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Estimation of Sedimentary Layer Thicknesses over Parts of Northern Bida Basin, Nigeria

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Abstract: *The study was carried out with the aim of interpreting the aeromagnetic data to delineate the sedimentary layer thickness over Northern part of Bida Basin for possible hydrocarbon potential. The study area is bounded by longitude 4^0 30' to 5^0 30' N and latitude 9^0 30' to 10^0 30'E with an estimated total area of 12100 km^2 covering four (4) aeromagnetic sheets of Auna, Kontagora, Kainji and Fashe. The Total magnetic intensity(TMI) map was subjected to the regional-residual magnetic field separation using the upward continuation filter. Subsequently, the residual magnetic field anomaly map was subjected to the estimation of the sedimentary layer thickness using; the Spectral depth analysis, Source parameter imaging (SPI) and Euler deconvolution (ED) methods. However, the Spectral analysis revealed a maximum sedimentary thickness of 3.16 km, SPI method revealed a depth of 3.78 km and also ED method also revealed a depth of 3.34 km. The results from the ED method were superimposed on the SPI map plot to measure the degree of similarity between the two interpretation methods and a very good correlation was observed. It was found that, the northwestern (NW) around Auna to southeastern (SE) at Fashe sheets has the highest sedimentation while the northeastern (NE) at Kontagora to southwestern at Kainji showed low sedimentation. Therefore, the maximum sedimentary layer thickness obtained from the Spectral analysis, SPI and ED techniques can perhaps act as prospective locations for hydrocarbon characterization.*

Keywords: *Total magnetic intensity, Residual magnetic intensity, Sedimentary layer thickness, Spectral analysis, Source parameter imaging, Euler deconvolution and Hydrocarbon.*

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I. Introduction

In Nigeria, the lucrative oil and gas sector has over the years acts as the major economic activity that has contributed significantly to the socio-economic development of the country. The exploitation of the potential hydrocarbon in the Nigeria predominantly occurs in both onshore and offshore of the Niger Delta sedimentary region of Nigeria[1]. Similarly, numerous studies have been carried out in the inland basins of Nigeria (such as Anambra, Chad, Dahomey, Bida, Sokoto and Benue trough) with the sole purpose of finding commercial hydrocarbon potentials as the case of some African countries; Sudan, Chad and Niger Republic[1]. Several geophysical techniques including gravity, seismic and magnetichave been adopted to estimate the sedimentary layer thickness. In particular, the aeromagnetic method measures the subsurface geology on the basis of anomalies in the Earth's magnetic field resulting from the magnetic properties of the underlying rocks[2]. These makes the method one of the cost-effective and reliable geophysical tool that is capable of estimating the sedimentary layer thickness,delineate the lithologic units and subsurface geological structures even in rugged terrain over a short period of time[3].

The estimation of the sedimentary layer thickness is an essential parameter used in the identification of prospective hydrocarbon prospective areas. In this regards, the search for hydrocarbon prospective zones is therefore the search for areas with high sedimentary layer thickness. Several aeromagnetic data interpretation techniques have been employed in the estimation of the sedimentary layer thickness. For example;[4] applied Source Parameter Imaging (SPI) on aeromagnetic data of the Upper Benue trough and southern part of Borno basin in order to investigate the sedimentary layer thickness. [5]carried out aeromagnetic data analysis over Ado-Ekiti, Southwestern part of Nigeria in order to interpret the geology and estimate the depth to basement using Euler deconvolution method was applied on the aeromagnetic data and the solution varies from 0.132 km to 2.23 km.[6] carried out aSpectral depth analysis of some part of lower Sokoto basin to determine the sedimentary. Spectral depth analysis was carried out on each aeromagnetic sheet to estimate the depth to basement and infer areas of probable hydrocarbon prospects.[7] combined Euler deconvolution, Source Parameter Imaging (SPI) and Spectral analysis to the estimate the sedimentary thickness over southern parts of the Bida Basin with the aim of identifying the possible areas of hydrocarbon potential.

Over the last decade, there has been a lot of speculations that the existing hydrocarbon reserve of the Niger Delta region will decline in productivity due to the continuous exploitation.There is need to extend the search of hydrocarbon prospective zones in the inland basins of Nigeria in order to increase the reserve. The Northern parts of the Bida Basin has not been given much attention by researchers. It is for this reason, the present study focusedon the application of theSpectral analysis, Source Parameter Imaging (SPI) and Euler deconvolution (ED) methods to identify the areas with high basement depth (sedimentary layer thickness) within the study area.

II. Geological Setting of the Study Area

The area of study, is bounded by longitude 4^0 30' to 5^0 30' N and latitude 9^0 30' to 10^0 30'E which falls under the northern part of Bida basin as illustrated in the (Figure 1.3) below. The study consists of both Cretaceous sediment and the Precambrian basement complex. The Cretaceous sediment of the basin are made up of conglomerates, sandstones, siltstones, mudstones and ironstones which are predominantly found along the southeastern extending to the northern part of the study. The basement complex covers the northern, northwest and northeastern segment of the study area.

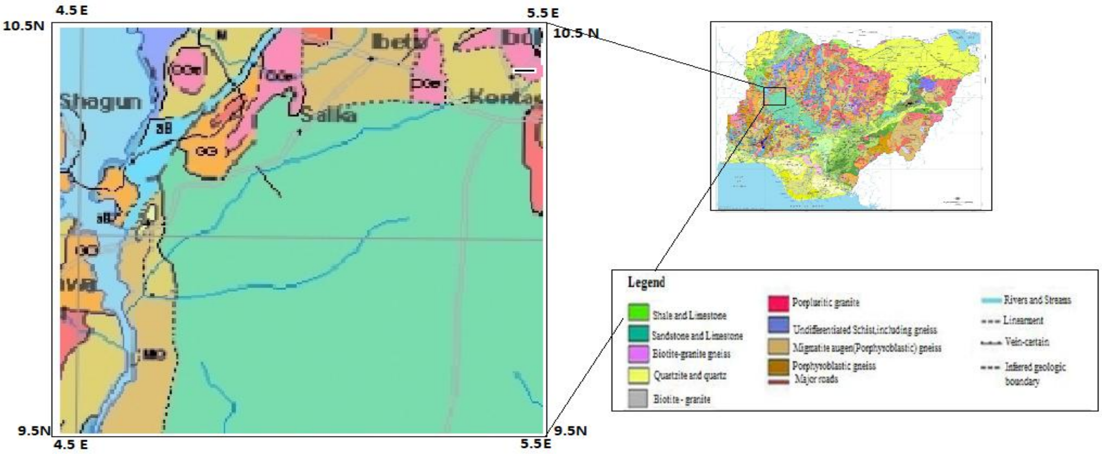

Figure 1.3. Geological map of the study area [8]

III. Materials and Methods

3.1 Data Acquisition

The Nigeria Geological Survey Agency (NGSA) carried out geophysical survey covering all part of Nigeria. The magnetic datasets were acquired through an attached 3×3 Scintrex CS3 cesium vapour magnetometer sensor on a fixed wing of the aircraft. The aircraft was flown along the NW-SE directions, with a line spacing of 500 m, mean sensor terrain clearance of 80 m and tie lines of 2000 m interval. The acquired data were corrected for both the Diurnal variation and the International Geomagnetic Reference Field (IGRF)[8]. The corrected aeromagnetic dataset was subjected to the Bi-directional gridding method to produce the Total magnetic intensity (TMI) anomaly grid shown in the Figure 2.The total magnetic intensity map of the study area was separated into regional-residual components using the upward continuation filter. Subsequently, the residual magnetic intensity anomaly was subjected to the spectral analysis, Euler deconvolution and source parameter imaging to appraise the sedimentary layer thickness over the study area.

3.2 REGIONAL SEPARATION

The regional separation was carried out usingthe upward continuation filter in order to enhances the deep seated structures which are also known as the regional anomalies. The UC filter smoothen out high frequency anomalies that emanates from shallow seated sources. The regional magnetic map was produced using upward continuation of the total magnetic intensity map at a distance of 100km. This was carried out in order to depict the deep seated magnetic anomalies that covers the study area.

3.3 RESIDUAL SEPARATION

The residual magnetic anomaly map of the study area was formed by subtracting the regional field from the total magnetic field. This was carried out with the aid of the Oasis Montaj software using grid math menu. The software generates the residual magnetic values by subtracting the regional magnetic field values from the total magnetic field values.

3.4SEDIMENTARY THICKNESS ESTIMATION

3.4.1 SPECTRAL ANALYSIS METHOD

The spectral analysis methodestimate the sedimentatry layer thickness (depths) via the computation of the widths and slopes of individual residual magnetic anomalies profiles. This method is measured the mahnetic field at the suface and considered it as the integral of magnetic signatures from all depths[9]. The spectral analysis technique employed the Fourier Transform equation to the regularly space magnetic field datasetas represented in the equation[10].

$$Y_i(x) = \sum_{n=1}^{N}\left[a_n \cos\left(\frac{2\pi n x_i}{L}\right) + b_n \sin\left(\frac{2\pi n x_i}{L}\right)\right] \quad (1)$$

Where $Y_i(x)$ is the reading at x_i position, L is length of the cross-section of the anomaly, n is the harmonic number of the partial wave N, number of data points, α_n real part of the amplitude spectrum and b_n is the imaginary part of the spectrum; for *(I =0,1,2,3,……..,n).* The linear segment slope was applied to obtain the depth to the magnetic source using the equation (1). However, if the frequency unit is in circle per kilometer, the relationship can be expressed as:

$$Z = -\frac{M}{4\pi} \quad (2)$$

Where Z is the depth to the magnetic source and M is the gradient of the linear segment (slope)[11].

3.4.2THREE DIMENSIONAL EULER DECONVOLUTION DEPTH ESTIMATE

Three dimensional Euler Deconvolution depths to the magnetic source were estimated from the total magnetic intensity map using the equation below. The Euler Deconvolution is based on the Euler homogeneity relation written in the form:

$$(x - x_0)\frac{\partial T}{\partial x} + (y - y_0)\frac{\partial T}{\partial y} + (z - z_0)\frac{\partial T}{\partial z} = N(B - T) \quad (3)$$

Where, xo, yo and zo are the position or coordinate of the top magnetic source, (*x, y, z*) are the location of the field measurement, T is the Total Magnetic intensity (TMI) anomaly value, B is the background field, $\frac{\partial T}{\partial x}, \frac{\partial T}{\partial y}$ and $\frac{\partial T}{\partial z}$are the derivative of the total field values T and N is the degree of homogeneity is also referred to as structural index (SI) which is a measure of the rate of change with distance of a field[12]. The appropriate use of SI value yields tight cluster of solutions whereas inappropriate application of SI value produces diffused solutions of source location that are not reliable[13]. The window size (grid point) were selected appropriately anda structural index value of zero was applied to determine geological model of magnetic contact.

3.4.3 SOURCE PARAMETER IMAGING (SPI) METHOD

The source parameter imaging (SPI) is a technique that is usually employed to appraise the depths to the top of magnetic sources anomalies[14]. The technique has edge in estimating the depths to the magnetic sources because it does not depend on the magnetisation direction[15]. The SPI technique employs the relationship between the source depth and the local wavenumber to estimate the depths to the magnetic source anomalies using the equation below:

$$K = \frac{\frac{\partial^2 F}{\partial x \partial z}\frac{\partial F}{\partial x} + \frac{\partial^2 F}{\partial x \partial z}\frac{\partial F}{\partial y} + \frac{\partial^2 F}{\partial x \partial z}\frac{\partial F}{\partial z}}{\left|AS\right|^2}$$

For dipping magnetic geologic contacts, the peaks of K are placed directly above the edges of isolated contacts. More so, the depth estimates are calculated using the reciprocal of local wavenumber, given as thus:

$$Depth_{x=0} = \frac{1}{K_{max}}$$

Where, Kmax is the maximum value of K (local wavenumber) over the step magnetic source. Therefore, the SPI technique was applied to the residual magnetic anomaly map of parts of study area, in order to estimate the depth to magnetic sources within.

IV. Results And Discussions

The total magnetic intensity map (TMI) is categorized into areas of high, intermediate and low magnetic anomalies (figure 2). The TMI map color legend bar with pink to red colors represents areas of high magnetic signatures which are predominantly found in the segment of northwest (NW), central and extending southward, green to yellow colors portrays the areas with intermediate magnetic signatures which are mostly found in the same direction with high magnetic signatures while the light blue to deep blue colors depicts low (weak) magnetic anomaly signatures are also observed in the eastern, western, northern and a portion in southern part of the study area. The magnetic susceptibility values of 78.4 to 120.4 nT, 27.6 to 75.6 nT and -34.6 to 24.2nT represent the zones of high, intermediate and low magnetic intensities respectively. The observed high magnetic intensity values are probably caused by the presence near surface igneous rocks of high magnetic susceptibilities valueswhile the weak magnetic anomaly values are attributed to the presence of sedimentary rocks and other non-magnetic sources [16].

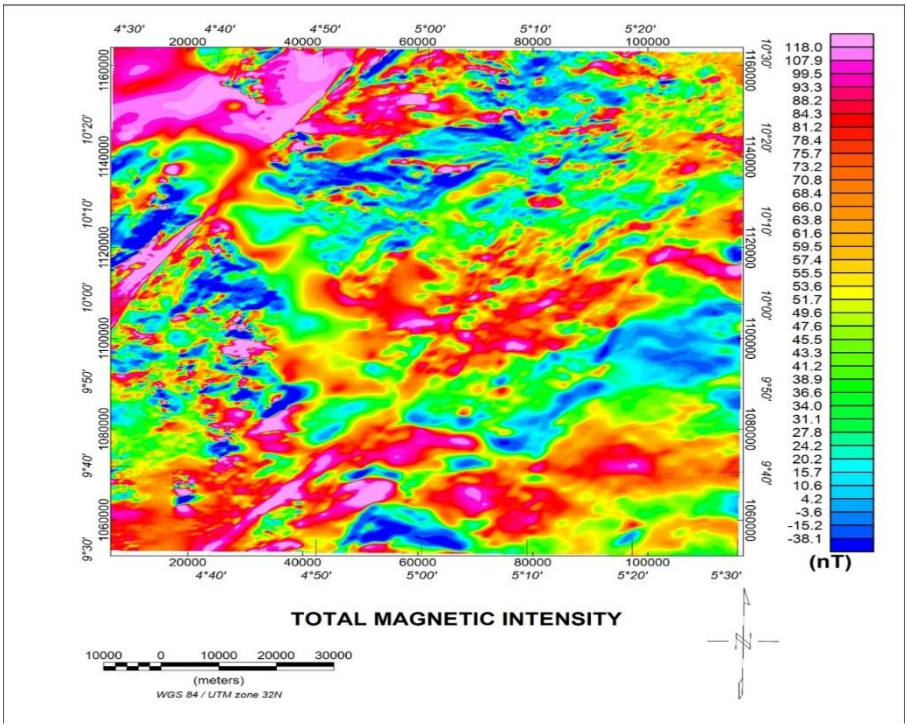

Figure 2. Total magnetic intensity map of the study area

The regional magnetic anomaly map (Figure 3) clearly divides the study area into three main zones namely; strong, intermediate and weak zones. The strong (high) magnetic anomalies are represented by pink to red colors, with magnetic intensities values in the range of 53.2 to 60.5nT. The intermediate zones are represented with green to yellow colors with intensity values in the range of 53.2 to 45.1nT. The weak (low) magnetic anomaly zones with light blue to deep blue are with anomalies values in the range of 40.8 to 45.1 nT. Evidently,there issudden decrease in the magnetic susceptibility values of the regional magnetic anomalies (Figure 2) when compared with total magnetic intensity map (Figure 1) of the study area. This indicate that, there is sediment fill from southeastern (SE) to the northwestern (NW) part of the study area. Moreover, the regional map depicts deeper sedimentation in the eastern than the western part of the study area.

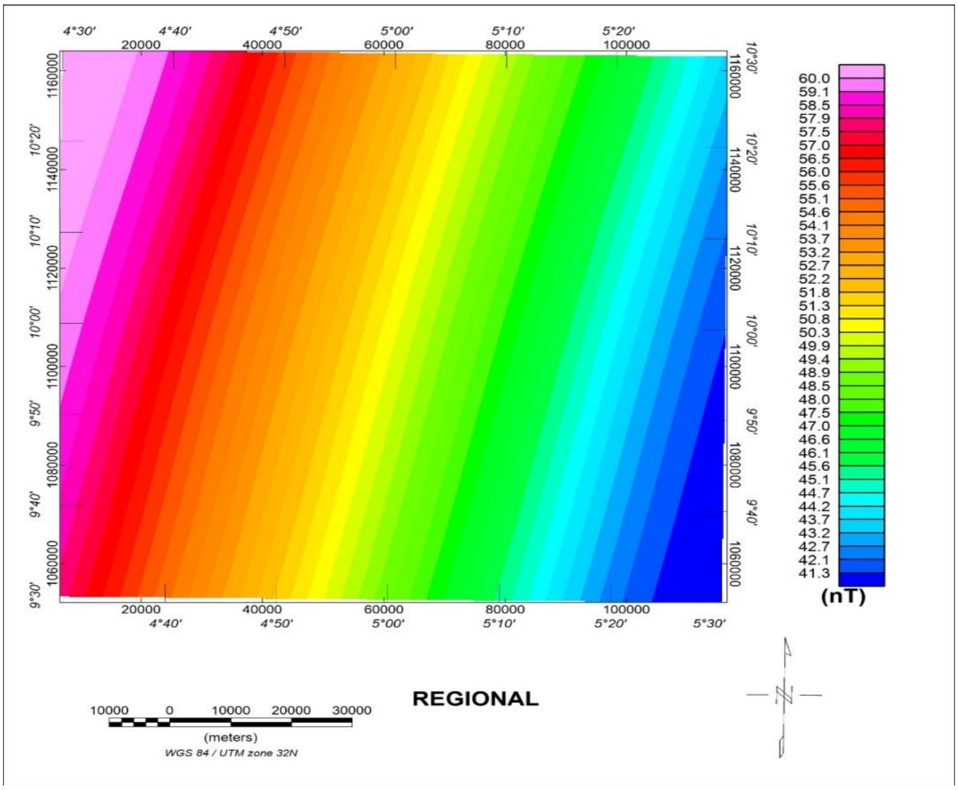

Figure 3. Regional magnetic intensity map

The residual map (Figure 4) shows areas with high and low magnetic susceptibility values represented in different colors. The pink to red colors represents the high positive magnetic susceptibility values in the range of 6.4 to 65.9nT. The green to deep blue colors signifies the low magnetic susceptibility values in the range of -94.5 to 6.4 nT. The residual magnetic intensity map is also trending along the same direction with the total magnetic intensity map (Figure 1)

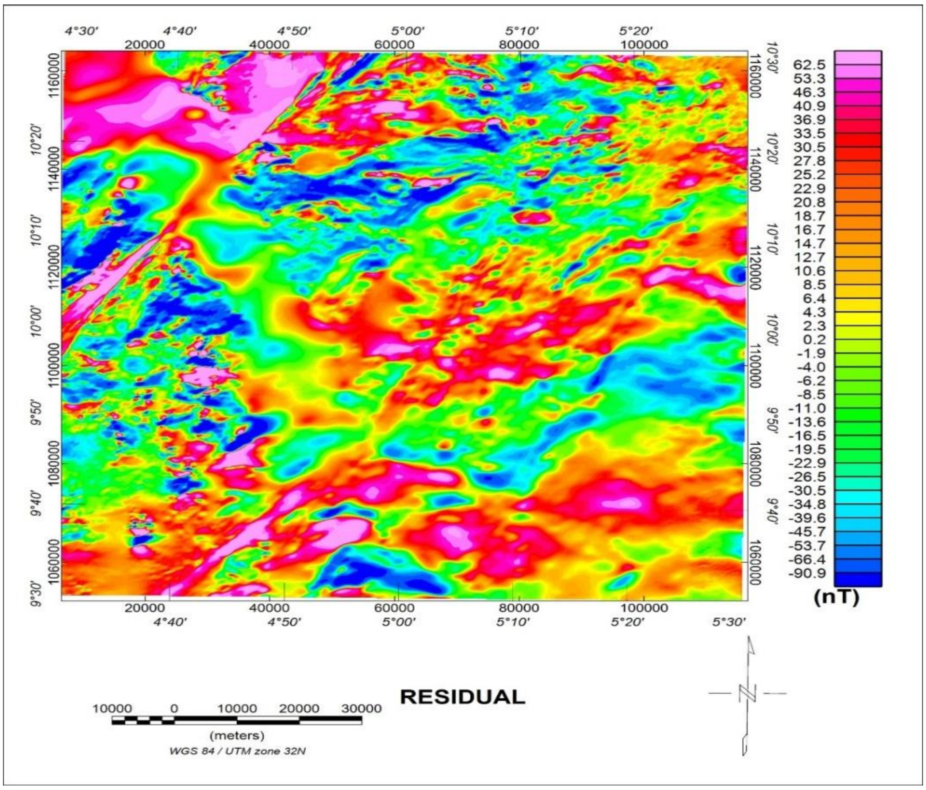

Figure 4. Residual magnetic intensity map

Table 1: The spectral analysis deeper depths estimates

Block	Sheet Name	Longitude	Latitude	H_1(km)
1	Auna	4.75	10.25	2. 93
2	Kontagora	5.25	10.25	1.99
3	Kainji	4.75	9.75	2.78
4	Fashe	5.25	9.75	3.16
5	Auna/Kontagora	5.00	10.25	2.92
6	Kainji/Fashe	5.00	9.75	2.58
7	Auna/Kainji	4.75	10.00	2.89
8	Kontagora/Fashe	5.25	10.00	3.12
9	Auna/Kontagora/Kainji/Fashe	5.00	10.00	2.58
			AVERAGE	2.76

Table 1 shows the deeper depths values obtained from the spectral analysis. The deeper depth varies between 1.99 km at (Kontagora) and 3.16 km at (Fashe) with an average value of 2.76 km. The contour Map and 3D surface wireframe plot for the deeper depth of the study area as shown in figure (5 a and b). The contour map of the basement depth is thicker in the southeastern (SE) part of the study area around Fashe and the northwestern (NW) part around Auna. On the other hand, the northeastern (NE) around Kontagora to southwestern (SW) around Kainji have shallow sedimentation. However, the 3D surface wireframe plot shows similar depth pattern with the contour map result.

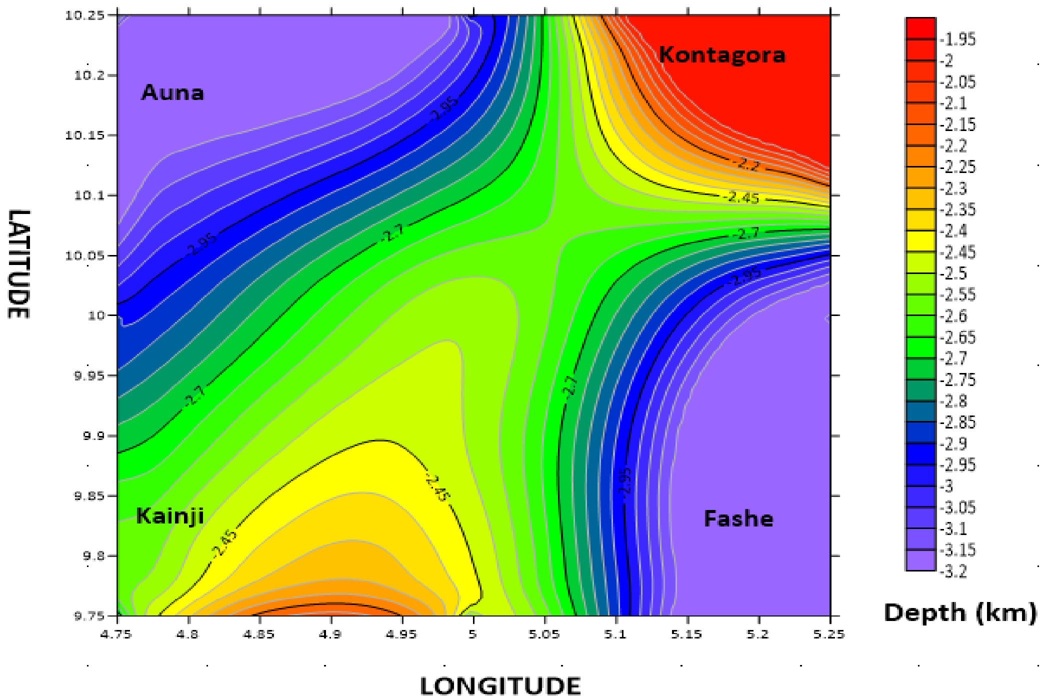

Figure 5a. Spectral analysis contour map

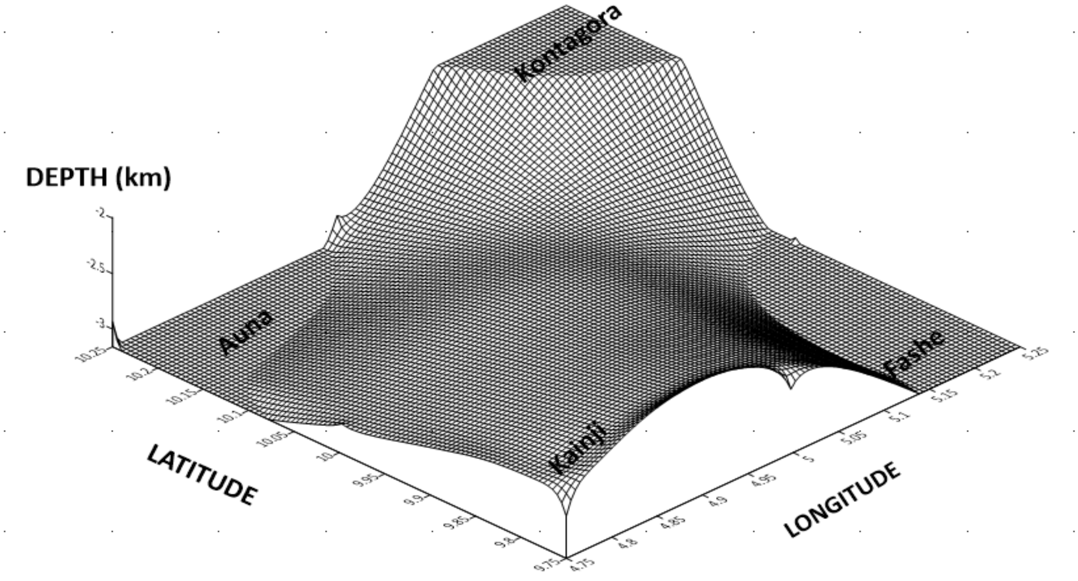

Figure 5b. 3D wireframe map of the spectral analysis

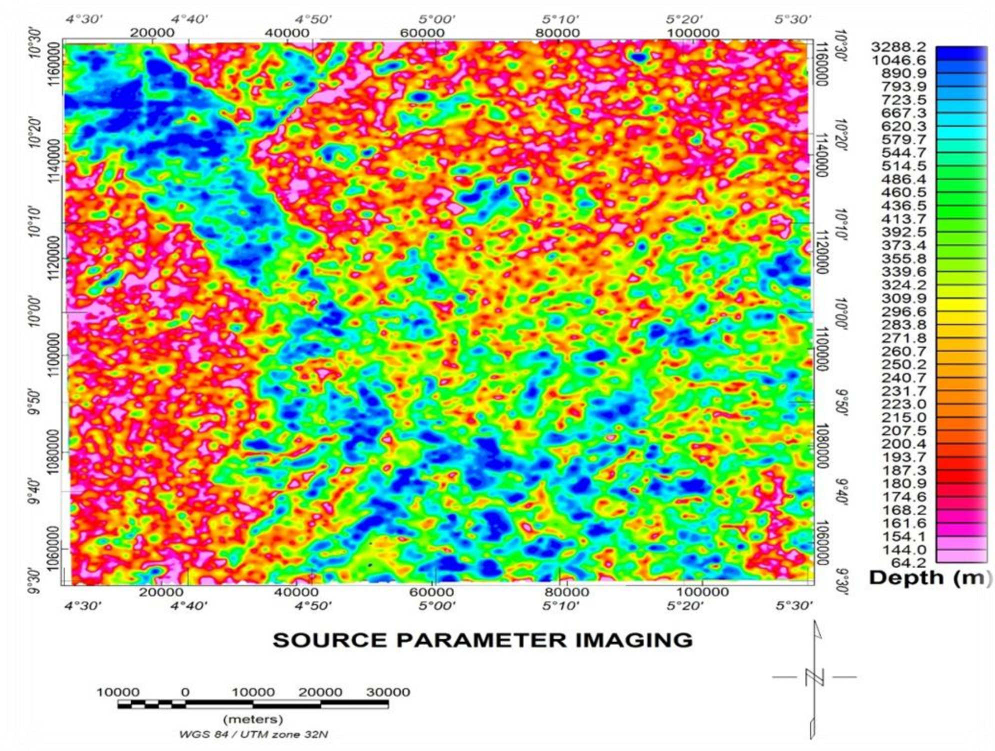

Figure 5c.Source parameter imaging (SPI) map

The green to pink colors are areas of shallow magnetic anomalies sources while the areas covered by deep blue color are characterized by deep seated magnetic bodies that are of thick sedimentary cover. The depth values obtained varies between 64.2 and 3288.2m with an average depth of 200.7 m.The SPI deeper depths trend analysis are observed along NW to SE directions with increasing basement thickness along the eastern flank of the study area.

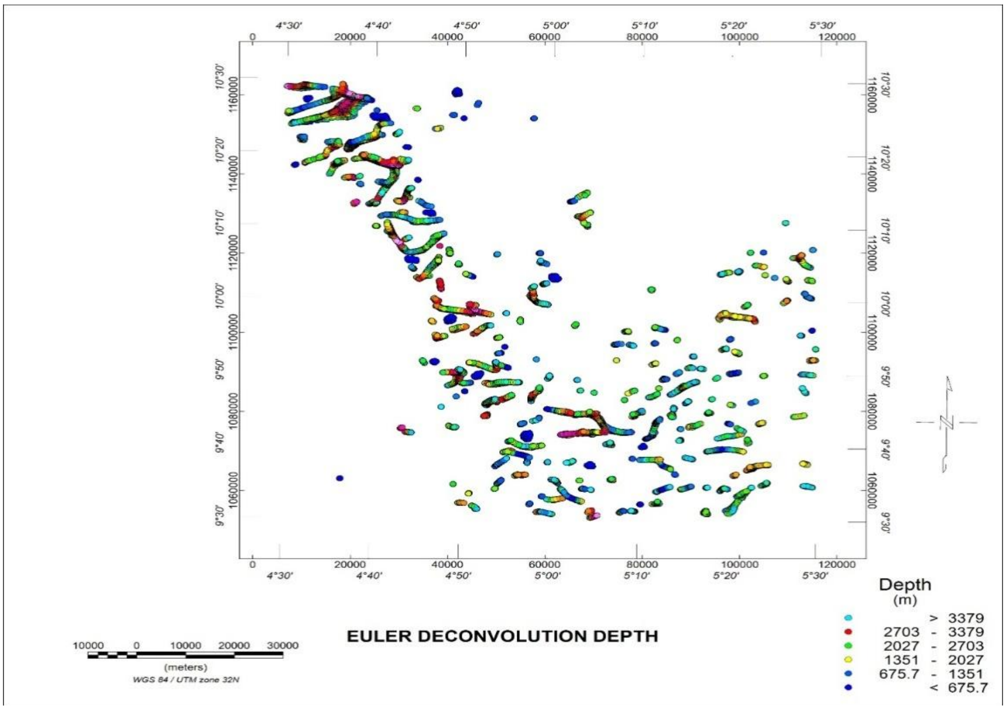

Figure 6. 3D Euler deconvolution depth plot

The 3D Euler deconvolution (ED) method has been employed to estimate the depth to magnetic contacts as shown in figure 6. The ED method was carried out using a window size of 3000 m and a maximum depth tolerance of 7%. The structural index of zero (0.0) geological model for magnetic contact was applied on the total magnetic intensity (TMI) map in order to locate and estimate the depths to magnetic contact. The estmimated depths varies between 107.3 to 3379 m with an average value of 813 m. The results of the ED method were superimposed on the SPI plot to measure the degree of similarity between them. A very good correlation was observed as illustrated (Figure 7). The trend of the ED depth analysis had similar NW to SE trending directions with increasing basement thickness along the eastern flank of the study area.

Hence, the adopted geophysical methods are synonymous with maximum basement depths values of 3.16km around Fashe, 3.28km around Fasheand 3.38km around Auna for spectral analysis, SPI and ED methods respectively. The findings from the study has clearly revealed Auna and Fashehas the highest sedimentary layer thickness which is above the 2.3km forhydrocarbon characterization[17]. Therefore, the Auna and Fashe areas are perhaps the prospective locations for hydrocarbon exploration.

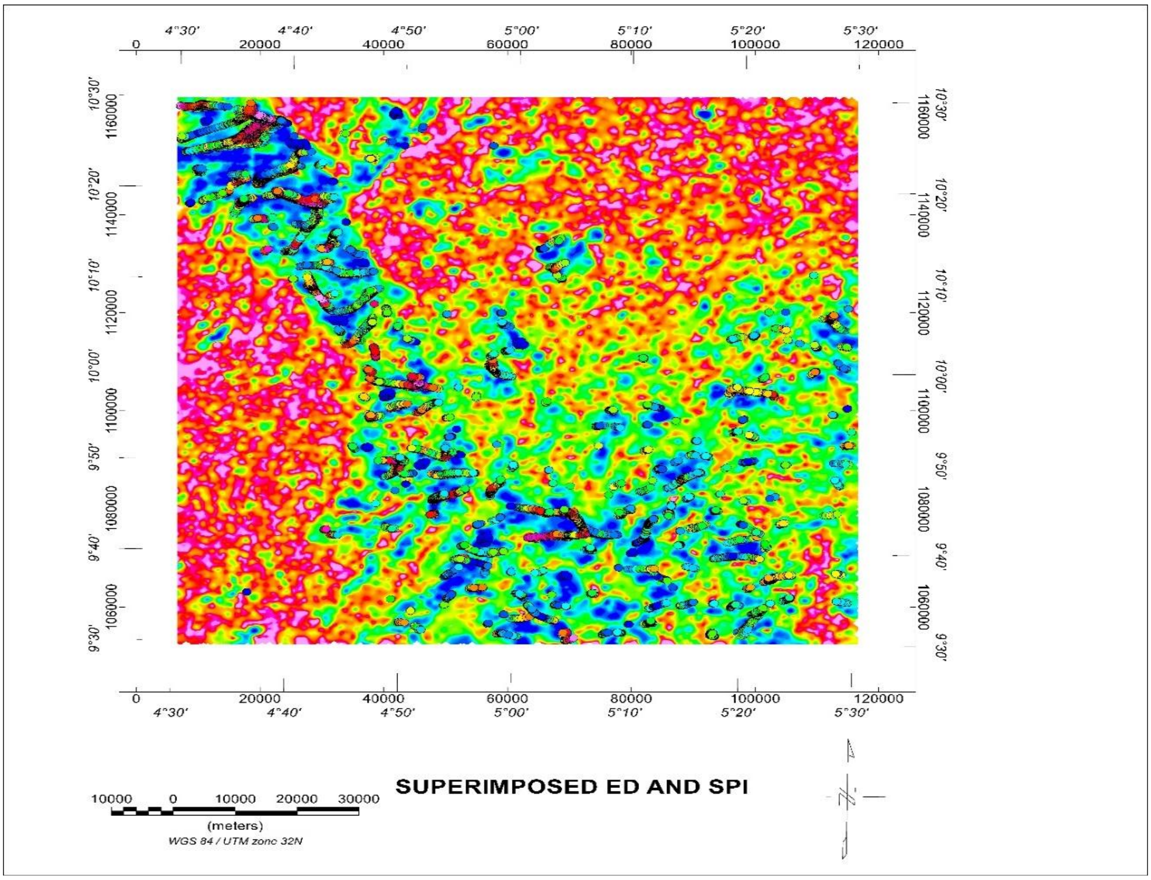

Figure 7. Superimposed SPI and ED depth plot

V. Conclusions

The interpretation of the total magnetic intensity map covering Auna, Kontagora Kainji and Fashe in the Northern part of the Bida basin has been carried out usingthe Spectral analysis, Source Parameter Imaging and Euler deconvolution methods in order to appraise the sedimentary layer thickness of the study area. The spectral analysis revealed a maximum depth of 3.16 km at Fashe, the source parameter imaging revealed a depth of 3.28 km at Fashe and the Euler deconvolution method also revealed a depth of 3.38 km atAuna. The results from the ED method were superimposed on the SPI plot to measure the degree of similarity between them and a very good correlation was observed. The major solutions trend are predominantly found in the NW at Auna to SE at Fashe. Therefore, the findings from the study revealed that the Auna and Fashe areas are perhaps the prospective locations for hydrocarbon characterisation.

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