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Prospecting for Hydrocarbon Using Aeromagnetic Data of Lokoja and Dekina Areas of Lower Benue Trough

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Abstract

Aeromagnetic data of Lokoja and Dekina area of Lower Benue Trough was interpreted qualitatively and quantitatively with the aim of estimating the depth to basement and, the basement topography in order to recommend possible area of hydrocarbon potential. Spectral analysis method was employed in quantitative interpretation. The result from spectral analysis strongly revealed two depth sources, deep and shallow depths. The deep source ranges from 2.001 to 4.082 km with an average depth of 3.156 km, while the shallow depth source ranges from 0.869 to 1.842 km with an average depth of 1.205 km. The maximum depth of 4.082 km obtained in Dekina area significantly indicates thick sediment that is feasible for hydrocarbon accumulation.

Introduction

The aim of magnetic exploration is to identify regions of the earth's crust that have anomalous magnetization. It can be carried out on land, at sea and in air (air borne). The airborne magnetic survey is a crucial aspect of magnetic surveying that permits faster and cheaper coverage of large exploration area [1].[]2 Aeromagnetic survey of exploration is popular for its suitability for locating buried magnetic ore bodies due to their magnetic susceptibility [3][4].

Despite the principal objective of aeromagnetic survey in assisting for mineral and groundwater development through improved geologic mapping, the method has gained prominence in the early stage of petroleum exploration to ascertain the depth and major structures of crystalline Basement rocks underlying the sedimentary basin [5][6][7]

Most economic minerals are concealed beneath the earth surface, therefore hidden from direct view [8][9]. The presence and magnitude of these minerals can only be determine by geophysical exploration of the subsurface geologic structures in the area [10][11]. If the area under investigation has no previous geological information and the objective of the study is to search for hydrocarbon deposits; the major task is to infer whether the sedimentary basin is thick enough and large enough to justify further investigations [12][13][14].

The determination of hydrocarbon potentials was carried out using statistical spectral method as a tool for determining depth to magnetic sources[15]. Spectral analysis is a useful technique based on the statistical analysis method using the Fourier Transform for the estimation of basement depth [16][17][18] Spectral analysis however has the advantage of estimating the depth of anomaly source approximated by a prismatic block based on the logarithmic radial energy spectrum of the total magnetic intensity[19][20].

The spectrum consists of a straight line whose gradient is related to the average depth to the tops of the prisms. Thus by dividing the study area into rectangular tiles, the mean depth to the top of the source at each point will be estimated with resolution relative to the number of the tiles. The method has the advantage of giving an estimate of the numerical value of the depth at each point [21][22].

The spectral analysis of aeromagnetic fields over the area would differentiate and characterize regions of sedimentary thickness from those of uplifted or shallow basement and also to determine the depth to the magnetic sources [23]. The results could be used to suggest whether or not the study area has the potential for oil, gas and mineral deposits concentration [24][25]The aim of this research is to analyze and interpret the high resolution aeromagnetic data over the study area in order to determine the possible areas of hydrocarbon potential. through Spectral analysis

Geology of the Study Area [26]

The study area lies between latitudes 7° 30' to 8° 00' North and longitudes 6° 30' to 7° 30' East. It is located within parts of Southern Benue Trough of Nigeria and Anambra Basin. Benue Trough is part of West African central rift. Sedimentation in the Southern Benue Trough commenced with the deposition of the Asu River group. The Asu River group comprises of the shales, limestones and sandstones lenses of the Abakiliki Formation in the Abakiliki area and the Mfasoming limestone in the calabar flank. Ojoh also reported some pyroclastic of Aptian-early Albian ages. Awi Formation is the basal, non- calcareous, sandy conglomeratic unit of Asu River Group directly overlying the basement complex (Oban Massif north of calabar).

The Cenomanian-Turonian Nkalagu formation and the interfingering regressive sandstones of the Agala and Agbani Formation are resting on the Asu River group. The Ogoja sandstone, the basal aspects of the Asu River Group directly overlying the basement complex have been characterised as consisting of conglomerates and arkosic sandstones in both Ikom and ogoja areas. The Eze-Aku Group: The "Eze-Aku Group" includes all the stratigrphic units deposited in the late Cenomanian to Turonian in the southern Benue Trough and in the southern parts of the central Benue Trough. These comprises of Eze-aku shales and the correlative units, the Konshisha Group, Amaseri sandstone, Nkalagu Limestone, the Igala sandstone and the Igumale sandstone.

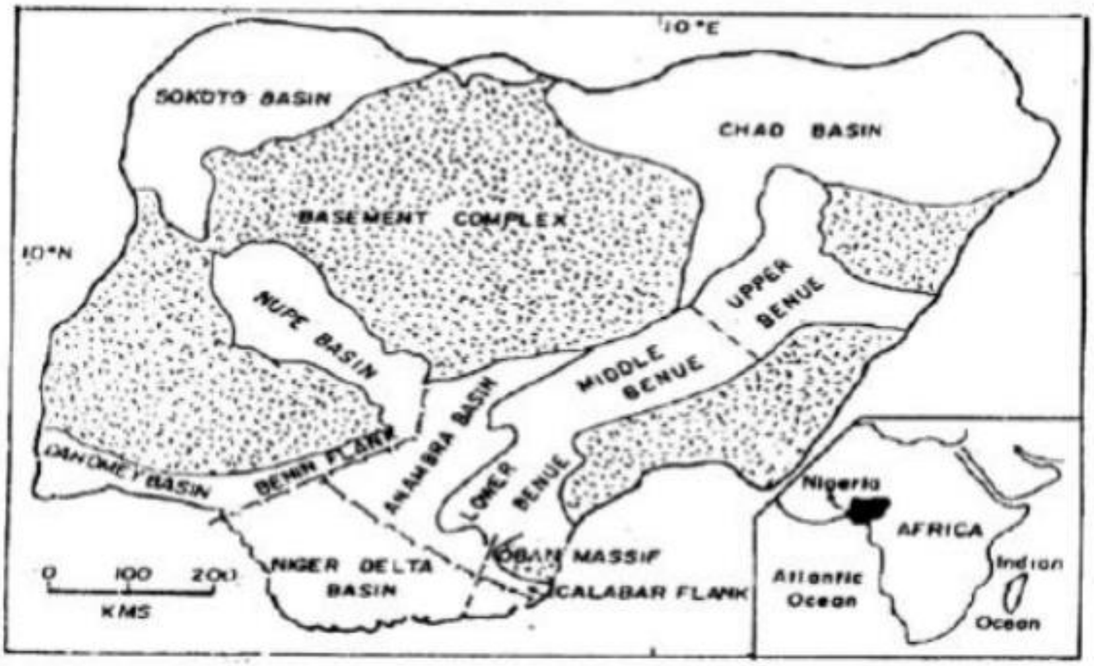


Figure1. *Map of Nigeria showing the study area*

The Igumale formationunit is a lateral equivalent of the makurdi Formation based on stratigraphic position. The Awgu Formation lies within the southern segment of the trough. It conformably overlies the facies of the Ezeaku Group. The succession commonly consists of the shale, sandstone and limestone. The age of Awgu formation span from late Turonian through Coniacian to early Santonian has been suggested by (Nwajide,2013) The age of the Agbani Formation is thought to be largely same as for the Awgu formation.Following Mid-Santonian tectonism and magmatism, depositional axis in the Benue Trough was displaced westward resulting in subsidence of the Anambra basin. Being a related structure that developed after the compressional stage, they implied that it was logical to include the Anambra basin in the Benue Trough, showed that the Anambra basin is a distinct and well demarcated lithostratigraphic entity overlying the Southern Benue Trough and is in turn overlain in its southern part by the Niger

Delta Basin. The lithostratigraphic units that filled the Anambra Basin have been divided into two groups: the Nkporo group and the coal measures overlie the Nkporo shale. This consists of fine grained sand, carbonaceous shales and coal with the thickest seam of l km typifying a transitional environment. Its type locality is the Enugu Cuesta. The Ajali Sandstone (Middle coal measures) overlies the Mamu Formation conformably. The Nsukka Formation (Upper coal measures) is the youngest formation from this cycle consisting of interdigitations of very finegrained sandstones, dark shale and coal indicating a parallic environment of Maastrichtian to Paleocene age. Fig 1 is the geology of the area

Materials and Methods

The materials that were used for this study include two sheets of aeromagnetic data of; Lokoja (sheet 247) and Dekina (sheet 248) which were obtained from the Nigerian Geological Survey Agency (NGSA).The aeromagnetic data were acquired using a 3 x Scintrex CS2 caesium vapour magnetometer by Fugro Airborne Surveys in 2009. The airborne magnetic survey was flown at a terrain clearance of 80 m along flight lines spaced 500 m apart. The flight line direction was 135°, with tie lines perpendicular (225°). Software applications used include: Oasis Montaj 8.4, Surfer 32, Microsoft excel.

The methods of data analysis include:

- **Merging of the Data**

The two sheets of aeromagnetic were merged together in Microsoft excel software which forms the total area of 6050 km^2 of the study area.

- **Importing of the Data to the Software**

The merged data was imported to the software Oasis Montaj 8.4 for the interpretation of the data.

- **Gridding of the Data**

Gridding is the process of interpolating data into an equally spaced of cells in a specified co-ordinate system. To produce the grids, the minimum curvature Grid tool of the Oasis Montaj 8.4 software was used to achieve this. The gridding of the aeromagnetic data produces the total magnetic intensity map of the study area.

- **Data Enhancement**

Polynomial fitting (regional-residual separation)

The regional anomalies were removed from the potential field anomaly to obtain the residual anomalies using the polynomial filtering tool of oasis montaj software. The residual anomaly is used to bring into focus local features which tend to be obscured by the broad features of the regional field.

- **Spectral Analysis**

To perform the analysis, the residual aeromagnetic data are divided into 18 cells of 18.333 km x 18.333 km for spectral depth analysis in MS Excel. The Fast Fourier Transform (FFT) is performed using the FFT function in the data analysis tool. The FFT function was used to separate the total magnetic intensity (TMI) data of the windows (called cells) into their frequency component and energy spectrum. The log of the energy spectrum (Log E) is plotted against the domain frequency in MS Excel according to Spector and Grant (1970) and the gradient of the linear segments are computed and the depths to the basement are determined using equation 3.1, 3.2, 3.3 and 3.4 respectively

$$M_1 = \frac{\Delta(LogE)}{\Delta(Freq.)} \quad 3.1$$

$$M_2 = \frac{\Delta(LogE)}{\Delta(Freq.)} \quad 3.2$$

$$D_1 = \frac{-M_1}{4\pi} \quad 3.3$$

$$D_2 = \frac{-M_2}{4\pi} \quad 3.4$$

where M_1 and M_2 are slopes of the first and second segments of the plots, while D_1 and D_2 are first and second depths respectively. The calculated values are imported into surfer software in order to produce the map of the deep depth, shallow depth to basement and topography map of the area.

Results and Discussion

Total Magnetic Intensity (TMI) Map

Figure 4.1 is the total magnetic intensity (TMI) map produced using the minimum curvature method of the oasis montaj software. The maps are presented as colour shades for easy interpretation. The coloured shades aid the visibility of a wide range of anomalies in the magnetic maps and the ranges of their intensities are also shown. The 2D TMI map of the study area as shown in Figure 4.1 shows that TMI values range from -92.7 to 143.0 nT. The 2D TMI map of the study area revealed that the area is magnetically heterogeneous. Areas of very strong magnetic values (129.3 to 143.0 nT) mainly at Lokoja area are caused probably by igneous or metamorphic rocks of high magnetic susceptibility values. The areas between -92.7 to -19.4 nT are most likely due to sedimentary intrusion like sandstone.

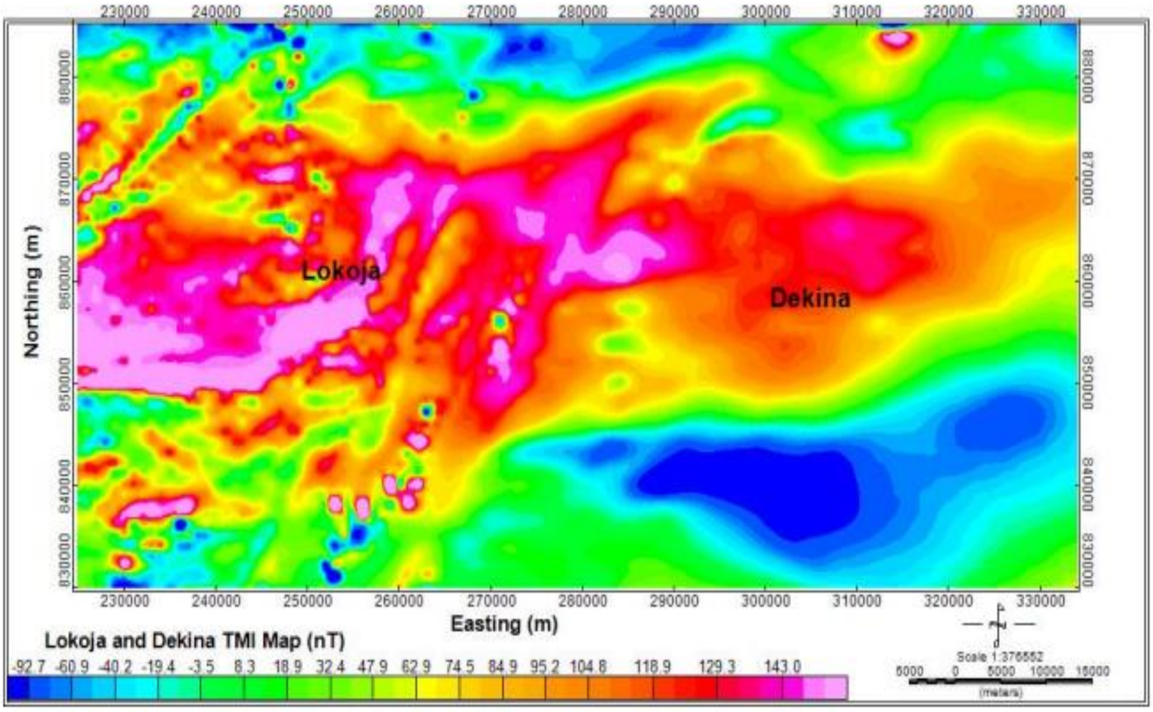


Figure4.1. *Total magnetic intensity map of the study area*

Residual Magnetic Intensity map

Figure 4.2 is the residual magnetic intensity map of the study area, which ranges from -144.1 nT (minimum) to 94.4 nT (maximum).

Generally, the entire study area revealed both positive and negative residual anomalies, indicating series of magnetic highs and lows.

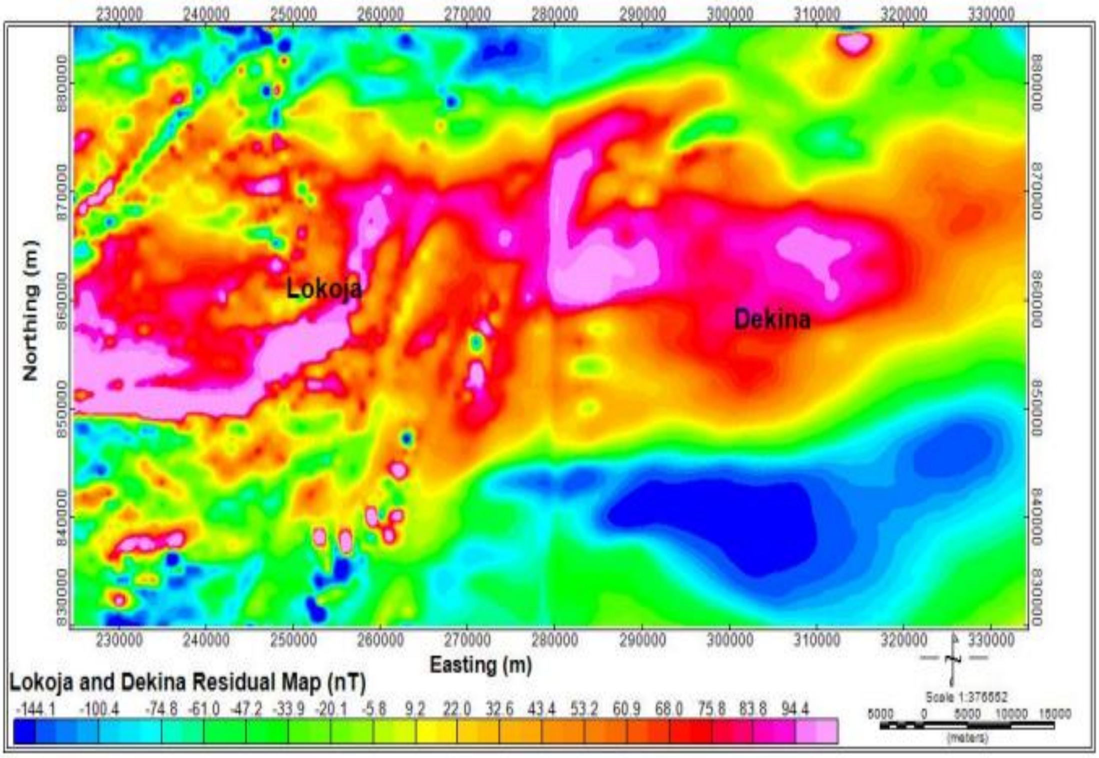


Figure4.2. *Residual magnetic intensity map of the study area.*

Regional Magnetic Map

Figure 4.3 is the regional magnetic intensity map of the study area with values ranging from 33.0 nT to 72.9 nT.

The values decreases from south to north indicating there is a fill of sediments more in the northern part than in the southern part of the study area.

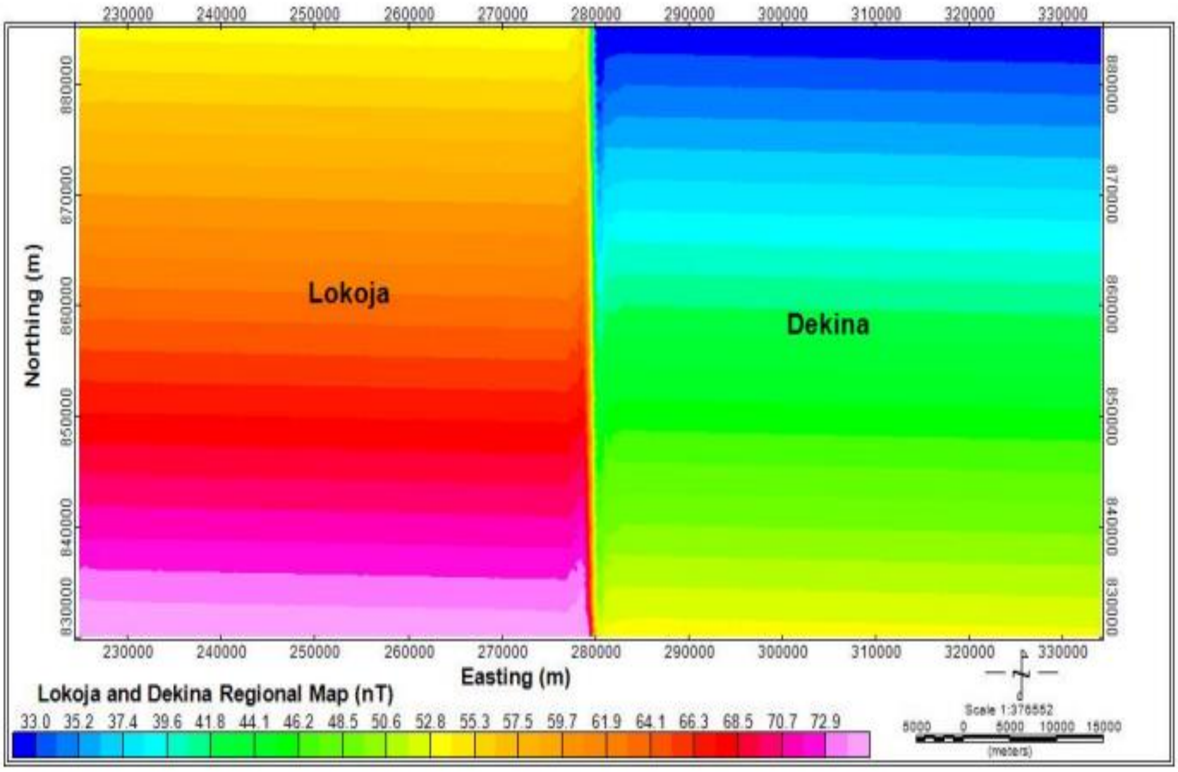


Figure4.3. *Regional magnetic intensity map of the study area.*

Quantitative Interpretation

Spectral Analysis

For the purpose of quantitative interpretation of potential field data of Lokoja and Dekina, spectral analysis method was employed in order to: estimate the depth to basement, delineate the basement topography in the area.

Estimation of Depth to Basement

- Divisions into Spectral Blocks

The study area was subdivided into eighteen (18) equal spectral blocks (Fig. 4.4) using the filtering tool of the micro soft excel sheet. Each profile covers a square area of 18.333 km by 18.333 km. Fast Fourier Transform (FFT) technique was used in Microsoft (MS) excel program to transform the magnetic data into the radial energy spectrum for each block. The average radial energy spectrum was calculated and displayed in a logarithm figure of energy versus frequency. Graphs of radial average energy spectrum were plotted in MS Excel using Excel chart wizard as Log of Energy (FFT magnitude) against Frequency in cycle per meter (cycle/m).

The graphs for the 18 spectral profiles are shown in Figure 4.5. The gradient of each of the line segments in Figure 4.5 was first evaluated. The average depth of buried ensemble was calculated to be 3.156 km for the deep depth and 1.205 km for the shallow depth. The coordinates and the two depth estimates (D_1 and D_2) for each of the eighteen spectral blocks are given on Table 4.1.

- Magnetic Basement Depth map

From the computed values (Table 4.1), the magnetic basement depth was plotted and contoured using surfer software. The deep magnetic sources vary from 2.0 to 4.1 km (Fig. 4.6), whereas the shallow magnetic source varies from 0.87 to 1.84 km (Fig 4.7). The deep depth to basement is shallowest (purple colour) at the western part of Lokoja area, while it is deepest (blue colour) in the central part of Dekina area.

- Basement Topography

Figure 4.8 is the three dimension (3D) basement topography map of the study area. The topographic map generated using Surfer software shows the undulating nature of the basement surface with thickest sediments at the central part of Dekina area and an elevation with shallowest sediments at western part of Lokoja area.

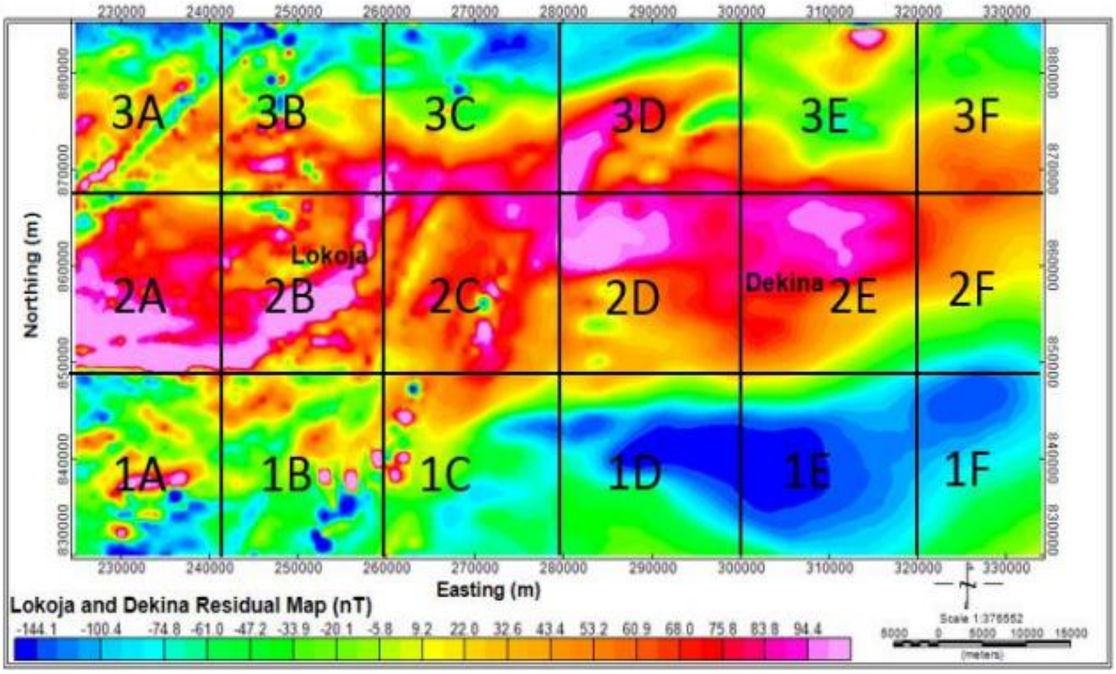
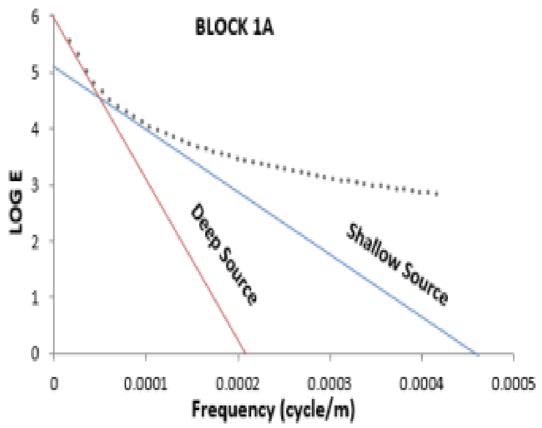
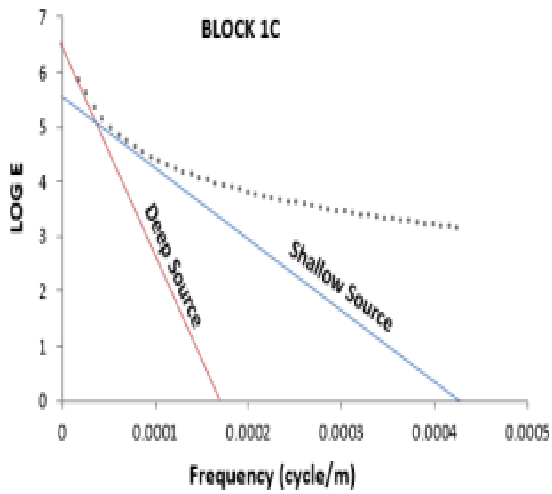
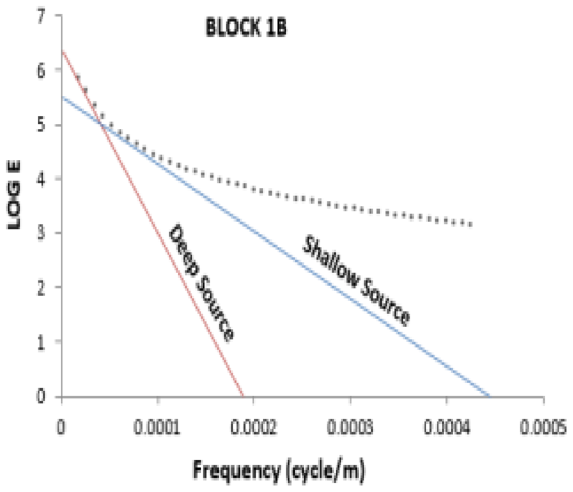
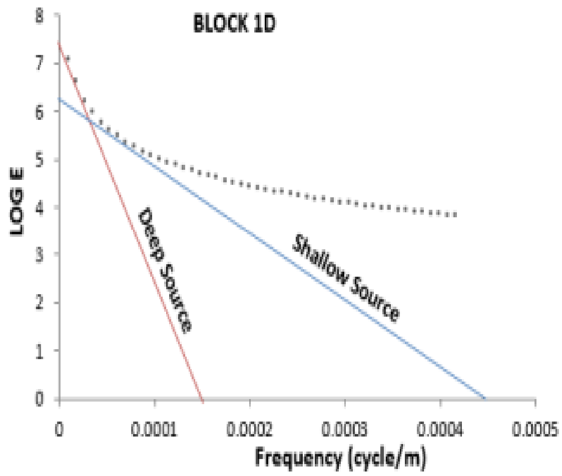


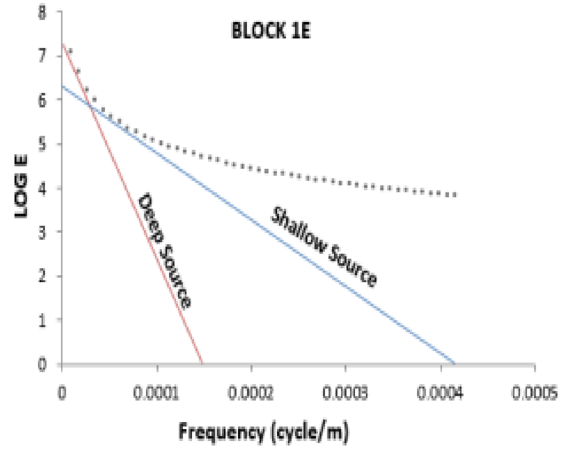
Figure4.4. Division of residual magnetic map into 18 spectral blocks







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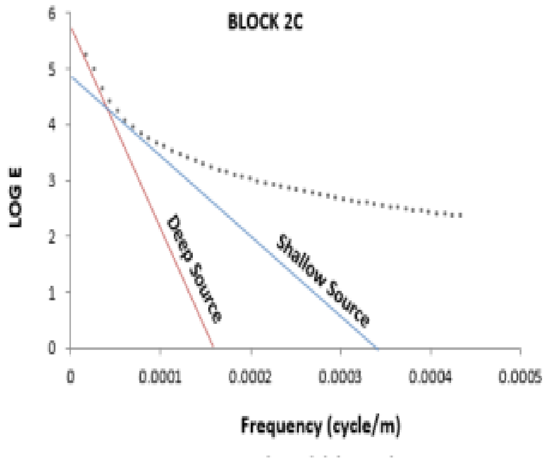
LOG E
Deep Source
Shallow Source
0 1 2 3 4 5 6 7 8
0 0.0001 0.0002 0.0003 0.0004 0.0005
Frequency (cycle/m)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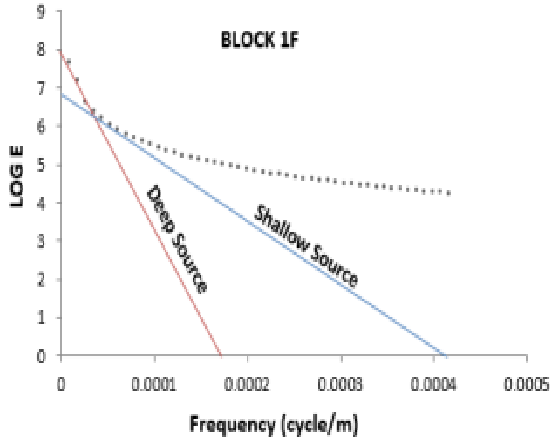
LOG E
Deep Source
Shallow Source
0 1 2 3 4 5 6
0 0.0001 0.0002 0.0003 0.0004 0.0005
Frequency (cycle/m)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Deep Source
Shallow Source
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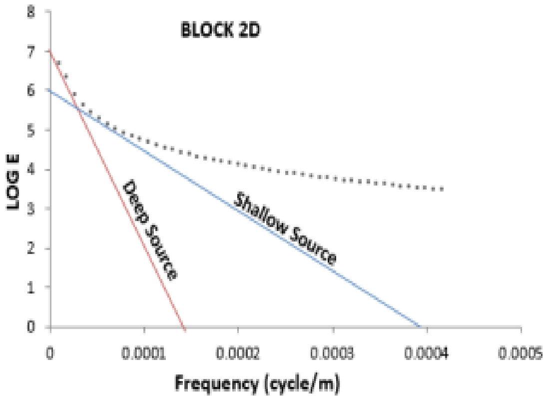
0 0.0001 0.0002 0.0003 0.0004 0.0005
Frequency (cycle/m)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LOG E
Deep Source
Shallow Source
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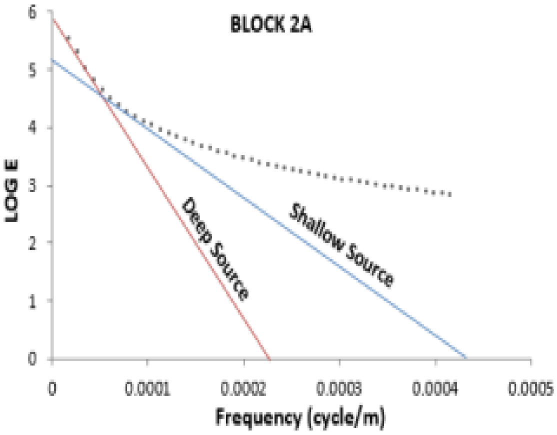
0 0.0001 0.0002 0.0003 0.0004 0.0005
Frequency (cycle/m)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LOG E
Deep Source
Shallow Source
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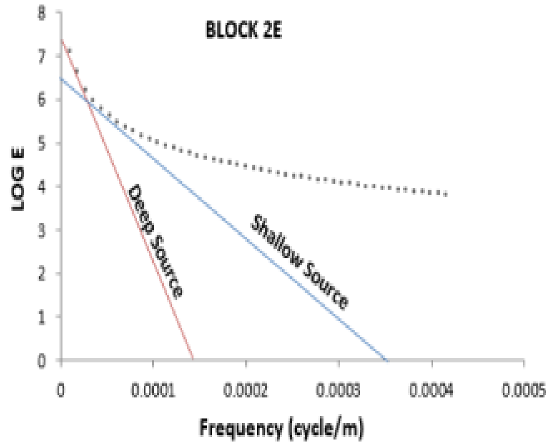
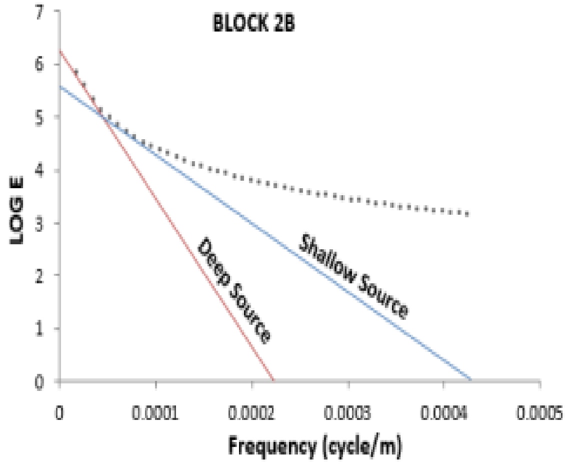
0 0.0001 0.0002 0.0003 0.0004 0.0005
Frequency (cycle/m)


BLOCK 2E
LOG E
Deep Source
Shallow Source
0 1 2 3 4 5 6 7 8
0 0.0001 0.0002 0.0003 0.0004 0.0005
Frequency (cycle/m)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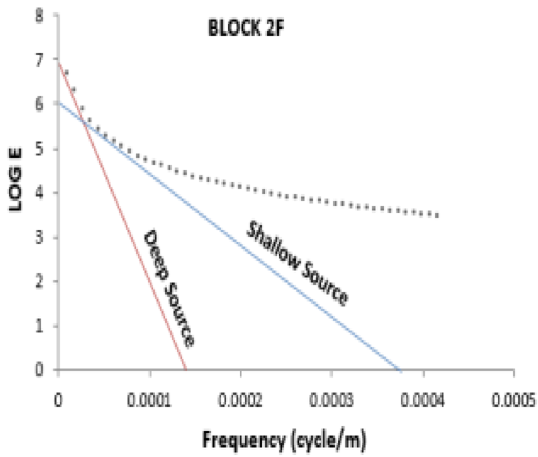
Frequency (cycle/m)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Frequency (cycle/m)

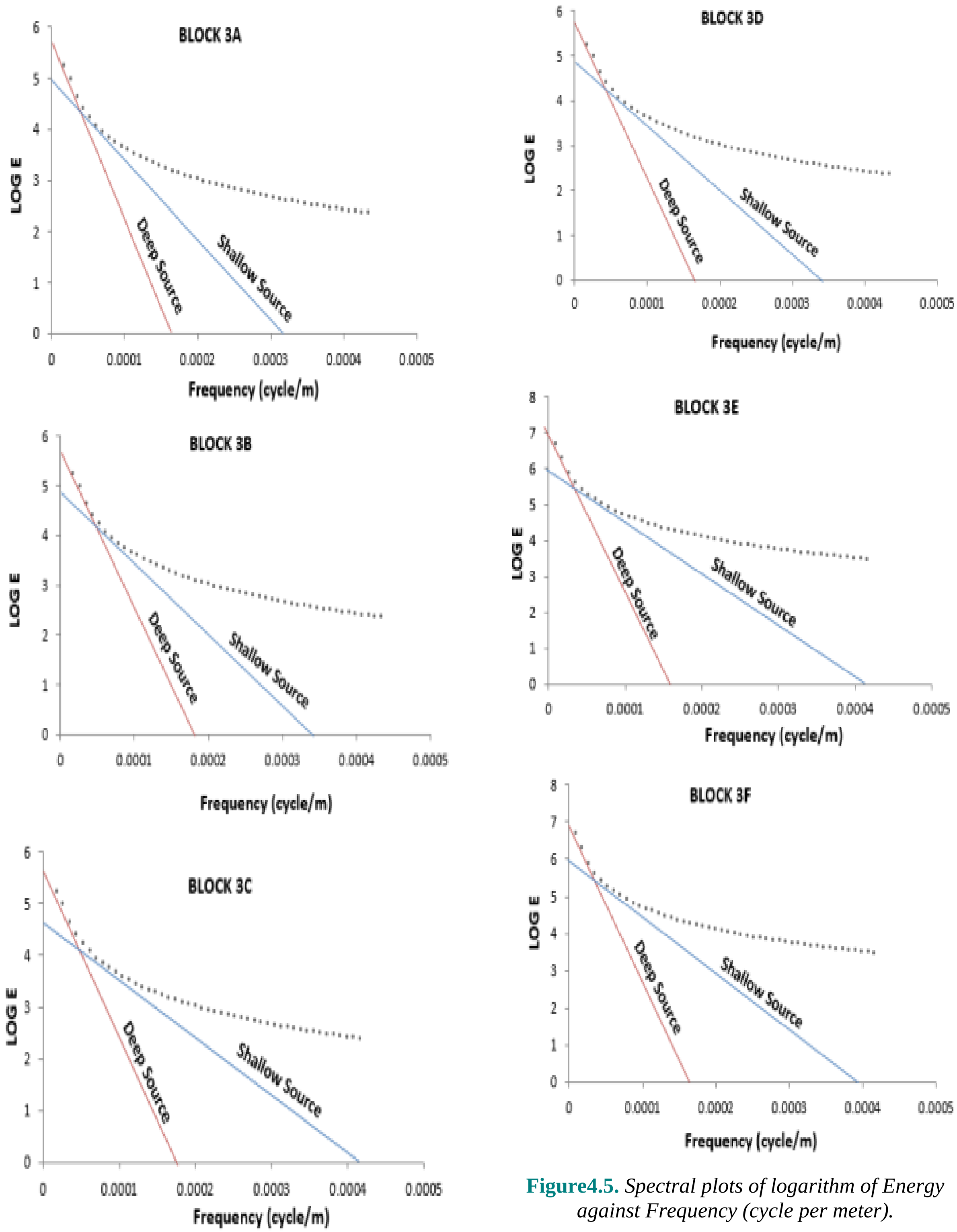

Figure4.5. *Spectral plots of logarithm of Energy against Frequency (cycle per meter).*

Table4.1. *Depth estimates of the first and second magnetic layers for the 18 spectral blocks and their coordinates.*

S/NO	SPECTRAL BLOCKS	CO-ORDINATES		DEPTH SOURCE VALUES	
	SECTIONS	X(Longitude) Meters	Y(Latitude) Meters	DEEP DEPTH D_1 (km)	SHALLOW DEPTH D_2(km)
1	1A	233820.6832	839146.3286	2.268	0.880
2	1B	251987.3502	839146.3286	2.822	0.992
3	1C	270154.0172	839146.3286	3.035	1.091
4	1D	288320.6842	839146.3286	3.915	1.093
5	1E	306487.3512	839146.3286	3.810	1.172
6	1F	324654.0182	839146.3286	3.735	1.285

7	2A	233820.6832	857479.6616	2.001	0.960
8	2B	251987.3502	857479.6616	2.237	1.034
9	2C	270154.0172	857479.6616	2.877	1.842
10	2D	288320.6842	857479.6616	3.968	1.221
11	2E	306487.3512	857479.6616	4.082	1.474
12	2F	324654.0182	857479.6616	3.912	1.287
13	3A	233820.6832	875812.9946	2.778	1.240
14	3B	251987.3502	875812.9946	2.469	1.120
15	3C	270154.0172	875812.9946	2.614	0.869
16	3D	288320.6842	875812.9946	2.708	1.741
17	3E	306487.3512	875812.9946	3.704	1.161
18	3F	324654.0182	875812.9946	3.869	1.221
AVERAGE DEPTH				3.156	1.205

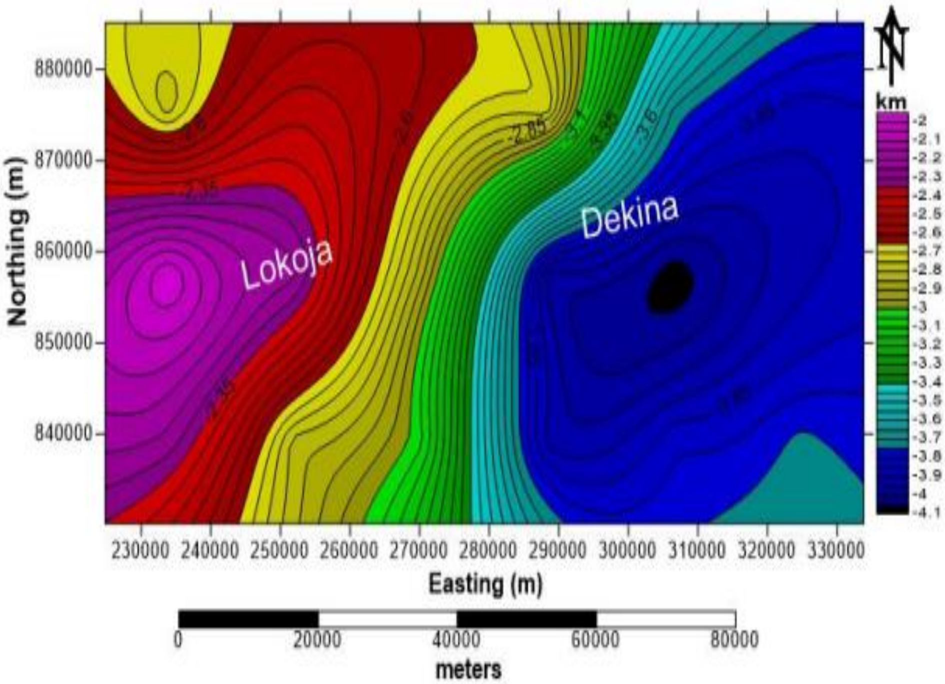

Figure4.6. *Deep depth to basement map (contour interval 0.05 km).*

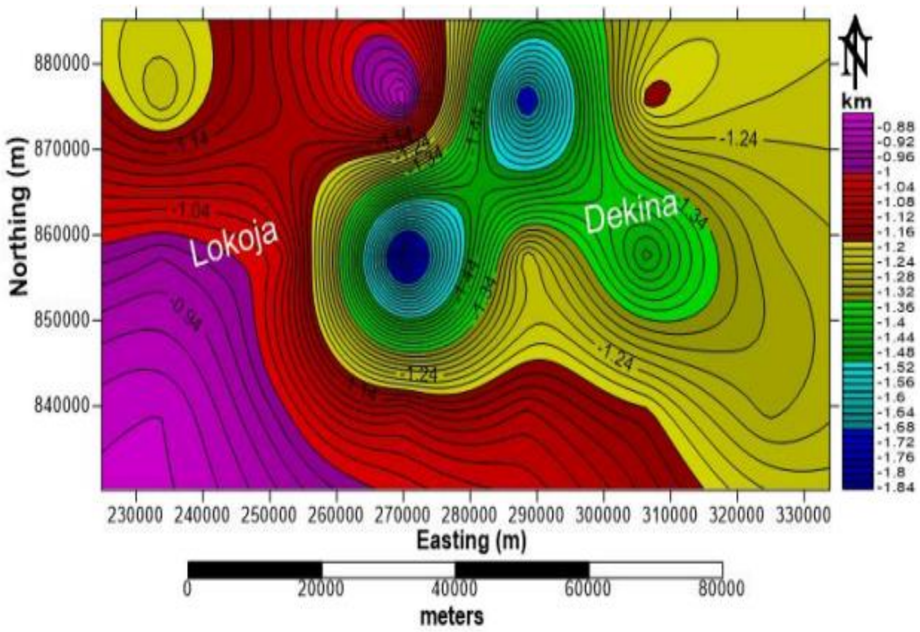

Figure4.7. *Shallow depth to basement map (contour interval 0.02 km).*

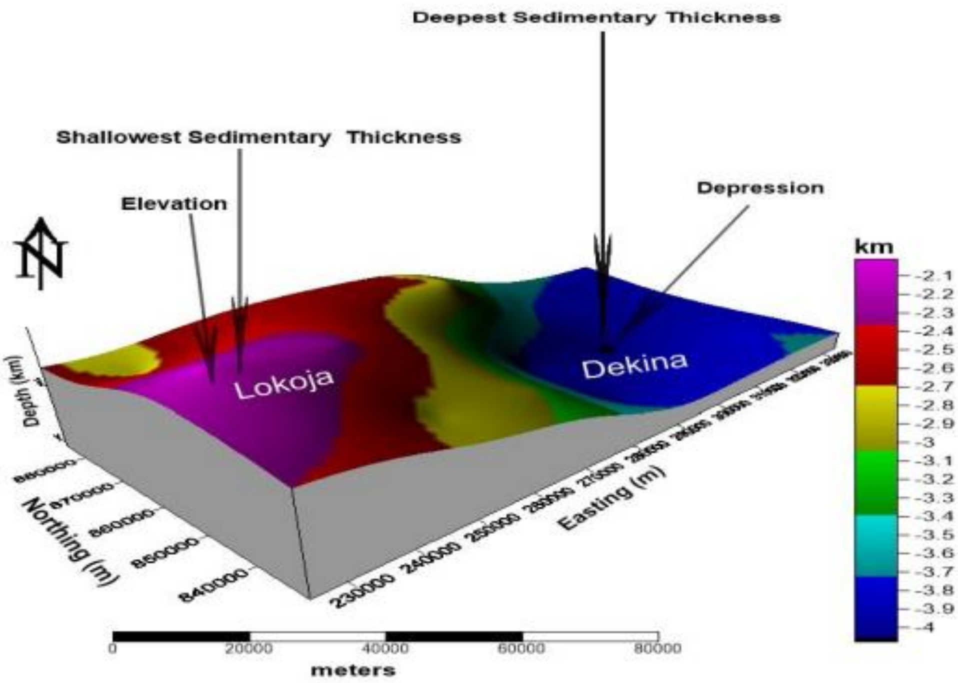

Figure4.8. 3D map showing basement topography

Discussion

The total magnetic intensity of Lokoja and Dekina show range of magnetic anomalies which vary from -92.7 to 143.0 nT while the residual values were from -144.1 to 94.4 nT. The residual field was used to bring into focus local features which tend to be obscured by the broad features of the regional field. The areas of strong positive anomalies likely indicate a higher concentration of magnetically susceptible minerals while areas with broad magnetic lows are likely areas of lower susceptibility minerals.

The result from spectral analysis shows that the depth to the magnetically deep sources range from 2.001 to 4.082 km with an overall average depth of 3.156 km, while the depth to the shallow sources ranges from 0.869 to 1.842 km with overall average depth of 1.205 km. The 3D basement topographic map presents irregular nature of the basement which is possibly associated with faults that aids the migration and entrapment of hydrocarbon and other mineralized deposits. The 3D map (Fig. 4.8) shows a linear depression with thickest sediments at the central part of Dekina area and an elevation with shallowest sediments at the western part of Lokoja area. The maximum depths of 4.082 km obtained in Dekina area show thick sediment that is feasible for hydrocarbon accumulation which agrees with the work of Osinowo and Taiwo (2020).

Conclusion

The aeromagnetic data of Lokoja and Dekina area Lower Benue Trough Nigeria, were interpreted qualitatively and quantitatively. The total magnetic intensity and residual intensity field show range of magnetic anomalies which reveal that the study area is magnetically heterogeneous. The sedimentary thickness obtained from the spectral analysis indicates the possibility of hydrocarbon generation and accumulation in the study area especially the Dekina region.

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