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Estimating the Thickness of Sedimentation within parts of Lower Sokoto Basin, Nigeria, Using Spectral depth analysis Euler Deconvolution and Source Parameter Imaging of aeromagnetic data

Badamasi Umar[1], Bonde D.S[2], Abbas M.[2] & Abubakar ISMAILA[1]
[1]Umaru Ali Shinkafi Polytechnic Sokoto
[2]Kebbi State University of Science and Technology Aliero, Department of physics

E mail: badamasiu106@gmail.com

ABSTRACT

*This study presents the results of the analysis and interpretation of aeromagnetic data over part of lower Sokoto basin with the aim of investigating the hydrocarbon potential of the study area. The study area is located between latitude 11.00^{o}N and 12.00^{o}N and longitudes 4^{0}30 ^{l}E and 5^{0}30 ^{l}E. 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 Euler deconvolution, Source parameter imaging and spectral method. The results of these methods corroborate; Euler deconvolution, Source parameter imaging and spectral method show a thick sedimentation of 0.125km to **1.54km**. The maximum sedimentary thickness of above 1.5 km obtained in this study at the south-western part. The study area was found to have a good prospect for hydrocarbon exploration.*

Keyword: Aeromagnetic data, lower Sokoto basin, Euler deconvolution, Source parameter imaging and spectral method, hydrocarbon potential

1.0 INTRODUCTION

1.1Background of the study

The mineral resources (metallic and non-metallic minerals), which the skill of man extracts from the bowels of the earth and his way of fashioning it into raw materials for our great industries aids in the development of any nation (Okwesili *et al*., 2019). This exploration of this natural resources beneath the earth surface have been of major concern as 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 (Ajakaiye *et al.*, 1991).

Sokoto Basin is one of the sedimentary basins in Nigeria; several researches such as Kamba *et al (2018)*, Bonde *et al*. (2014), Ofor and Udensi (2014), Ofoha *et al*. (2016), Stephen and Iduma (2018), Labbo and Ugodulunwa (2007), and Bonde and Sani (2019), were conducted in the basin to investigate its hydrocarbon potentials. All these works pointed out that in some sections of the basin, the basin is thick enough for possible hydrocarbon maturation and the thickness of the sediments generally increases northwards toward the border with Niger republic where petroleum has been discovered. Therefore, this research work was motivated by the call to re-investigate all the basins in the country for hydrocarbon prospect and to locate the section of the study area with sufficient sediment thickness for possible hydrocarbon exploration

Aeromagnetic survey is widely employed in modern geophysics because of its fast and cheap coverage over large exploration area. This method of investigating the earth's subsurface geology is based on the magnetic anomalies in the earth's magnetic field resulting from the magnetic properties of the underlying rocks and minerals. The shape, dimensions and amplitude of the induced magnetic anomaly is a function of the

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orientation, geometry, size, depth and magnetic susceptibility of the body as well as the intensity and inclination of the earth's magnetic field in the survey area (Asielue *et al* 2019 and Biswas, 2017).

Salako *et al* (2019), Bonde and Sani (2019), (Asielue *et al* 2019 and Biswas, 2017) have shown that any of the spectral analysis, source parameter imaging and Euler deconvolution method of aeromagnetic data analysis can be regarded as a proxy for an estimation of the thickness of sedimentation.

In this research we aim to assess the estimate thickness of the study area sediment for possible Hydrocarbon potential and exploration, using spectral depth analysis source parameter imaging and Euler deconvolution method of aeromagtic method.

1.2 Geology of the Study Area

The study area is part of the Sokoto Basin, in northwestern Nigeria (Figure1). Sokoto Basin is predominantly consists of a gently undulating plain with an average elevation varying from 250 to 400m above mean sea-level Obaje, (2009) and Odebode (2010). This plain is occasionally interrupted by low mesas. A low escarpment, known as the "Dange Scarp" is the most prominent feature in the basin and it is closely related to the geology (Odebode, 2010). The Sokoto (Sedimentary) Basin forms the south-eastern segment of a large synclinal basin that is known as the Iullemmeden basin. The Iullemmeden basin lies entirely within the Pan African province of West Africa; which encompasses parts of Algeria, Mali, and Republic of Benin and Niger Odebode (2010).

Additionally, found in the basin (figure 1) are sequences of sands, clay, some limestone and ironstone, and semi consolidated gravels. It consists of about 60% of the sedimentary and 40% of basement (Zboril, 1984). The sedimentary sequences are subdivided into late Jurassic to early Cretaxeous Illo and Gundumi Formation, the Maestrichtian Rima Group, the late Paleocene Sokoto Group and the Eocene-Miocene Gwandu Formation (Kogbe, 1979 and 1981).

Kogbe (1979) described Sokoto basin as a series of crystalline massif rocks outcropping to the east and south of the basin consisting of granite gneisses, schist, phyllites, quartzites and some amphibolite, diorite, gabbro and marble of pre-Cambrian age. The lowlands and plains of the basement areas are sometimes covered on the surface by Quaternary sediments of Aeolian and fluvial origin especially along the flood plains of the major rivers and streams.

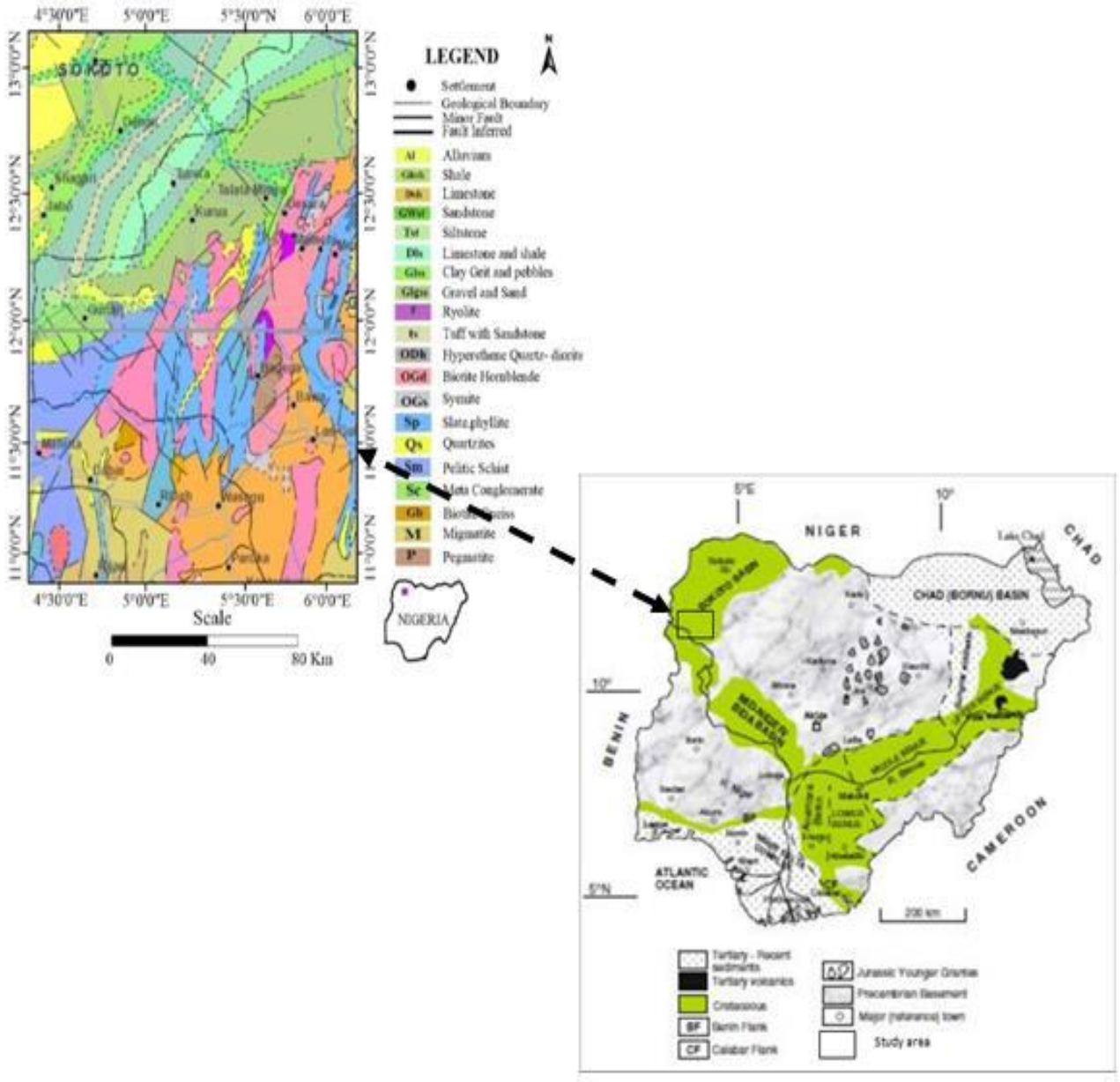

Figure 1: Geological Map of Nigeria showing the study area in black outline (Source: Obaje, 2009)

2.0 MATERIALS AND METHODS

Four digitized aeromagnetic data sheets 73 (Fokku), 74 (Danko), 96 (shanga) and 97 (Wudil) were acquired, assembled for the work. These data were procured from the Nigeria Geological Survey Agency, NGSA as part of the Data NGSA collected from the airborne magnetic survey carried out in the year 2009 by Fugro.

The data were acquired along a series of NW-SE flight with a spacing of 2 km and an average flight elevation of about 150 m while tie lines occur at about 20 km interval. The area covered is about 12,100 km2. Using Oasis software, the first step in this study was to assemble the four maps covering the area. The next step was to contour the data to produce the total field aeromagnetic intensity map. Furthermore, the contoured total-field intensity map contains both the regional and residual anomaly. The regional gradient was removed from the map by fitting a linear surface to the digitized aeromagnetic data using polynomial fitting techniques. 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) Euler deconvolution, (ii) Source parameter imaging and (iii) spectral analysis.

2.1 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. Euler deconvolution technique is employed in magnetic interpretation because it requires only a little prior knowledge about the magnetic source geometry (Thompson, 1982; Reid *et al*., 1990). It is used for depth estimation and location of features that represent structures. The Euler deconvolution method is based on Euler's homogeneity equation. This is an equation that relates the potential field and its gradient components to the location of the source, with the degree of homogeneity, N which may be interpreted as a structural index, SI (Thompson, 1982 and Okwesili *et al*, 2019).

The SI is an exponential factor corresponding to the rate at which the field falls off with distance, for a source of a given geometry. Euler's homogeneity equation can be defined as Reid *et al*., *(*1990):

$$N(B-\mathrm{T}) = (x-x_0)\frac{\partial \Delta \mathrm{T}}{\partial \mathrm{x}} + (y-y_0)\frac{\partial \Delta \mathrm{T}}{\partial \mathrm{y}} + (z-z_0)\frac{\partial \Delta \mathrm{T}}{\partial \mathrm{z}} \quad (1)$$

where (x_0, y_0, z_0) 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 a coefficient, called structural index (SI), N=-n, (Thompson 1982).

For this work, Oasis Montaj software was utilised in the computing and gridding of Euler 3D using equation (1), wherein images were produced and depth to the suspected magnetic bodies was then computed. Using two structural indices, SI =1.5 and SI= 2), four Euler 3D grids were generated.

2.2 The Source Parameter Imaging: The Source Parameter Imaging (SPI^{TM}) is a technique using an extension of the complex analytical signal to evaluate magnetic depths. This approach developed by Thurston and Smith (1997) and Thurston *et al*. (1999) sometimes referred to as the local wave number method 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. (Ajala *et al 2021 and* Salako *et al, 2019)*

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

$$depths = \frac{1}{k_{max}} \quad (2)$$

$$k_{max} = \sqrt{(\frac{dA}{dx})^2 + (\frac{dA}{dy})^2 + (\frac{dA}{dz})^2} \quad (3)$$

where K max is the peak value of the local wave number K over the step source.

Tilt derivative $A = tan^{-1}\frac{\frac{dM}{dz}}{\sqrt{(\frac{dM}{dx})^2+(\frac{dM}{dy})^2}}$ (4)

and

M= he total magnetic field anomaly grid

2.3 Spectral Depth Analysis

It is a depth estimating method used in geophysics. It is used in 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 method discovered by Bhattacharryya (1966) and later developed by (Spector and Grant, 1970) has been utilized widely

in the analysis of magnetic anomalies. It depends on the expression of Power spectrum for the total magnetic field anomaly. In this technique various (more than one) anomaly can be utilised to compute the depth to buried magnetic materials.

The technique permits an estimate of depth of magnetized blocks of varying depth, width, thickness and magnetisation. Most approaches used include Fourier transformation of the aeromagnetic data to estimate the energy (or amplitude) spectrum. The energy spectrum is then plotted on the Logarithm scale against frequency. The plot shows the straight line graph which diminish in slope with rising frequency. The slopes of the segments yield estimates of depths to magnetic sources (Aliyu *et al., 2018).*

Hence, a plot of the energy spectrum of a single ensemble of prism against angular frequency would yield a straight line graph whose slope is directly proportional to the average source depth, z of that ensemble. That is, the logarithm plot of the radial would yield a straight line whose slope,

$$m = -2z \quad (5)$$

$$z = -\frac{m}{2} \quad (6)$$

Equation (6) 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

$$z = -\frac{m}{4\pi} \qquad (7)$$

3.0 Discussion of Result

3.1 Total Magnetic Intensity (TMI)

The total magnetic intensity map (TMI) of the study area (Figure 3.1) shows variation of highs and lows in magnetic signature, ranging from -55.6nT to 91.2nT (33000nT have been removed by the NGSA for proper handling so, to get the actual value, a background value of 33000nT must be added to each value to get the actual value). 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 south-western part of the of the study area, trending West-East, it could also be found in part of the North-western and central part. Although the low magnetic signatures denoted with **L** is well pronounced in the eastern (especially the South eastern) part of the study area trending NE-SW, it scattered all round the study area.

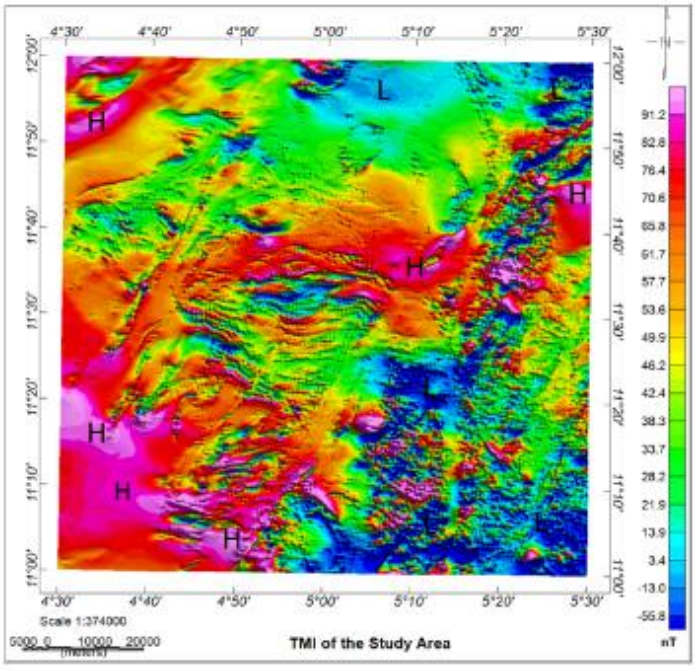

Figure 3.1: TMI anomaly contour map of the study area (add a background value of 33000nT to each value to get the actual value)

3.2 Residual Map

The residual magnetic intensity map (Figure 3.2) of the study area shows that the area is made up of magnetic intensity values ranges from -72.8 nT to 42.0 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 South- Eastern part trending approximately South-East. The high magnetic signature can also be found in the central part trending North-West and the extreme of North-West while the low magnetic anomalies associated with the sedimentary region was well pronounced in Eastern, while other scattered at the central part of the study area. The varying amplitude of these magnetic anomalies is an indication of different sedimentary thickness in the study area.

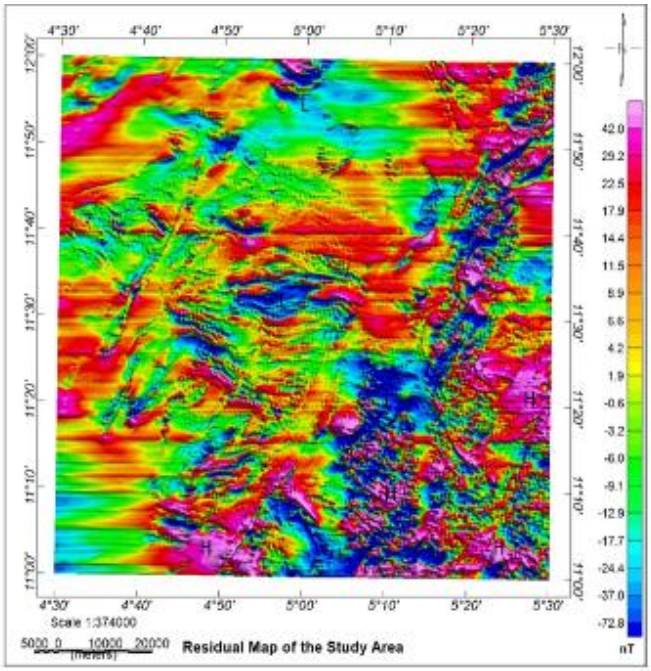

Figure 3.2: Residual map of the study area

3.3 Euler deconvolution

The Euler depths were estimated using vertical derivatives in three dimensions (x, y, and z). Vertical derivatives enhance shallow magnetic bodies. Hence, depths of shallow magnetic anomalies for different structural index

are displayed by Euler method. Different structural index numbers were tried but it was found that the index number 1.5 and 2, Figure (3.3 and 3.4) were the best for the data as it reflected the geological information of the area. The pink colour indicates shallow magnetic bodies, while the blue colour indicates deep lying magnetic bodies. The Euler depth result ranges from-149.5 m (shallow magnetic bodies) to -1380.9m (deep lying magnetic bodies) for SI=1.and a value of -211.6m to 1496.1 was obtained for SI=2

3.4 Source Parameter Image (SPI)

The SPI figure (Figure 3.5) shows varied colours supposedly depicting 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 source parameter imaging (Figure 3.5) of the study area shows that most of the features are aligned in the same manner trends as it is in the two Euler depth map of the study area (Figure 3.3 and 3.4). The thick sediment dominates the North eastern and south-western portion of the area while the least depth dominate major part of the southern especially the south-eastern part.

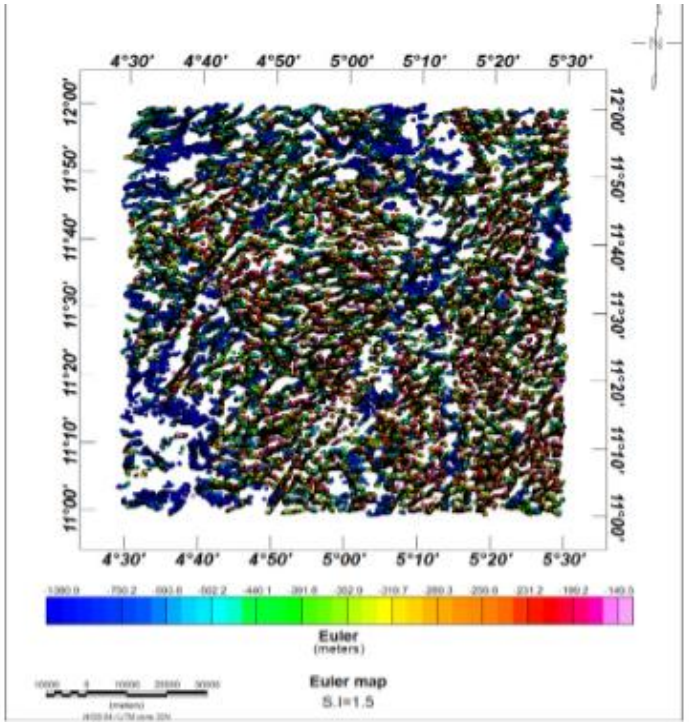

Figure 3.3: Euler depth map of the study area for SI=1.5

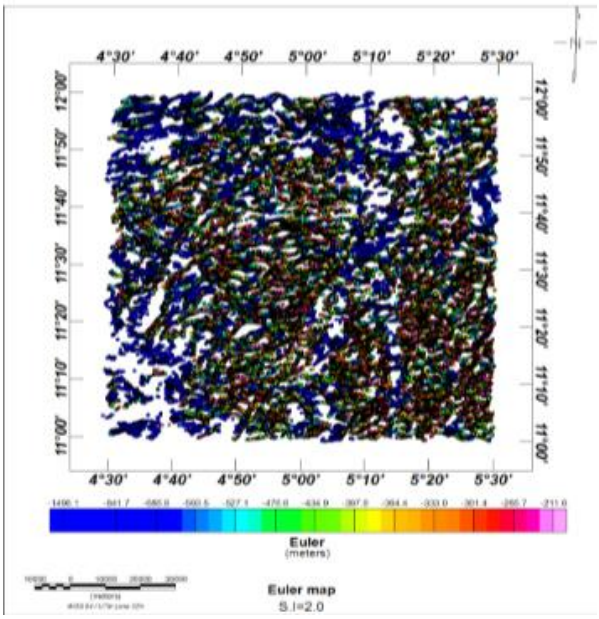

Figure 3.4: Euler depth map of the study area for SI=2

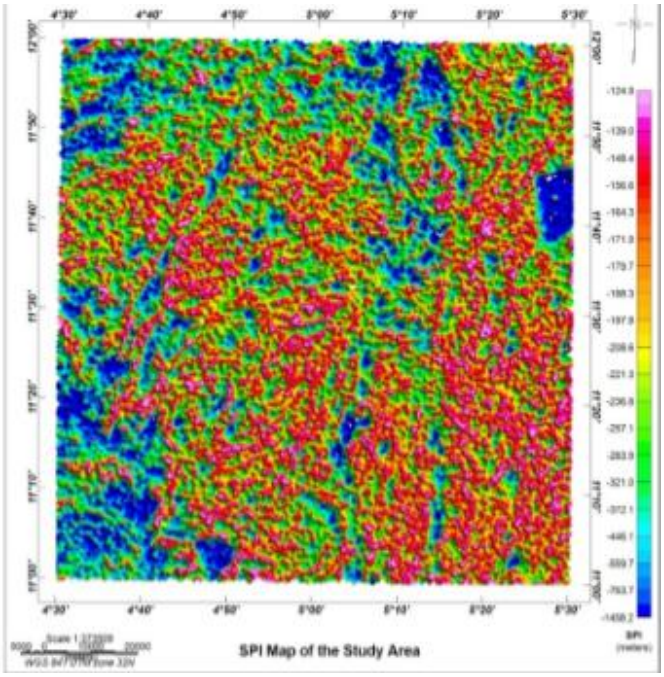

Figure 3.5: Source Parameter Imaging (SPI) map of the study Area

3.5 Spectral Analysis

The residual map (Figure 3.2) of the study area was divided into twenty four (Blocks 1 - 28) overlapping magnetic sections. 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 1 to 4 are shown in (Figure 3.6). The second slope in the plot was used to compute the sedimentary thickness in line with equation 7.

The results obtained as shown in Table 3.1 indicated that the study area Depth to top of basement which is equivalent to the sedimentary thickness, varies between 0.65km to 1.54km. The high sedimentary thickness can be observed from the Northeastern increasing to the south-western portion of the area while the least depth dominates major part of the Northwestern part.

This results (0.65km to 1.54km) largely aligned with the results obtained earlier with Source Parameter Image method that range from 124.9m to 1458.2m and the results obtained with Euler Deconvolution method that range between -149.5m to 1496.1m

Results from the three estimate approaches agreed largely with other published works in the studied area. Bonde and Sanni (2019) obtained a value of 0.35km and 2.09km on the immediate north ward of this study area; Kamba (2018) obtained two layer depths with the deeper magnetic sources vary between 2.506 km to 3.2 km and the shallower magnetic sources; vary between 0.589 km to 1.249 km.

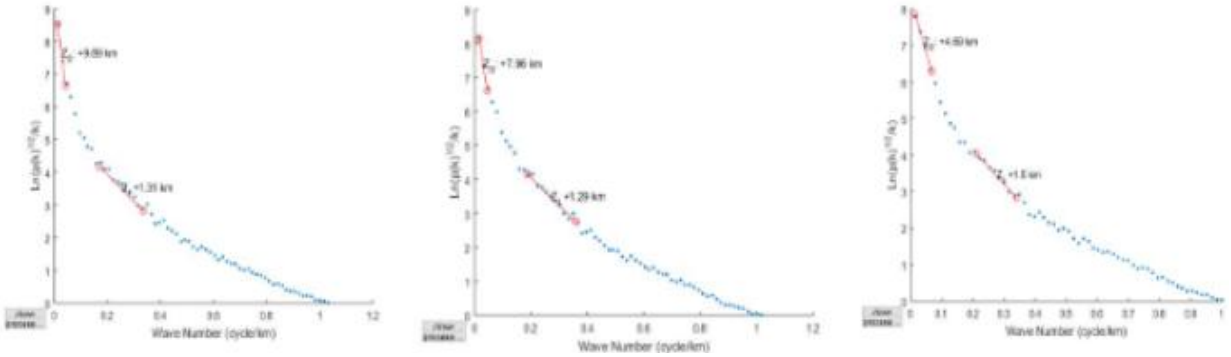

Figure. 3.6 Graph of the logarithm of spectral energies against frequencies obtained for block 1, 2 and 3.

Table 3.1: Location and depth estimation of sedimentary thickness

Block	Long (Deg.)	Lat (Deg.)	Depth to top of basement (Km)
1	4.75	11.75	0.71
2	4.83	11.75	0.65
3	4.91	11.75	0.68
4	5.00	11.75	1.21
5	5.08	11.75	0.82
6	5.16	11.75	0.72
7	5.25	11.75	1.15
8	4.75	11.58	0.94
9	4.83	11.58	0.70
10	4.91	11.58	1.03
11	5.00	11.58	0.79
12	5.08	11.58	1.01
13	5.16	11.58	1.09
14	5.25	11.58	0.92
15	4.75	11.41	0.79
16	4.83	11.41	0.82
17	4.91	11.41	1.01
18	5.00	11.41	0.83
19	5.08	11.41	1.03
20	5.16	11.41	1.19
21	5.25	11.41	1.01
22	4.75	11.25	1.54
23	4.83	11.25	0.97
24	4.91	11.25	1.09
25	5.00	11.25	1.22
26	5.08	11.25	1.05
27	5.16	11.25	1.1
28	5.25	11.25	1.12

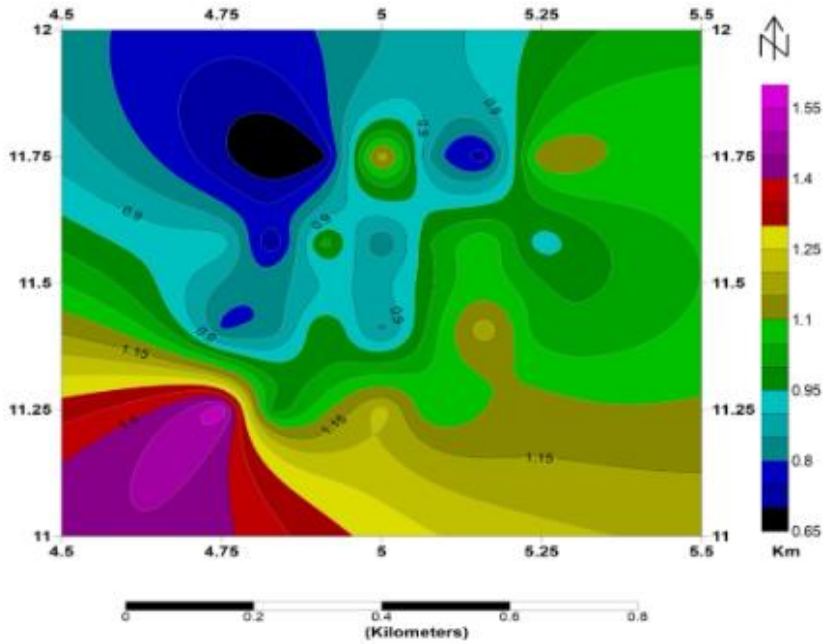

Figure. 3.7 contour map for the sedimentary thickness

4.0 CONCLUSION

The result obtained from this study using spectral analysis method, source parameter imaging method and euler deconvolution method shows that the study area has sedimentary thickness value that vary between 0.125km to 1.54km.

The outcome of this research shows that the maximum depth of sedimentation within the study area is approximately 1.54 km. It is understood by earth researchers that one of the conditions for hydrocarbon generation and accumulation is guided by thickness of sediments.

A seismic survey should be performed within the southwestern portion of the study area where the maximum thickness of sediments is obtained. Moreover, further exploratory drillings within the main basins are recommended to reassess the possibility of the presence of hydrocarbons.

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