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# Estimation of sedimentary thickness using spectral analysis of aeromagnetic data over Otukpo and Ejekwe areas of the lower Benue Trough, Nigeria

**Asielue, K. O.[1], Ugwu, G. Z.[2*] and Ikeh, J. C.[3]**

[1] School of Business Studies, Delta State Polytechnic, Ogwashi-Uku, Delta State, Nigeria.
[2]Department of Industrial Physics, Enugu State University of Science and Technology, Enugu, Nigeria.
[3]College of Physics, Xiangtan University, Xiangtan, China.

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**The aeromagnetic data of Otukpo (sheet 270) and Ejekwe (sheet 289) areas of the lower Benue Trough of Nigeria were interpreted quantitatively. The quantitative interpretation employed spectral analysis technique with the aim of locating specific basement depths to buried magnetic source rocks in the study area. First order polynomial fitting was adopted for regional-residual separation of the total magnetic intensity (TMI) map. The result of the spectral analysis indicates two depth source models; with depths to the deep sources varying from 2546.5 to 4177.3 m, having an average depth of 3058 m; while the depths to the shallow magnetic sources vary from 309.4 to 762.5 m, with an average depth of 527 m. The Otukpo area has greater sediment thickness capable of hydrocarbon accumulation than the Ejekwe area. This is supported by the presence of many intrusions at the Ejekwe area, with large lateral extents, indicative of over mature source rocks.**

**Keywords:** Aeromagnetic data, spectral analysis, basement depths, hydrocarbon potential.

## INTRODUCTION

The search for mineral deposits and hydrocarbons has remained a major business challenge in Nigeria. Over 80% of the country's revenue comes from export and domestic sale of oil and gas. As the hydrocarbon reserves of the prolific Niger delta of Nigeria continuously get depleted due to continuous exploitation, coupled with youth restiveness in the area leading to cut in oil production, attention has shifted to other basins in Nigeria. This work was therefore motivated by the call to re-investigate all the basins in the country for hydrocarbon prospect.

The study area lies within the Lower Benue Trough of the Anambra basin. Intense geological investigations have been carried out in this region at different times in search of mineral deposits (Uzuakpunwa, 1974; Olade, 1975; Hoque, 1984). Major structural features have also been delineated which control the anomalous mineralization in the region (Olade, 1976; Ofoegbu, 1984). On the contrary, not much detailed geophysical investigations have been carried out in this part of Benue Trough for hydrocarbon occurrence. In order to contribute to better understanding of the geology and petroleum geology and

*Corresponding author. E-mail: ugwugz@yahoo.com.

petroleum potential of this part of Benue Trough, an investigation of the thickness of the sediments lying above the basement by analyzing the aeromagnetic data of the area was considered.

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 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 (Biswas, 2017).

The use of spectral analysis in interpretation of aeromagnetic data has been successfully carried out and reported by so many authors (Spector, 1968; Mishra and Naidu, 1974; Ofoegbu and Onuoha, 1991; Onwuemesi, 1997; Abudullahi et al., 2014; Alasi et al., 2017; Ikeh et al., 2017; Ugwu et al., 2018). This research is therefore considered useful, especially on reconnaissance basis, for oil and mineral prospecting in the area. In this paper, we present the variation of basement depths as determined from a two-dimensional spectral analysis of the aeromagnetic data over Otukpo and Ejekwe areas of the Lower Benue Trough, Nigeria.

## Geology of the study area

The study area lies between longitude 8° 00′ E and 8° 30′ E and latitude 6° 30′ N and 7° 30′ N. The Benue Trough is widely held to have originated as a result of tectonic and repetitive sedimentation in the Cretaceous era whose origin was closely linked with the separation of Africa and South America continents during the Mesozoic. The sequence of events that led to the formation of the Benue Trough and its component units are now well documented (Nwachukwu, 1972; Olade, 1975, Ofoegbu, 1985, 1986). The depositional history of the Benue Trough is characterized by phases of marine regression and transgression which culminated into a sequence of four different geological formations (Reyment, 1965; Murat, 1972). The oldest sediments belong to the Asu River Group which unconformably overlies the Precambrian basement complex that is made up of granitic and migmatic rocks. The Asu River Group whose type section outcrops near Abakaliki has an estimated thickness of 2000m and is Albian-Cenomanian (Ofoegbu, 1985). The Asu River Group comprises of argillaceous sandy shale, laminated sandstone, micaceous sandstone and minor limestone with an interfingering of mafic volcanics (Nwachukwu, 1972). The shale is fossil, highly fractured and is associated with pyroclastic rocks, especially around Abakaliki and Ezilo areas (Uzuakpuwa, 1974; Olade, 1975, 1976). Deposited on top of these Asu River Group sediments in the area were the Upper Cretaceous sediments, comprising mostly the Eze-Aku shale. The Eze-Aku shale consists of nearly 1000 m calcareous flaggy shale and siltstone, thin shaley limestone and calcareous sandstone (Reyment, 1965). They are Turonian in age and are overlain by younger sediments of the Awgu shale (Coniancian). The Awgu shale consists of marine fossil ferrous grey bluish shale, limestone and calcareous sandstone. The Awgu shale is overlain by Nkporo shale (Campanian-Maastrichtian) and is also marine in character with sandstone members. A geological map of the Benue Trough is shown in Figure 1.

## MATERIALS AND METHODS

### Data acquisition

Two digitized aeromagnetic maps (sheets 270 and 289) covering Otukpo and Ejekwe areas were acquired from the Nigeria Geological Survey Agency (NGSA) which undertook the aeromagnetic survey of substantial part of Nigeria between 1974 and 2008. The high resolution and most recent aeromagnetic maps of 2008 used were produced by Fugro Airborne Geophysical Surveys Limited for NGSA. The data were collected at a nominal flight altitude of 152 along N-S flight lines spaced approximately 2km apart. The maps are on a scale of 1:100,000 and half degree sheets contoured mostly at 10nT intervals. The maps are recorded in digitized form (x, y, z) to express respectively the longitude, latitude and total magnetic intensity (TMI) of each data point.

### Data reduction

The software applications used for data reduction and interpretation included Oasis Montaj, Winglink, PotentQ 4:10:07, and Surfer 10.

The first step in the data reduction process was to merge the two separate sheets into a single composite sheet which formed the study area. The merged aeromagnetic sheet was further divided into eighteen different cells for spectral analysis. Each profile covers a square area of 18.3 km by 18.3 km in order to accommodate longer wavelengths so that depths up to about 6.0km could be investigated. The second step in the data reduction process was the polynomial fitting in order to remove the regional anomalies from the total magnetic intensity to obtain the residual anomaly.

Other data enhancement techniques applied on the residual intensity field include First Vertical Derivative (FVD), Horizontal Derivative (HD) and Upward Continuation. The first vertical derivative enhanced shallow sources by suppressing deeper ones which gave a good resolution of the data and hence there was no need for the second vertical derivative. Random noise was also removed by upward continuation of the aeromagnetic anomaly field.

### Spectral analysis

Fast Fourier Transform (FFT) is the mathematical tool used for spectral analysis and applied to regularly spaced data such as the aeromagnetic data to calculate and interpret the spectrum of the potential field. It transforms magnetic data from space domain to frequency domain. The 2-D FFT technique was used in Microsoft-Excel and Oasis Montaj to transform the magnetic field data into the radial energy spectrum for each block. Bhattacharyya (1966), Spector and Grant (1970) described 2-D techniques for spectral

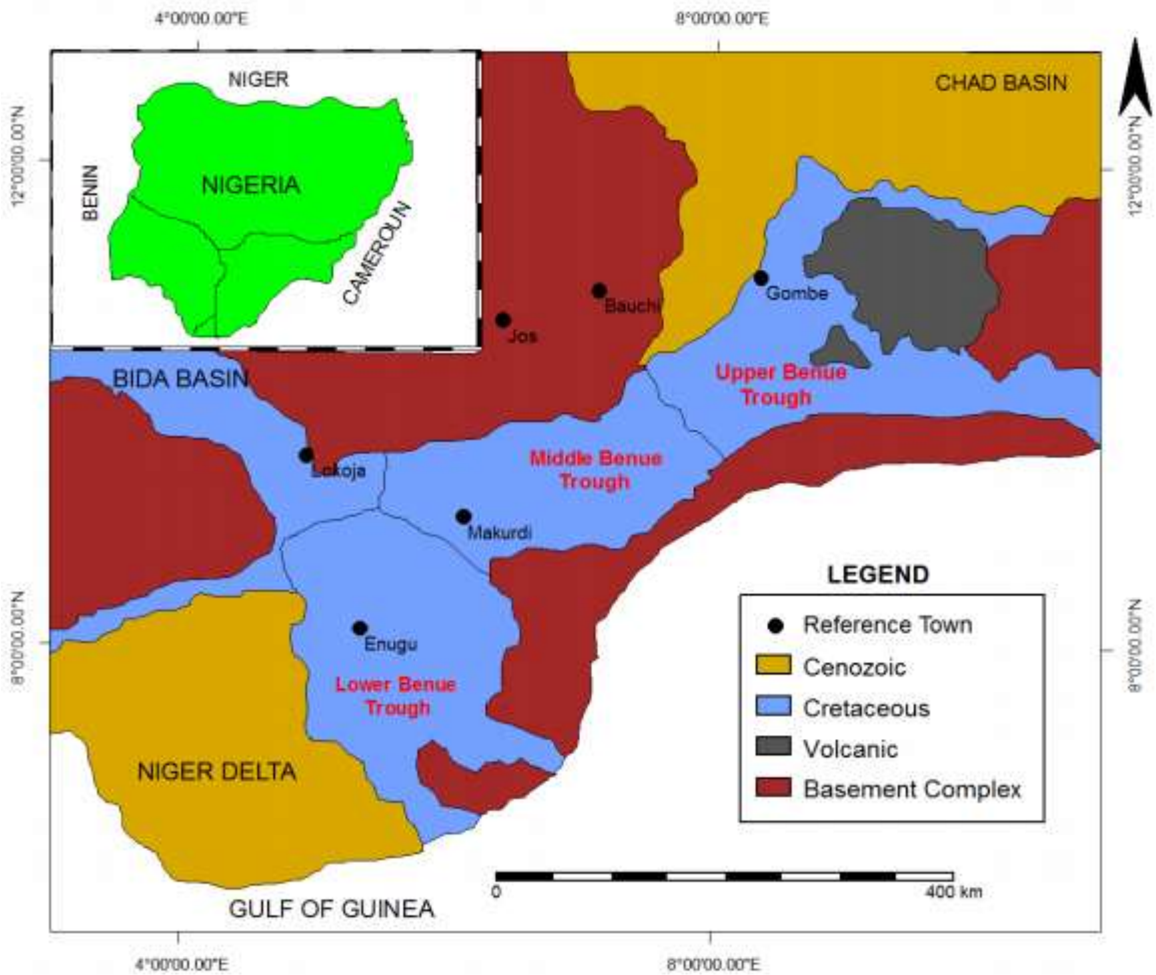


**Figure 1.** Geological map of the Benue Trough (Fatoye and Gideon, 2013).

analysis of aeromagnetic anomalies for the power spectrum of the total magnetic field intensity over each rectangular block. To perform this analysis, the average radial energy spectrum was calculated and graphs of the natural logarithm of energy against frequency were plotted and the gradient of the linear segments computed in order to obtain the depths to the basement (Bhattacharyya, 1966; Spector and Grant, 1970):

$$M_1 = \frac{\Delta y\ (LogE)}{\Delta x\ (Frequency)} \quad (1)$$

$$M_2 = \frac{\Delta y\ (LogE)}{\Delta x\ (Frequency)} \quad (2)$$

$$D_1 = \frac{-M_1}{4\pi} \quad (3)$$

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

Where, $M_1$ and $M_2$ are the slopes of the first and second segments of the plots. The negative sign shows depth to the subsurface. The energy spectrum generally has two sources. The deep source ($D_1$) and the shallow source ($D_2$), corresponding to the first and second depth segments respectively. The deep source corresponds to the small wavenumber end of the spectrum while the shallow depth corresponds to the large wavenumber end of the spectrum. The slope of each of the line segments for the eighteen spectral blocks were first evaluated and the depth estimates $D_1$ and $D_2$ for each of the 18 spectral blocks then determined.

## RESULTS AND DISCUSSION

The total magnetic intensity map of the study area is as shown in Figure 2 while the residual field anomaly map is shown in Figure 3. The 3-D surface plot of the residual field anomaly is also presented in Figure 4 while Figure 5 shows the magnetic lineament map of the study area. Figures 6, 7 and 8 respectively shows the first vertical derivative, horizontal derivative and upward continuation map of the residual field anomalies.

The residual anomaly map of the study area ranges from -260 to 200 nT (Figure 3).The colour bar shows the variation of the magnetic intensity in the area. The visual inspection of the shape and trend of the major anomalies on the residual map shows that the contour lines at the northern part of the study area (Otukpo area) have large contour closures of quiet relief, suggesting that the depth

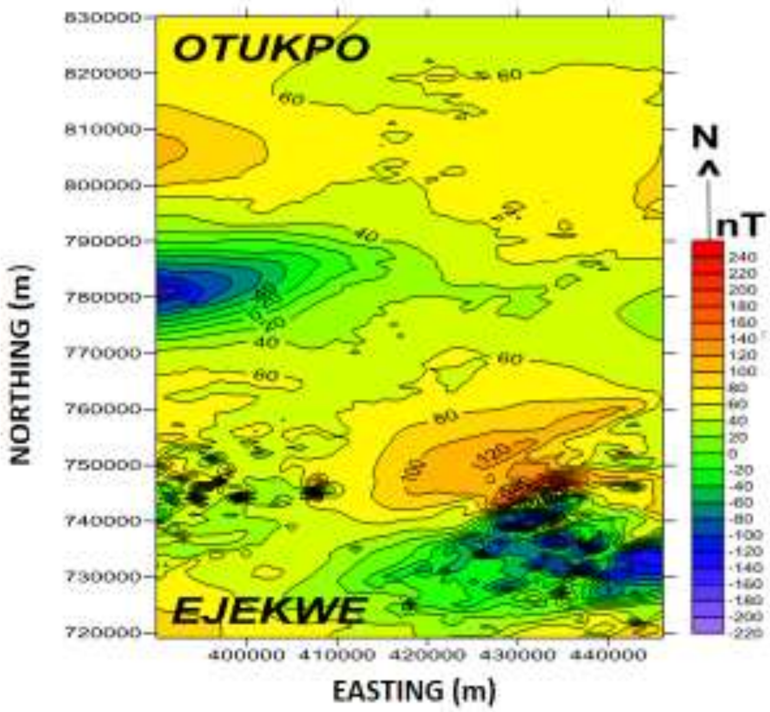


**Figure 2.** TMI map of the study area.

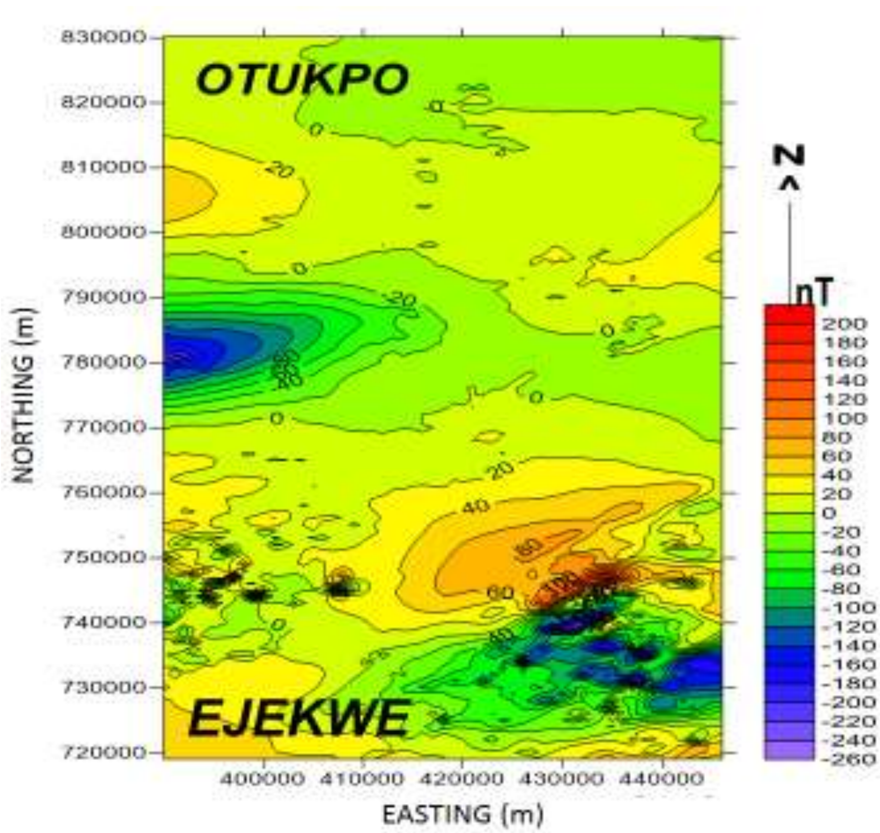


**Figure 3.** 2-D residual field anomaly map of the study area.

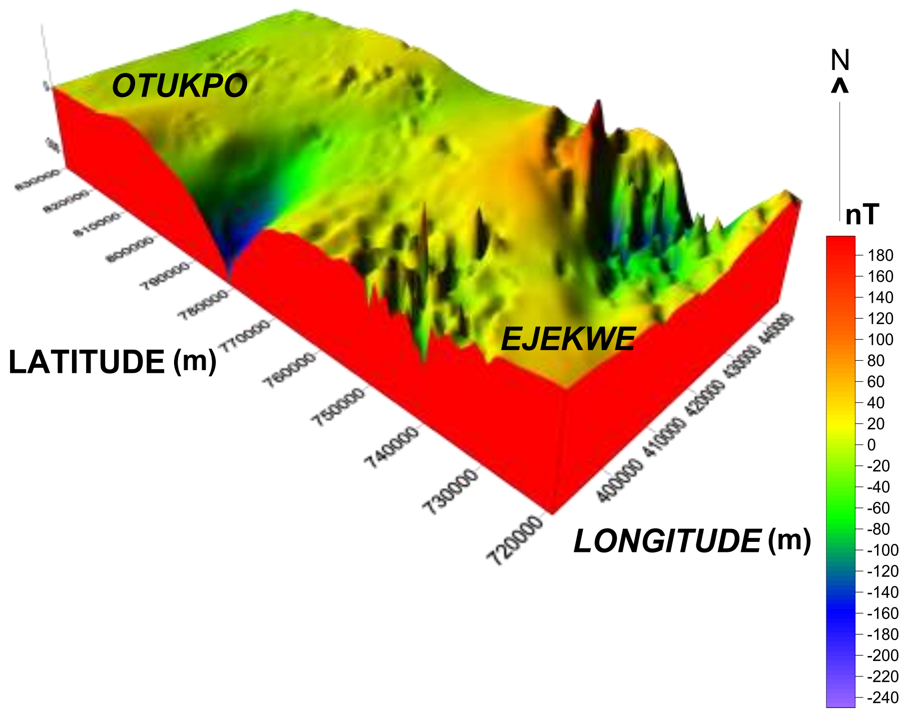


**Figure 4.** 3-D residual field anomaly map of the study area.

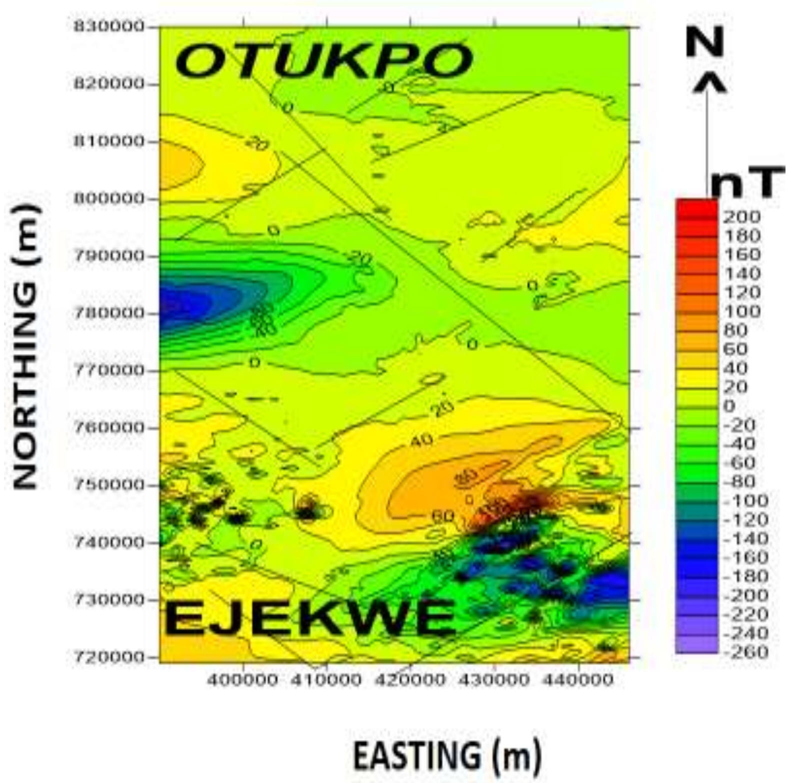


**Figure 5.** Linearment map of the field anomaly.

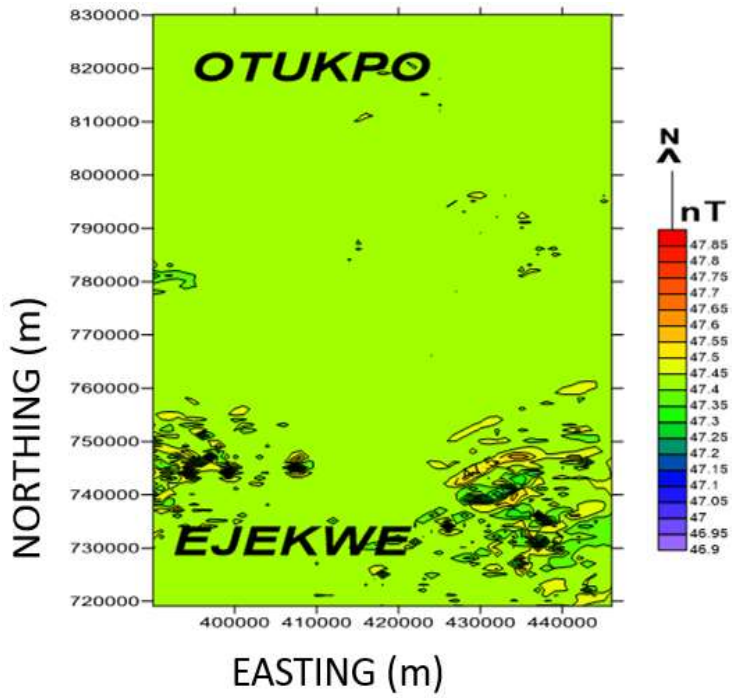


**Figure 6.** First vertical derivative map.

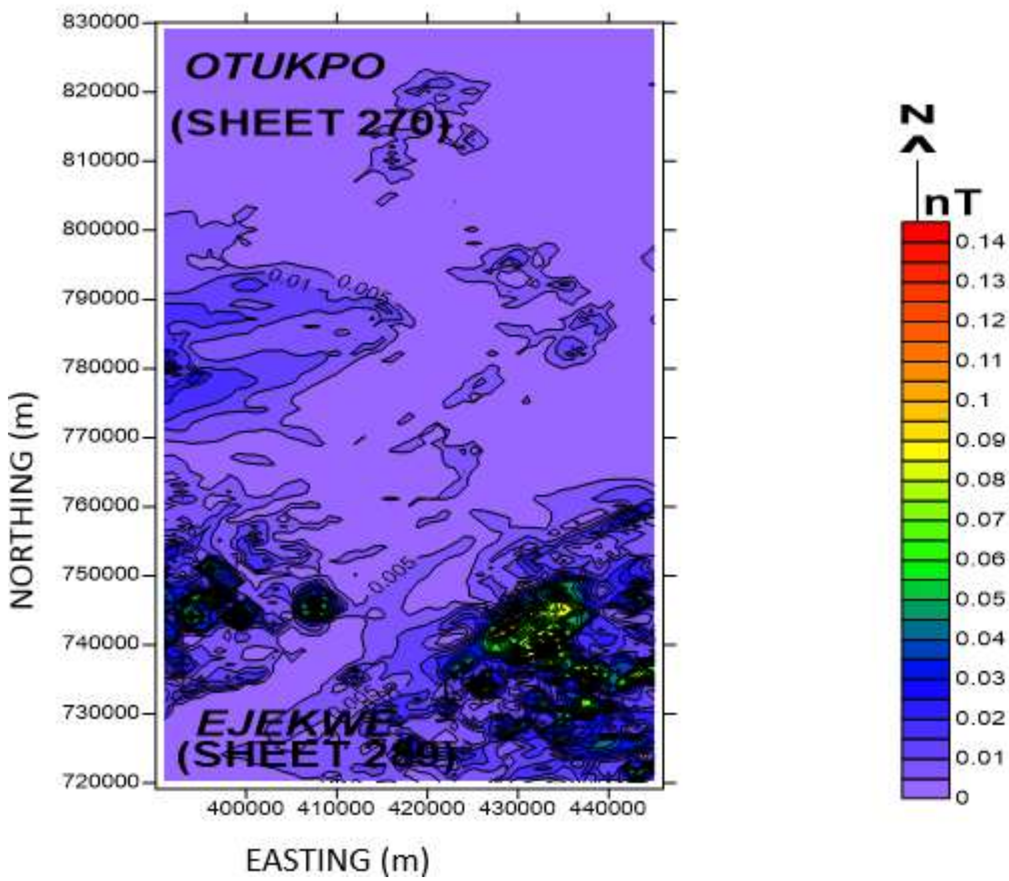


**Figure 7.** Horizontal derivative map.

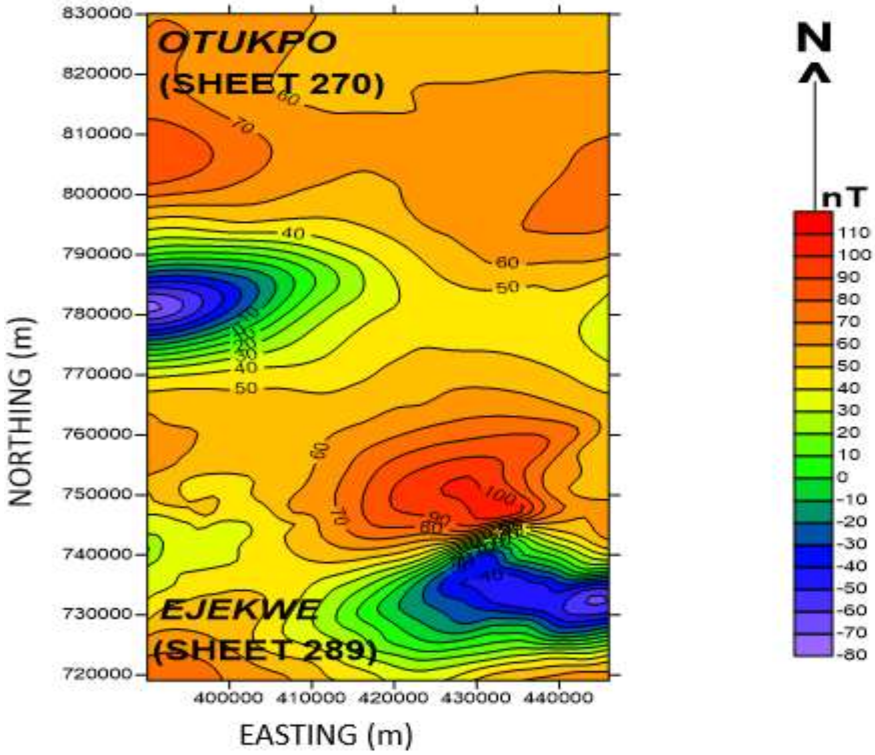


**Figure 8.** Upward continuation map.

to basement is greater at this part than at the southern part (Ejekwe area) where there are relative number of intrusive rocks. The magnetic lineament map (Figure 5) shows major faults trending NE-SW direction, with minor faults trending SE-NW and ENE-WEW directions. These trends are in conformity with the structure of the basement complex of northeastern Nigeria and could serve as migration pathway for hydrocarbon or hydrothermal fluids.

The result of the spectral analysis of the aeromagnetic data over the study area is summarized in Table 1. Two representative plots of the energy spectrum against frequency over the study area are as shown in Figures 9 and 10, corresponding to spectral blocks 1 and 10 respectively. Block 1 has the deep depth ($D_1$) as 2983.3 m and the shallow depth ($D_2$) as 762.5 m while Block 10 has the deep depth ($D_1$) as 4177.3 m and the shallow depth ($D_2$) as 397.8 m. The depth to the deep source ($D_1$) represented by the low frequency segments of the spectrum is considered to reflect magnetic bodies on the basement surface. These deep magnetic sources lie at depths that range from 2546.5 to 4177.3 m, with average depth value of 3057.9 m. On the other hand, the shallow magnetic horizon ($D_2$) which lies at 309.4 to 762.5 m with average depth value of 526.9 m that represent the high frequency components can be attributed to the effect of magnetic bodies intruded into the sediments. Using values of the basement depths ($D_1$) of Table 1, a map of magnetic basement depth over the study area was plotted as shown in Figure 11. Deeper sedimentary thicknesses were obtained around the northern part (Otukpo area) than at the southern part (Ejekwe area). The depth results agree with those obtained from other research works done in the Lower Benue Trough (Ofoegbu, 1984; Ofoegbu and Onuoha, 1991; Onwuemesi, 1997). Wright et al. (1985) reported that when all other conditions for hydrocarbon accumulation are favourable, the minimum thickness of the sediment required for the commencement of oil formation from marine organic remains would be 2.3 km. The basement depth (sediment thickness) of 2546.5 to 4177.3 m recorded in this study is therefore capable of holding hydrocarbon potentials. Previous geological and geophysical studies carried out by Ofoegbu (1984, 1986) in the Benue Trough showed that the area possesses qualities like thick sedimentary sequence, marine source bed, block faulting and suitable traps notable with the oil producing regions of Nigeria.

## Conclusion

Spectral analysis of the aeromagnetic data over Otukpo and Ejekwe areas of the Lower Benue Trough have been

**Table 1.** Summary of depth of spectral blocks.

| Spectral Block | Easting (m) | Northing (m) | Deep Depth (m) | Shallow Depth (m) |
|---|---|---|---|---|
| 1 | 398500 | 72700 | 2983.8 | 762 .5 |
| 2 | 417000 | 72700 | 2546.5 | 309.4 |
| 3 | 435500 | 72700 | 2783.4 | 682.0 |
| 4 | 398500 | 745500 | 2874.4 | 696.4 |
| 5 | 417000 | 745500 | 3083.2 | 663.0 |
| 6 | 435500 | 745500 | 2976.3 | 626.6 |
| 7 | 398500 | 764000 | 2884.3 | 530.4 |
| 8 | 417000 | 764000 | 2946.3 | 497.6 |
| 9 | 435500 | 764000 | 3651.4 | 514.8 |
| 10 | 398500 | 782500 | 4177.3 | 397.8 |
| 11 | 417000 | 782500 | 3845.7 | 388.4 |
| 12 | 435500 | 782500 | 3978.4 | 393.6 |
| 13 | 398500 | 801000 | 4111.0 | 386.4 |
| 14 | 417000 | 801000 | 3182.7 | 486.4 |
| 15 | 435500 | 801000 | 3062.7 | 476.8 |
| 16 | 398500 | 819500 | 3013.2 | 564.3 |
| 17 | 417000 | 819500 | 2983.8 | 525.2 |
| 18 | 435500 | 819500 | 3014.8 | 583.5 |
| AVERAGE | | | 3057.9 | 526.9 |

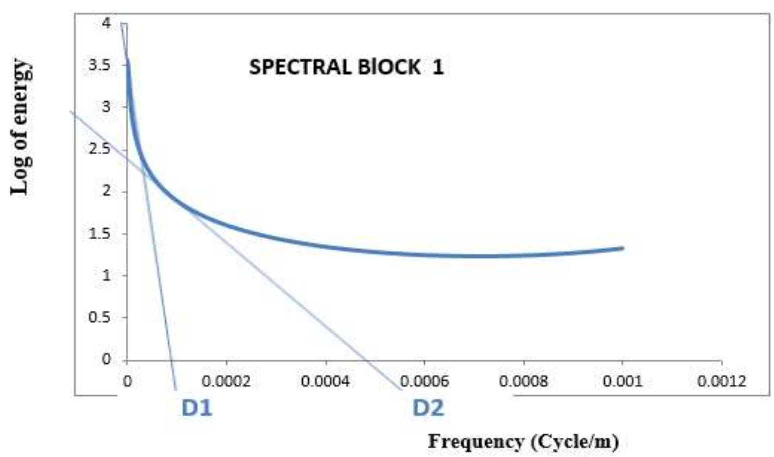


**Figure 9.** Spectral plot of Log of energy versus frequency for block 1.

carried out to estimate the depth to magnetic basement of the area. The result of the interpretation shows that the northern part of the study area has deeper basement depth than the southern part. More intrusions were however revealed at the southern part (Ejekwe area) than at the northern part.

Knowledge of the basement depth (sediment thickness) of this path of the sedimentary basin of Nigeria is fundamental in investigating its hydrocarbon potentials. The lineament map revealed major faults trending NE-SW direction, with minor faults trending SE-NW and ENE-WEW directions. These fault trends could serve as migration pathways for hydrocarbon or hydrothermal migration pathways for hydrocarbon or hydrothermal fluids.

The result of this study shows that this part of the Benue Trough has an average sediment thickness of 3.06 km. If all other conditions for hydrocarbon accumulation are favourable, the sediment thickness obtained in this study is sufficient for hydrocarbon accumulation.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

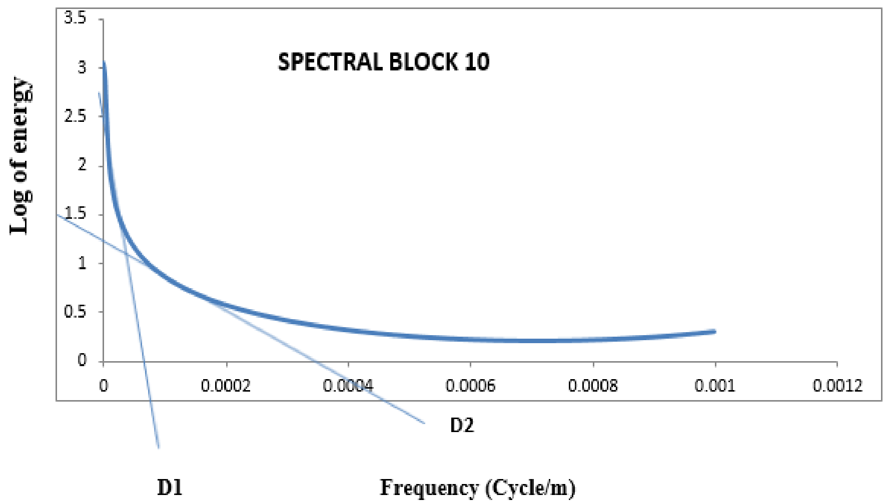


**Figure 10.** Spectral plot of Log of energy versus frequency for block 10.

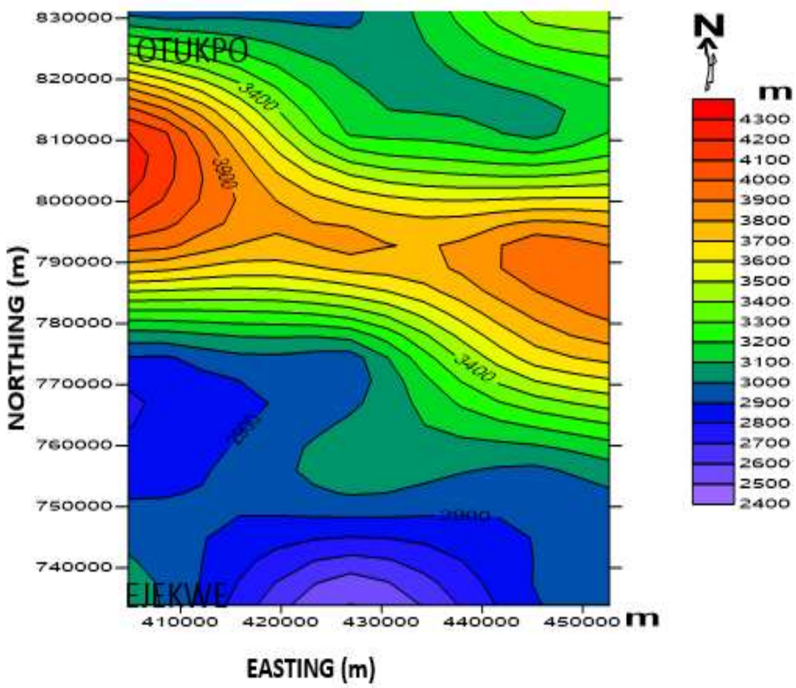


**Figure 11.** Basement map of the study area.

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