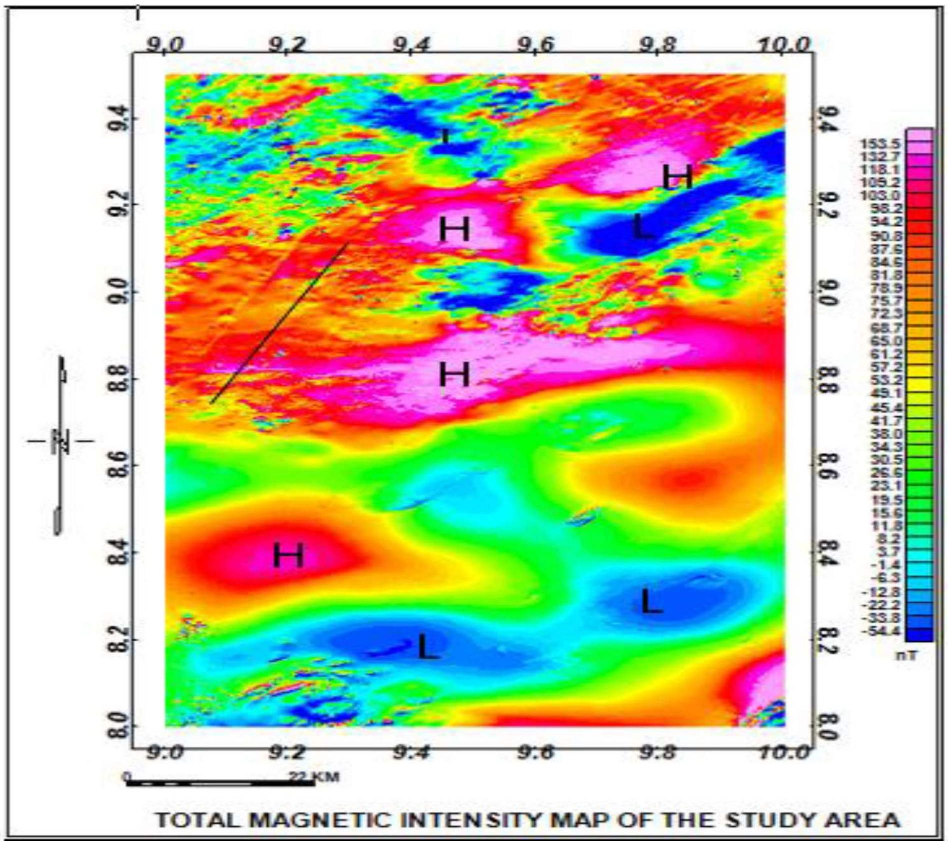

Figure 2: TMI anomaly contour map of the study area (add a background value of 33000nT to each value to get the actual value)

4.2 Regional map of the study area

The TMI is always a combination of the superposition of the impacts of all underground magnetic sources. Normally the targets in this aeromagnetic investigation are the anomalies of the basement rock, and their magnetic field is superimposed in the regional field that originates from larger or more profound sources, and must be separated to get the residual.

A look at the regional map (Figure 3) shows that the northern part is dominated with highs and low magnetic signatures are predominant at the southern part of the study area. The trends appeared in uniform variation (represented by parallel evenly spaced contours) can be observed to run in the NW-SE direction.

The regional field dips gently and uniformly towards the South-western part of the study area from the North-Eastern part

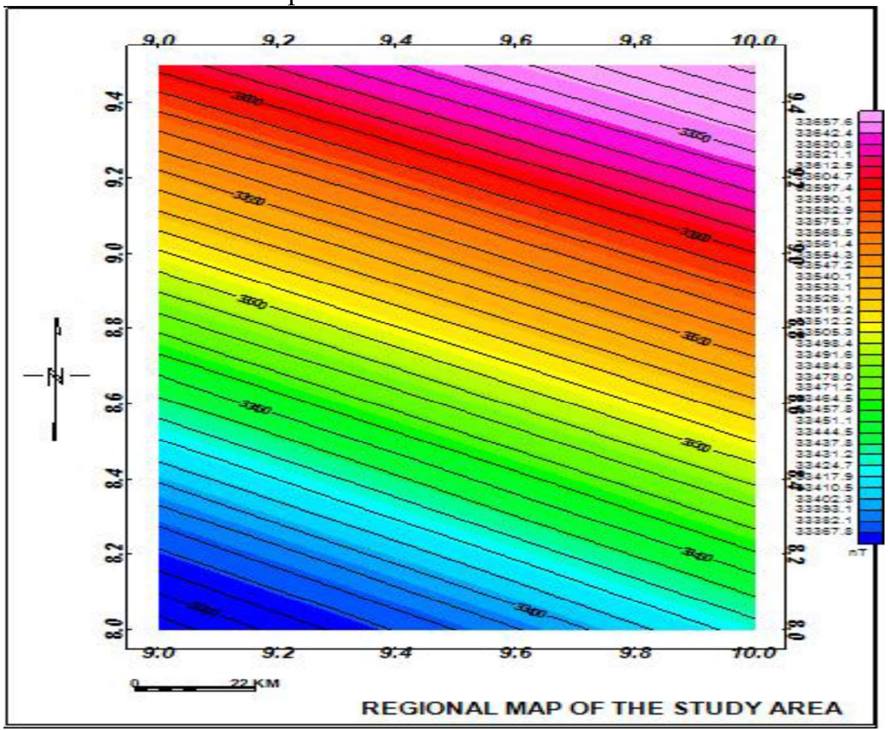

Figure 3: Regional map of the study area

4.3 Residual Map

The residual magnetic intensity map (Figure 4) of the study area shows that the area is made up of magnetic intensity values ranges from -109 nT to 99.9 nT. The negative values imply areas that are magnetically subdued or quiet while the positive values are magnetically responsive. The magnetically subdued areas are the magnetic lows of the study area and this is typical of a sedimentary terrain while the magnetic responsive areas are the magnetic highs regions which are assumed to be due to the likely presence of outcrops of crystalline igneous or metamorphic rocks, deep seated volcanic rocks or even crustal boundaries. The high magnetic anomaly which can probably be attributed to igneous intrusion and shallower sediment is well pronounced in the central part trending approximately East-West similar to the one in TMI map (figure 2). The high magnetic signature can also be found in the North-Eastern part trending North-West while the low magnetic anomalies associated with the sedimentary region was well pronounced in North-Western, North-Eastern, while other scattered at the edges of North-Eastern part of the study area.

About one third of the map can be seen to be greenish (featureless) which may correspond to alluvium deposition in the southern part of the study area.

The varying amplitude of these magnetic anomalies is an indication of different sedimentary thickness in the study area. These variations in the anomaly amplitude may also indicate possibly the occurrences of basement complex rocks containing varying amounts of magnetic minerals.
The traced line on the map is probably a fracture (fault line) At some places on the southern part of the residual map (Figure 4.3) there are anomalies that are not present on the total magnetic map (Fig. 4.1). These anomalies are due to magnetic source of shallow origin.

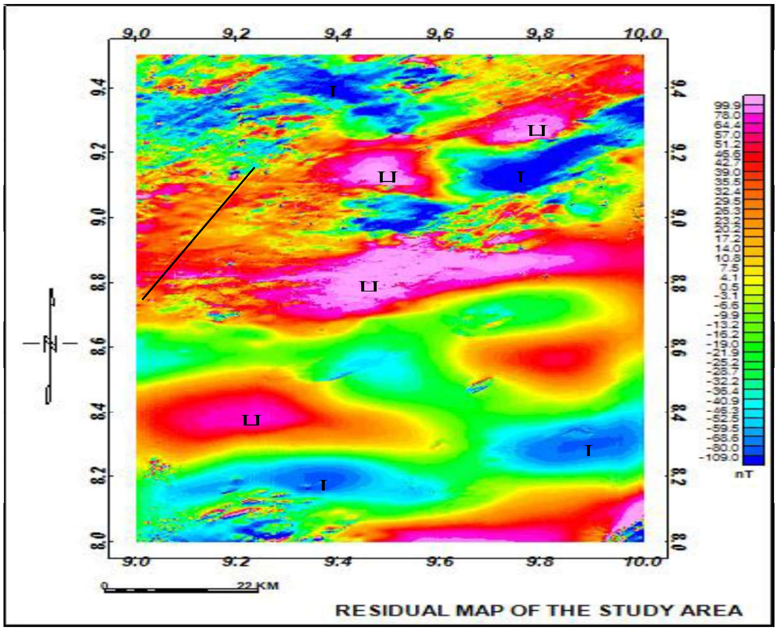

Figure 4: Residual map of the study area

4.4 Analytical signal

The analytic signal map (Figure 5) of the study area indicates contrast in magnetic anomalies amplitude, the lower magnetic anomalies amplitudes ranges from light green to deep blue colour as indicated in the legend. Red, yellow and orange colour depicts areas of higher magnetic anomalies amplitude.

The high amplitude magnetic anomalies were very much pronounced in the northern part and at the edges of the study area. The low amplitude magnetic anomalies were located at the central part and trends towards the south east. The high amplitude magnetic anomaly is probably due to basement intrusion close to the surface.

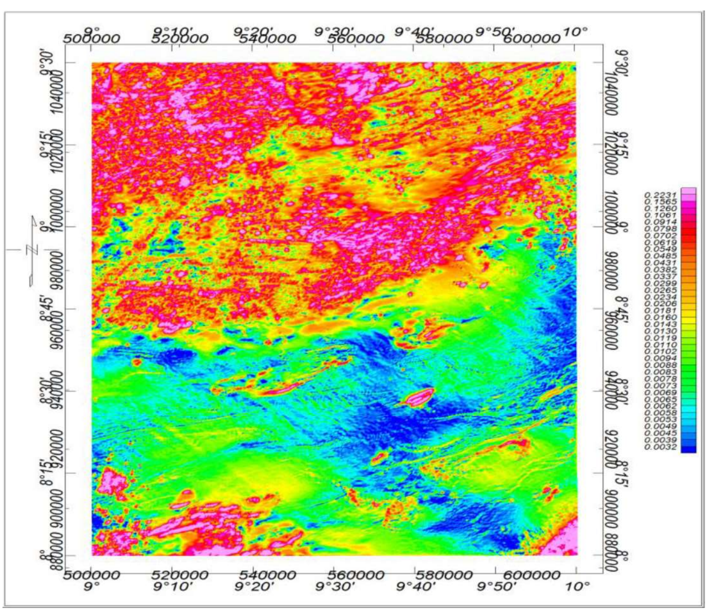

Figure 5: Analytic Signal Map of the Study Area

SPI image and interpretations

The source parameter image (SPI) figure (Figure 6) shows varied colours supposedly demonstrating distinctive magnetic susceptibilities variation in the studied area, and could likewise depicting the undulations in the basement surface. The negatives in the numbers on the legend imply depth. The light blue to deep blue colours indicates areas of thicker sediments or deep lying magnetic bodies, the purple and orange colour depicts areas of shallower sediment or close surface lying magnetic bodies. The white areas/ portion of the SPI are the areas where the derivative used to estimate the local wave number are so small that the SPI structural index cannot be estimated reliably. The model-independent local wave number had been set to zero in that portion.

The source parameter imaging (Figure 6) of the study area shows that most of the features are aligned in the same manner trends as it is in the analytic signal map (Figure 5). The area of highest sedimentary thickness in SPI (Figure 6) conforms to area of lower amplitude magnetic anomalies in analytical signal map (Figure 5).
From Figure (6), the depth to sedimentary/basement interface varies between 101.8 m and 2550.0 m. The thick sediment dominate the southern portion of the area while the least depth dominate major part of the southern portion. However, relatively lower depths are seen scattered around southern part.

According to Ofoha *et al* (2016), the thick sediments which range from 0.98 km to 2.6 km (represented with the blue colour) is synonymous to depth of over burden sediment which has a very important significance as to the hydrocarbon generation potential. And the least depth 0.1 to 0.8 (represented by the magenta, yellow, orange and green colours) indicates shallow seated magnetic bodies that have intruded unto the sedimentary cover and this falls short of the average thickness needed for the accumulation of oil and gas.

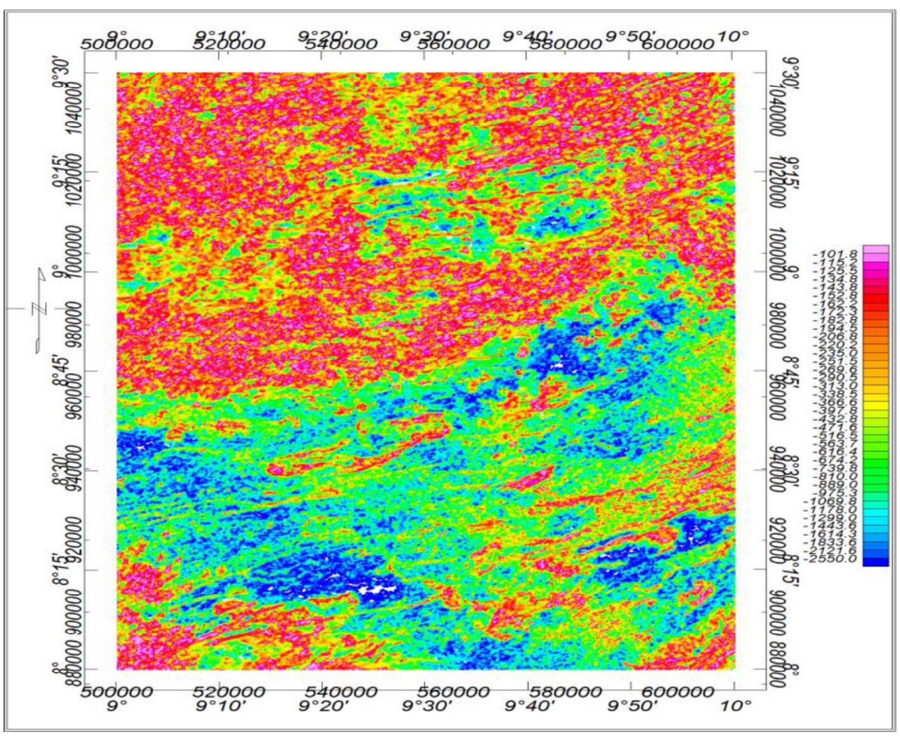

Figure 6: Source Parameter Imaging (SPI) map of the study Area

4.4 Spectral Analysis

The residual map (Figure 4) of the study area was divided into fourteen (Blocks A - N) overlapping magnetic sections in which six (Blocks A - F) covered 55km by 55km data points, three other division (Block G,H and I) covered 110km by 55 km data points, J, K and L covered 110km by 110km and Block M and N covered the remaining 165 km by 55 km part of the study area. In doing this division we ensured that essential parts of anomaly were not cut by the blocks.
The divisions of residual map into spectral sections or blocks were done with Oasis Montaj. The analysis was carried out using a spectral program plot (SPP) developed with MATLAB. Graph of the logarithm of spectral energies against frequencies obtained for blocks A, B, C, and D are shown in (Figure 7) while others are shown in Appendix. The second slope in the plot were used to compute the sedimentary thickness in line with equation 8.
From the result sedimentary thickness ranges from 1.20 km to 3.20 km which largely agrees with the result obtained earlier with SPI that range from 0.101 km to 2.55 km.
Results from the three estimate approaches agreed largely with other published works in the studied area. Nwogbo (1997) got 2km to 2.62km for deeper source and 70m to 0.63km for shallow source from spectral analysis of upper Benue trough; Alkali and Kasidi (2013) obtained two layer depths with the deeper magnetic sources vary between 1.2 km to 4.8 km and the shallower magnetic sources; vary between 0.5km to 1km.
Nwosu (2014) got an average depth of 1079.5 m for shallower source while the deeper magnetic source bodies) have an average depth of 3245m. Alagbe and Sunmonu (2014) using spectral analysis obtained values ranging between 1.22km and 3.45km for depth to magnetic basement
The contour map for the sedimentary thickness is shown in figure 8

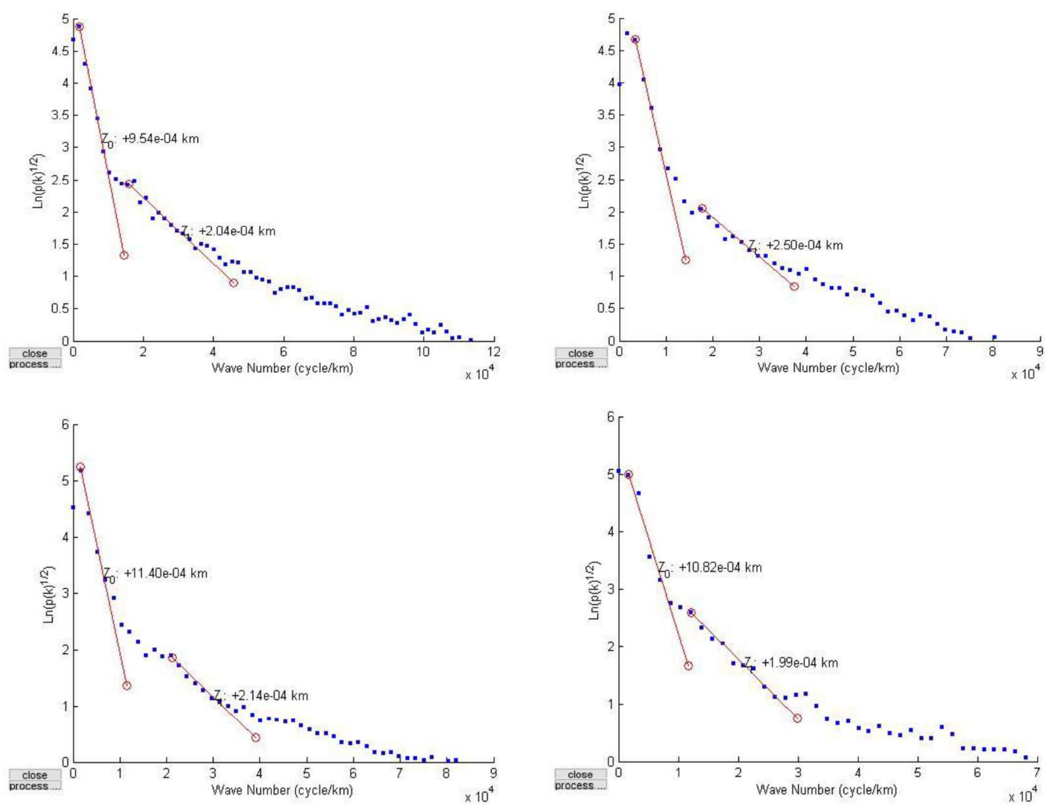

Fig. 7. Typical plots of the logarithm of spectral energies against frequencies obtained for block A, B, C, and D

Table 4.1. Location and depth estimation of sedimentary thickness (Z_t)

Blocks	**Longitude (degree)**	**Latitude (degree)**	**Sedimentary thickness Z_t(km)**
A	9.25	9.25	2.04
B	9.75	9.25	2.50
C	9.25	8.75	2.14
D	9.75	8.75	1.98
E	9.25	8.25	1.20
F	9.75	8.25	1.40
G	9.5	9.25	2.00
H	9.5	8.75	3.20
I	9.5	8.25	1.70
J	9.5	9.0	1.50
K	9.5	8.0	1.84
L	9.25	8.25	2.08
M	9.75	8.25	1.86
N	9.5	8.25	1.65
Average			1.94

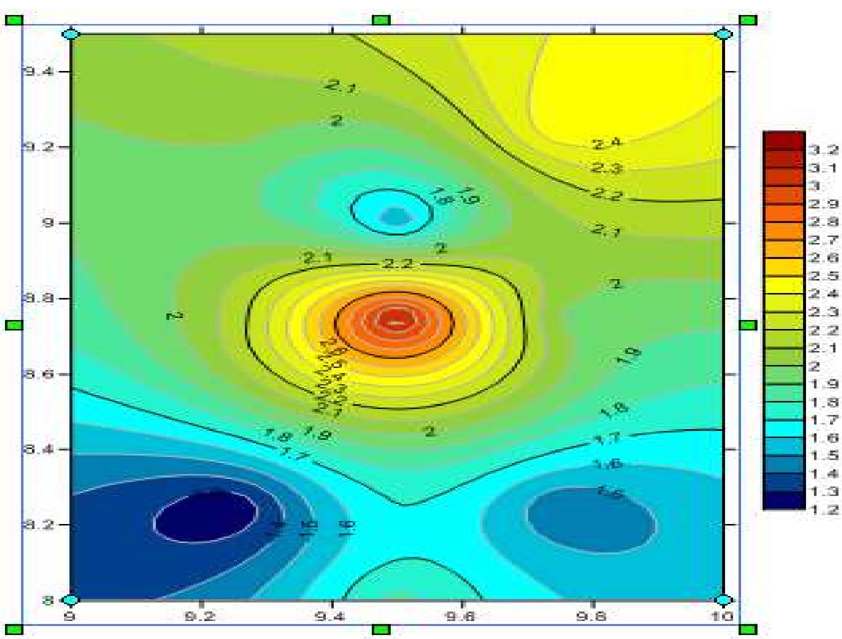

Figure. 4.7 contour map for the sedimentary thickness

CONCLUSION

The results of this study have suggest that the sedimentary thickness of the study area vary between 1.20 to 3.20 km. the high sedimentary thickness can be observed from the central part to the Northern part. These areas correspond to areas with highest magnetic values in total magnetic intensity (TMI) map of Figures 2 and residual map of Figure 4.

hence, the thick sedimentary cover in this region could be associated with hydrocarbon maturation or to series of volcanic activities that led to the formation of intrusive within the Middle Benue Trough.

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