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Estimation of sedimentary thickness using spectral analysis of aeromagnetic data over Abakaliki and Ugep areas of the Lower Benue Trough, Nigeria

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Aeromagnetic data over Abakaliki and Ugep areas of the lower Benue Trough were interpreted to determine the depth to magnetic source rocks of the area. The study area covered latitudes 5° 30' and 6° 30'N and longitudes 8° 00' and 8° 30'E with an estimated total area of about 6000 km^2. Quantitative interpretation was carried out using spectral analysis method to compute for depth to basement while the polynomial fitting method was adopted for the regional-residual separation of the total magnetic intensity. Interpretation of the total magnetic intensity (TMI) over the area showed NE and NW main trends in the study area. The 3-D surface map also showed a linear depression with sedimentary accumulation trending E-W. The spectral analysis over the area showed a sedimentary thickness that ranged from 0.64 to 4.25 km. High sedimentary thickness of over 4 km was obtained at the central part of the study area while the minimum sedimentary thickness of about 0.60 km was obtained at the southern part of the study area which is around Ugep. The maximum sedimentary thickness of about 4.25 km could be capable of hydrocarbon accumulation prospect.

Key words: Aeromagnetic data, spectral analysis, magnetic anomaly, intrusions and sedimentary thickness.

INTRODUCTION

Aeromagnetic survey has remained a powerful tool in modern geological mapping and mineral exploration purposes. This method of investigating the subsurface geology is based on the magnetic anomalies in the earth's magnetic field resulting from the magnetic properties of the underlying rocks. Measurements of the horizontal or vertical component or horizontal gradient of the magnetic field may also be made (Biswas et al., 2017). The shape, dimensions, and amplitude of an 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, 2016, 2017; Biswas and Acharya, 2016). For exploration purposes, both ground and aero-magnetic data have been used to investigate the presence of mineral deposits in

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combination with gravity. In the mining industry, both magnetic and gravity method are still widely used as an exploration tool to map subsurface geology and estimate ore reserves for some massive ore bodies (Mandal et al., 2013; Biswas et al., 2014a, b; Mandal et al., 2015; Biswas and Sharma, 2016). Aeromagnetic survey for determining the depth to magnetic source of anomaly over an area utilizes the principle that the magnetic field measured at the surface can be considered as an integral of the magnetic signatures from all depths. The power spectrum of the surface field can be used to estimate the average depth to basement (sedimentary thickness) across the geological area.

The study area lies within the southern portion of the Lower Benue Trough and consists of sheet 303 (Abakaliki sheet) and sheet 314 (Ugep Sheet). The area is delineated by latitudes 5° 30' and 6° 30'N and longitudes 8° 00' and 8° 30'E. The area is characterized by a number of economic minerals which have generated a lot of interest on the economic potential of this mineral belt (Uzuakpunwa, 1974; Olade, 1976; Hoque, 1984; Njoku, 1985; Ofoegbu, 1985; Ofoegbu and Onuoha, 1991; Obi et al., 2010; Ugwu and Ezema, 2012; Ugwu et al., 2013). Previous studies of the magnetic anomaly over the area suggest that the anomalies can best be explained in terms of the combined effects of deep lying basement and basic to intermediate intrusions at both shallow and deep depths (Ofoegbu, 1984a, b; Ofoegbu and Onuoha, 1991; Ugwu and Ezema, 2012). Ofoegbu (1984a) estimated the thickness of the sediments in the Lower and Middle Benue Trough to vary between 0.5 and 7.0 km. Nkwonta and Kene (2005) used various graphical methods of aeromagnetic interpretation to estimate the depth to anomalous structures in the Lower Benue Trough to lie between 0.55 and 9.20 km. Some of the anomalies were interpreted in terms of dykes and volcanic plugs (Ofoegbu, 1984b; Ugwu and Ezema, 2012).

In order to contribute to a better understanding of the anomalous structures in the southern portion of the Lower Benue Trough, we have considered the use of spectral analysis of the aeromagnetic data over Abakaliki and Ugep areas to compute the depth to magnetic source rocks in the area.

Interpretation of aeromagnetic data can be carried out both quantitatively and qualitatively. Quantitative interpretation involves making numerical estimates of the depth and dimensions of the sources of anomalies and this often takes the form of modeling of sources which could, in theory, replicate the anomalies recorded in the survey (Biswas, 2015; Biswas, 2016; Singh and Biswas, 2016; Biswas et al., 2017). Spectral analysis has successfully been applied in interpretation of aeromagnetic data (Bhattacharyya, 1966; Spector, 1968; Mishra and Naidu, 1974; Hahn and Mishra 1976). The power spectrum of the surface field has been used to identify average depths of source ensembles (Spector and Grant, 1970). This technique can be used in identification of the characteristic depth of the magnetic basement, on a moving data window basis, merely by selecting the steepest and therefore deepest straight-line segment of the power spectrum, assuming that this part of the spectrum is sourced consistently by basement surface magnetic contrasts. A depth solution is calculated for the power spectrum derived from each grid sub-set, and located at the center of the window. Overlapping the windows creates a regular, comprehensive set of depth estimates.

Geology of the study area

The geology and evolution of the Lowe Benue Trough is now fairly well documented (Nwachukwu, 1972; Olade, 1975; Ofoegbu, 1985). The Lower Benue Trough is underlain by a thick sedimentary sequence deposited in the Cretaceous. The major component units of the Lower Benue Trough include the Anambra basin, the Abakaliki Anticlinorium and the Afikpo Syncline. The oldest sediment of the sequence belong to the Asu River Group (Figure 1) which unconformably overlies the Precambrian basement complex that is made up granitic and magmatic rocks (Ofoegbu and Onuoha,1991). The Asu River Group whose type outcrops in Abakaliki has estimated thickness of about 2000 m (Ofoegbu, 1985a) and is Albian to Cenomanian. It comprises of argillaceous sandy shales, laminated sandstones units and minor limestones with an interfingering of mafic volcanic (Nwachukwu, 1972).The shales are fissile and highly fractured. In the vicinity of the study area, the shales are associated with pyroclastic rocks and brine (Okezie, 1965; Uzuakpunwa, 1974). Deposited on top of those Asu River Group sediments in the area is the Upper Cretaceous Eze- Aku shale.

The Turonian Eze-Aku shales consist of nearly 1000 m of calcareous flaky shales and siltstones, thin sandy and argillaceous limestones and calcareous sandstones (Reyment, 1965). The Eze-Aku shales sits unconformably over the Precambrian Gneiss to the north of Ugep and it is conformably overlain by the Semonian sandstones and Upper coal beds along Ugep (Obi et al., 2010). The Nkporo shales are the youngest unit of the sequence and overlie the Eze-Aku shales unconformably. They are Campanian-Maaestrichtian in age and are mainly marine in character, with some intercalations of sandstones.

MATERIALS AND METHODS

Digitized aeromagnetic data sheets 303 (Abakaliki) and 314 (Ugep) were acquired from Nigerian Geological Survey Agency (NGSA). The data were obtained from the survey carried out in 2008 by Fugro Airborne Surveys Limited for NGSA. These data were acquired along a series of NW-SE flight line with a spacing of 500 m and flight line spacing (infill) of about 250 m, while the tie lines

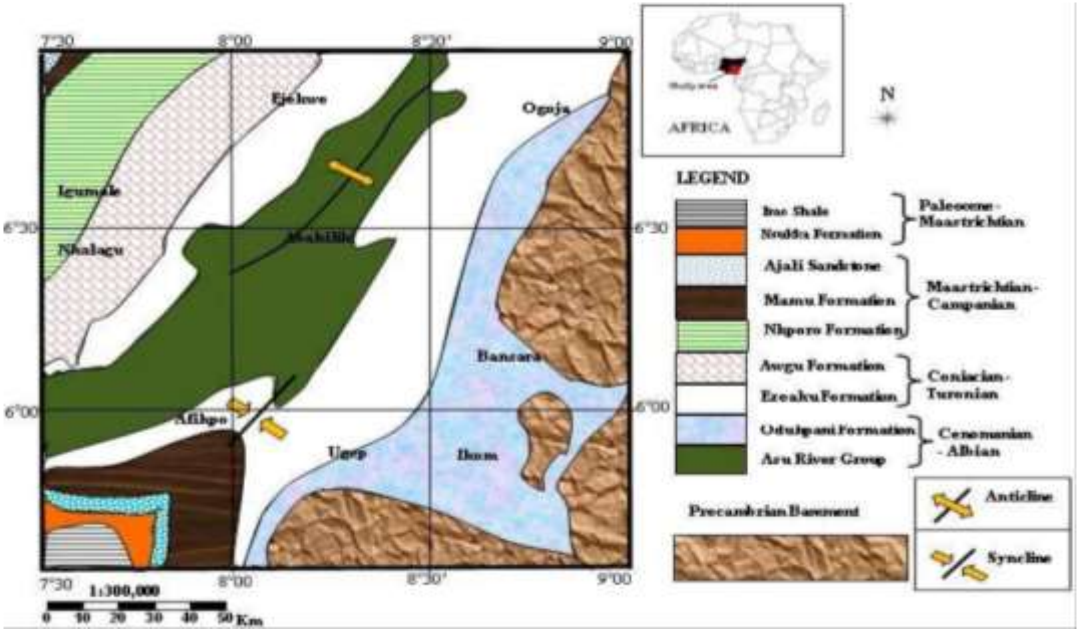

Figure 1. Geologic map of southern part of Lower Benue Trough.
Source: Onuba et al. (2013).

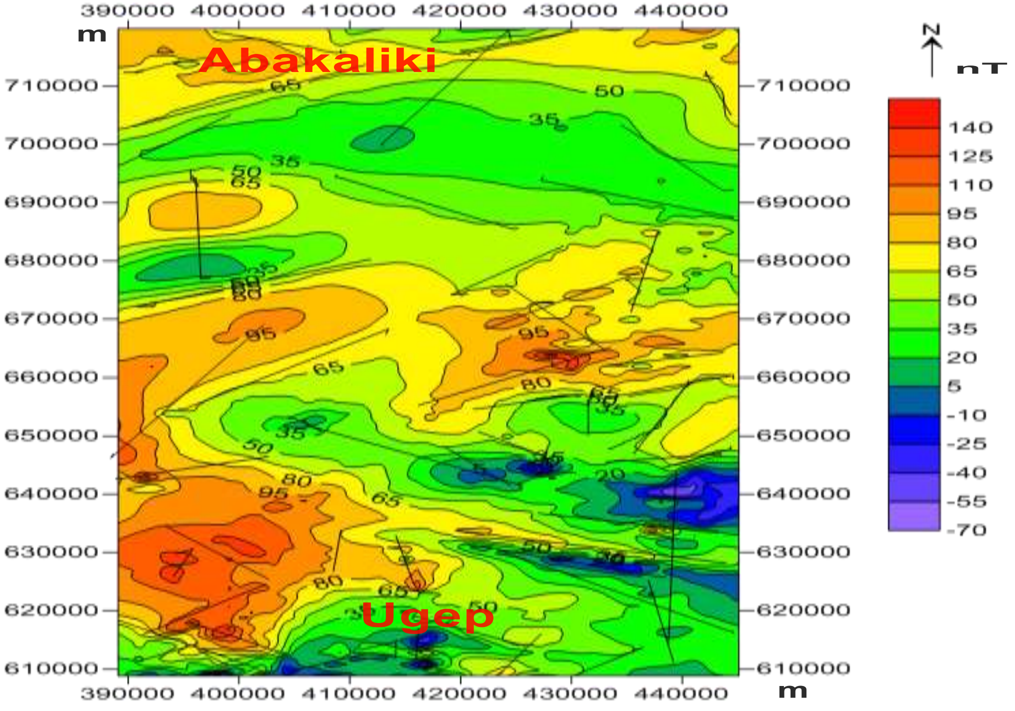

Figure 2. TMI map of the study area (contour interval ≈ 15nT).

were at about 5000 m interval. The geomagnetic gradient was removed from the data using the International Geomagnetic Reference Field (IGRF). The covered area was about 6050 km^2. The contoured data of total magnetic field intensity (TMI) contained both the regional and residual anomalies (Figure 2). The regional fields were removed from the TMI data using first order polynomial fitting to obtain the resultant residual aeromagnetic anomaly data (Figure 3) and their digital terrain models employing WingLink and

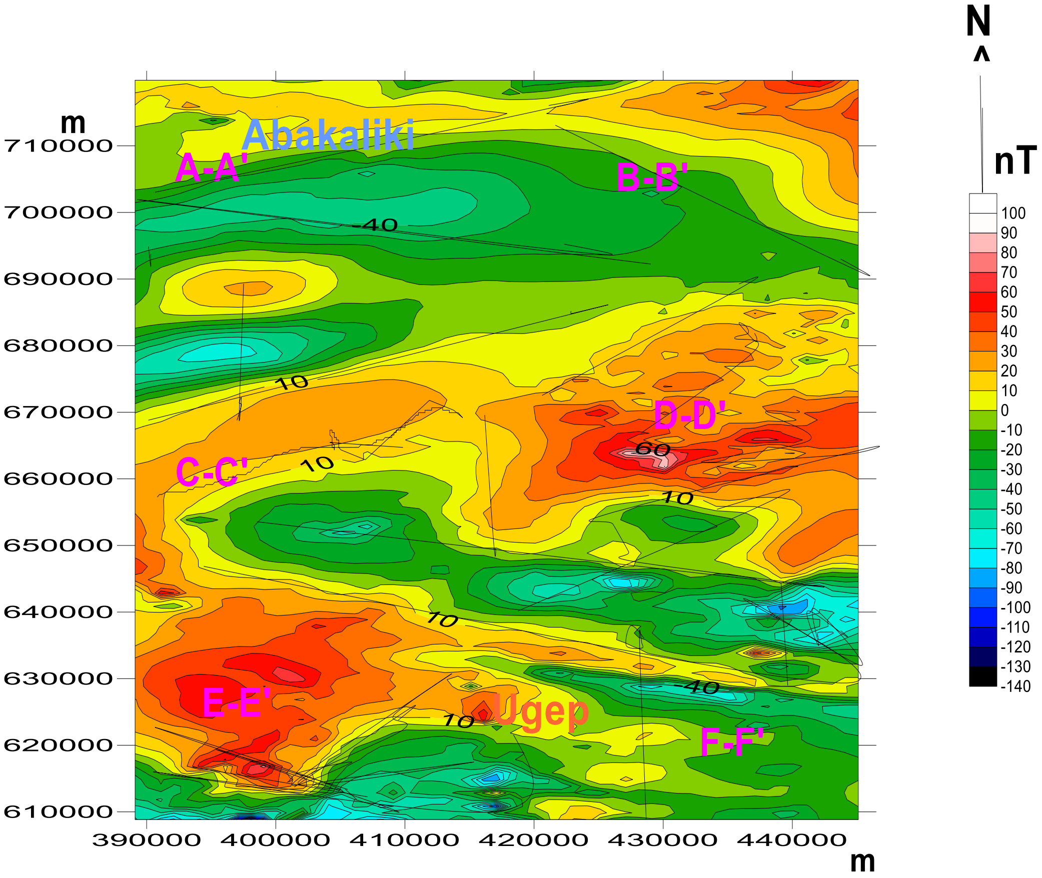

Figure 3. Residual anomaly map of the study area (contour interval ≈ 15nT).

Surfer 10 software at interval of 15nT. Different orders of the polynomial fitting were tried but the first order fitting was found to be the best for the data.

Six profiles were taken, cutting across anomalous features in the area under study. The anomalies identified on these profiles were subjected to spectral analysis using discrete Fourier transform. The discrete Fourier transform 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. In order to carry out the spectra analysis of the aeromagnetic data, the study area was divided into blocks containing 18 × 18 data points. In doing this, it was necessary to ensure that essential parts of each anomaly were not cut off by the blocks. Care was also taken to ensure that each block contained more than one maximum, as suggested by Hahn and Mishra (1976). To achieve this, a few of the blocks were made to overlap each other. Graphs of the logarithms of amplitude (spectral energy) against frequency were plotted and the linear segments from the low frequency portion of the spectral drawn from the graphs. The gradient of the linear segments were computed and the depths to the basement were determined using the equations according to Negi et al. (1983), Ikumbur et al. (2013) and Akanbi and Fakoya (2015):

$D_1 = -m_1/4\Pi$
$D_2 = -m_2/4\,\Pi$

Where M_1 and M_2 are the slopes of the first (shallow) and second (deep) depths, respectively. D_1 and D_2 are, respectively the first and second depths.

RESULTS AND DISCUSSION

The aeromagnetic field map of the area is characterized by a series of local anomalies as can be seen from the difference between Figure 2 and Figure 3 obtained after the regional-residual separation using first degree polynomial fitting. The structural trends revealed from the first degree polynomial surfaces have a preponderance of NE-SW and NW-SW directions. The 3D surface map of the residual anomaly is also shown in Figure 4. The map helps to quantify the different magnetic responses of structures in the shallow and deep sedimentary sections in the basement. The 3D surface map also shows a linear depression with sedimentary accumulation trending E-W.

Figures 5 to 10 show the representative plots of spectral energy against frequency for each of the six profiles taken, namely; AA^{I}, BB^{I}, CC^{I}, DD^{I}, EE^{I} and FF^{I}. Two depth models were estimated for all the blocks and these values are summarized in Table 1 for the 18 blocks making up the study area.

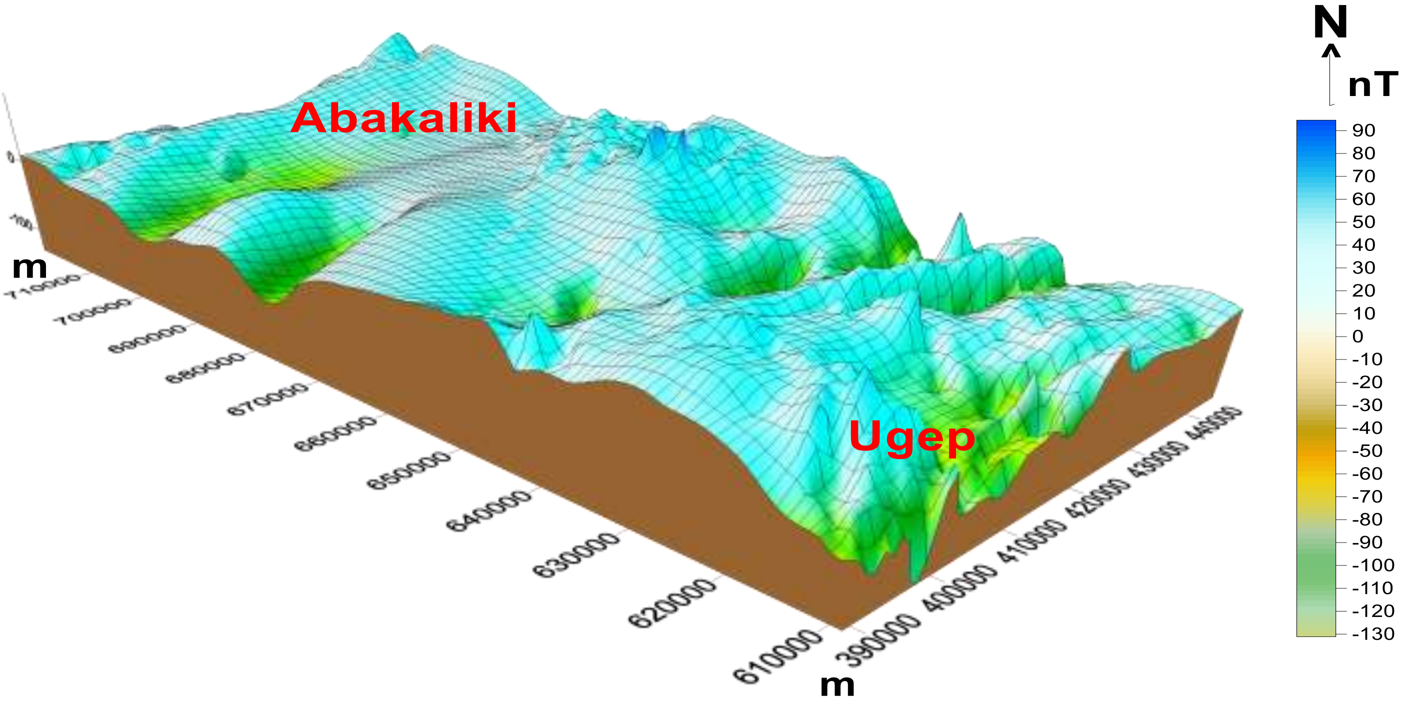

Figure 4. 3D Surface map of residual anomaly.

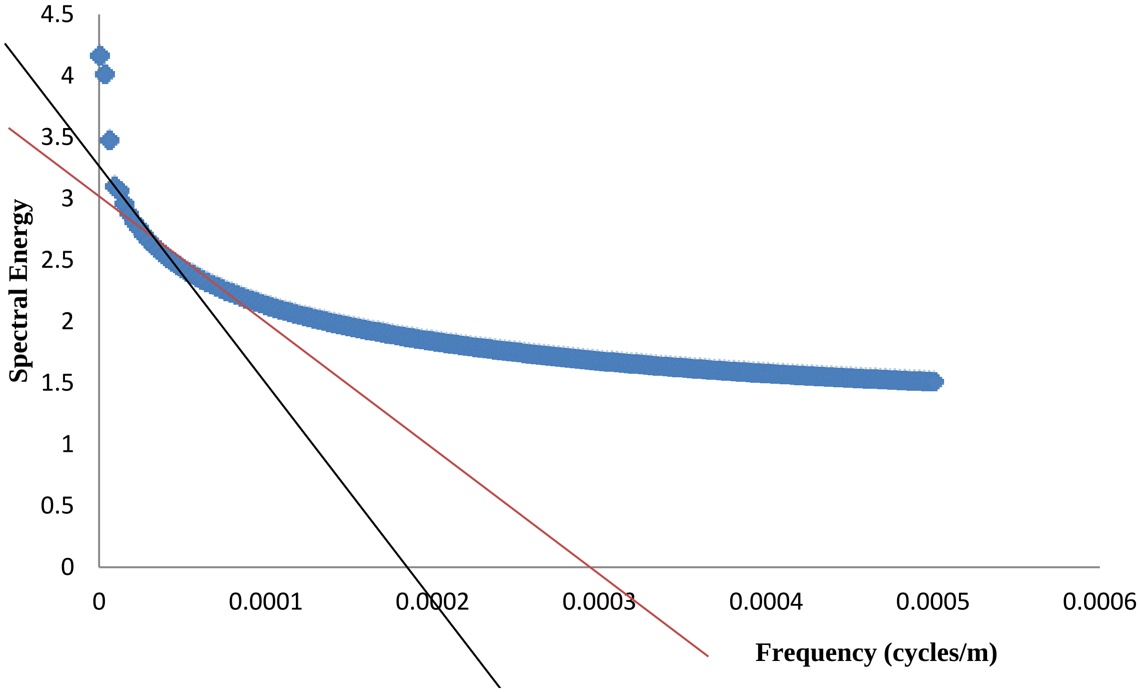

Figure 5. Profile AAˡ estimation of depth to source.

Result of the spectral analysis (Table 1) estimated the deep (maximum) depths of the of the profile to range from 2548 to 4246 m, while the shallow (minimum) depth ranges from 637 to 877 m. Estimates of deep (maximum) depths represented by the first segment of the spectrum in all the cells of the profiles reflect the Precambrian

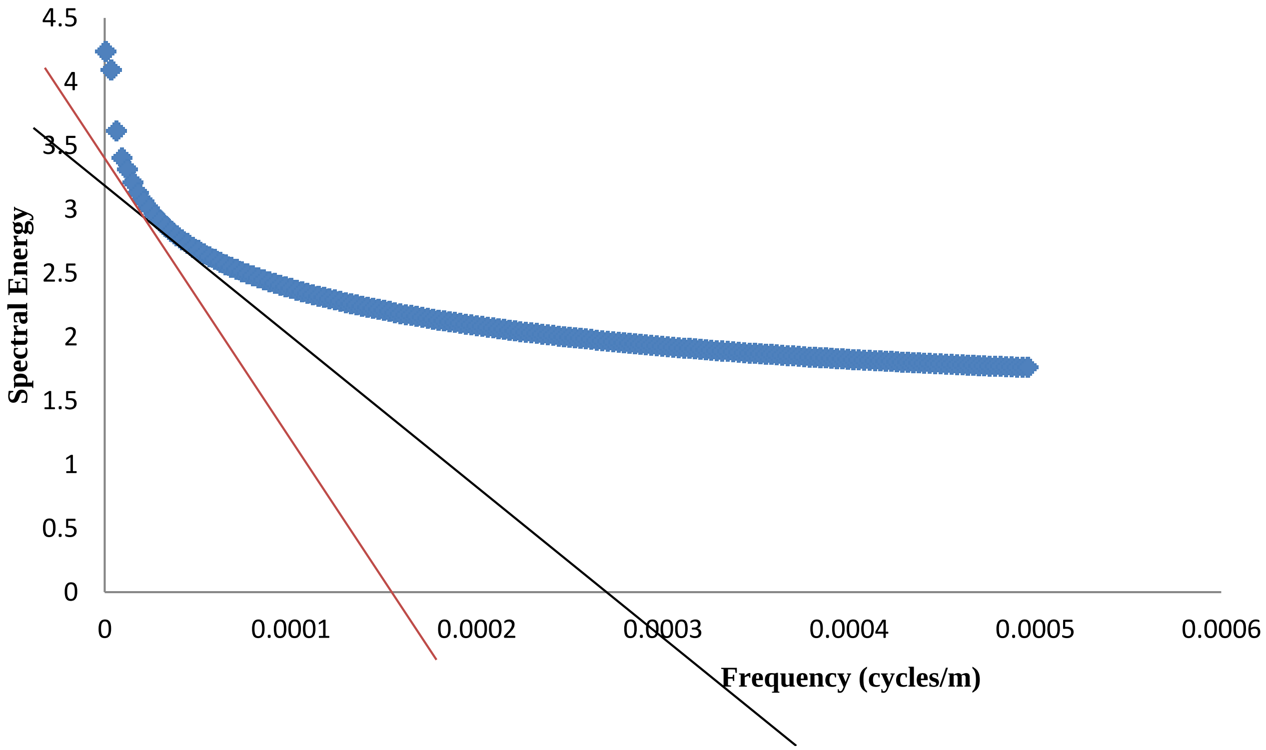

Figure 6. Profile BBꞌ estimation of depth to source.

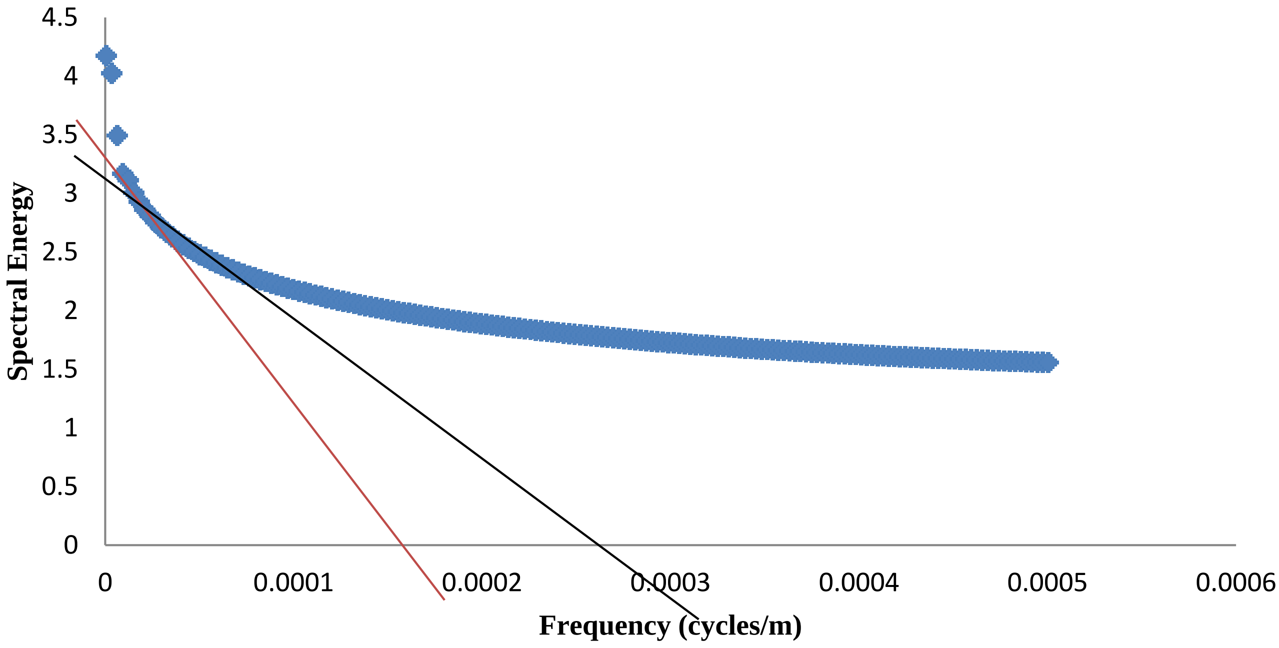

Figure 7. Profile CCꞌ estimation of depth to source.

basement of the study area. The results of Figure 11 shows maximum sedimentary thickness of over 4000 m at the central part of the study area while the minimum sedimentary thickness of about 600 m was obtained at the southern part of the study area, which is around Ugep. Maximum sedimentary thickness over 4000 m

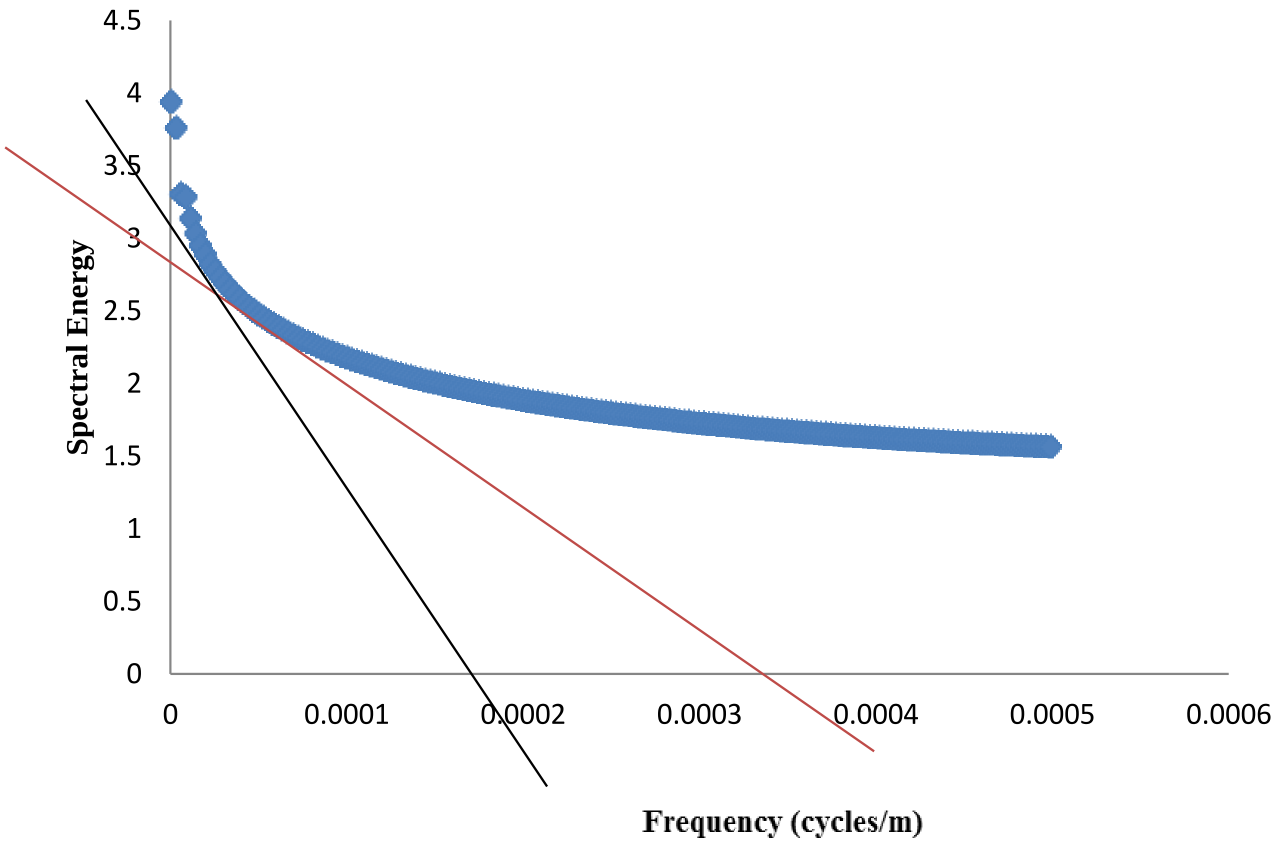

Figure 8. Profile DDᴵ estimation of depth to source.

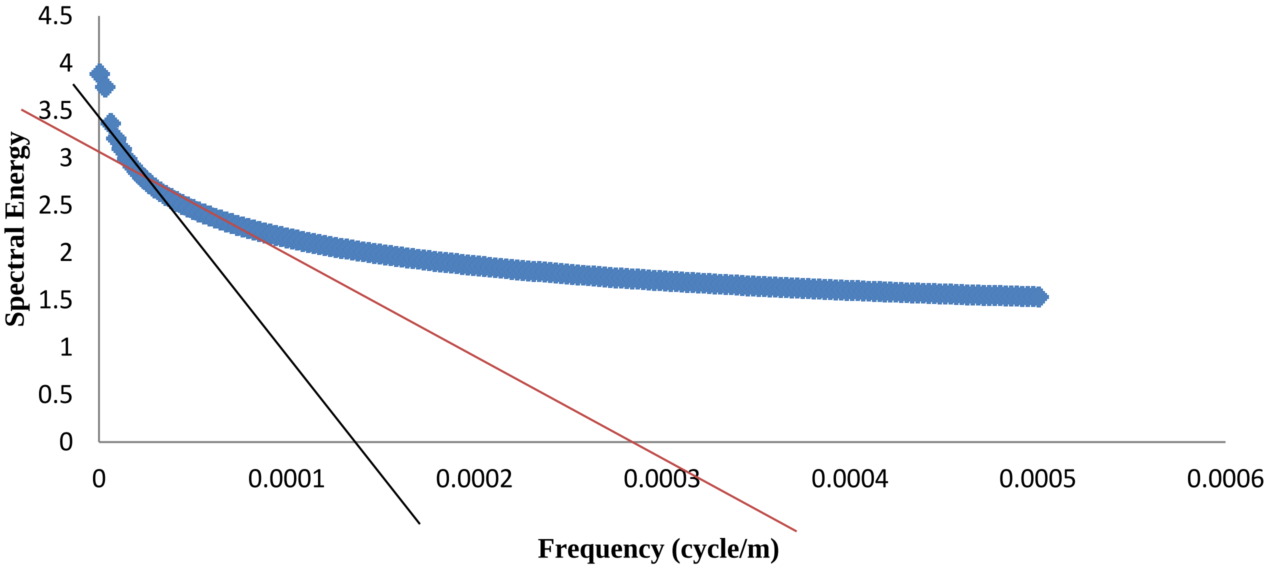

Figure 9. Profile EEᴵ estimation of depth to source.

found in the study area is capable of holding hydrocarbon prospect. This result is in agreement with that of Ofoegbu and Onuoha (1991) who obtained sediment thickness of 2 to 5 km for the same area.

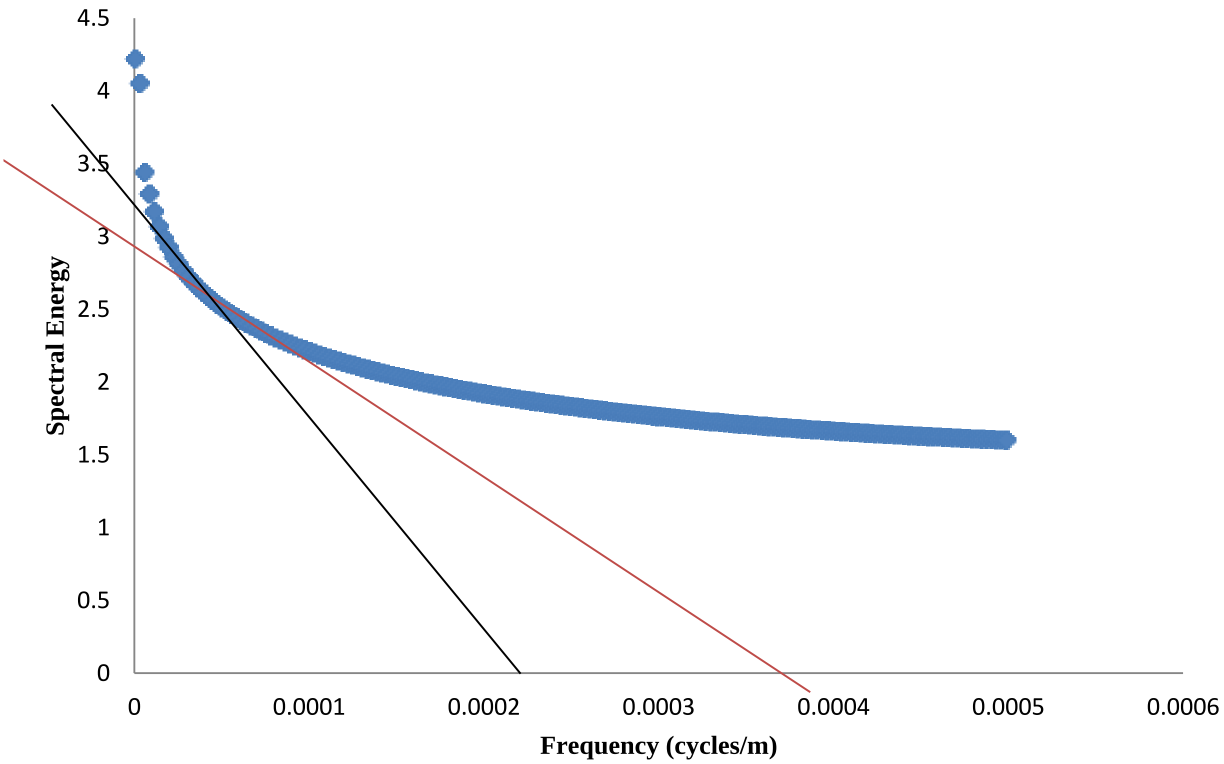

Figure 10. Profile FFꞋ estimation of depth to source.

Table 1. Summary of estimates of depth to basement over the study area from spectral analysis.

Profiles	Block	Shallow depth (m)	Deep depth/Thickness of sediments (m)
A-AꞋ	1	811	3715
	2	780	4246
	3	732	3185
B-BꞋ	4	859	3609
	5	796	3284
	6	637	2548
C-CꞋ	7	845	3867
	8	877	3867
	9	796	3867
D-DꞋ	10	812	3609
	11	845	3715
	12	845	3715
E-EꞋ	13	796	3867
	14	732	3715
	15	732	3715
F-FꞋ	16	812	3284
	17	764	2997
	18	812	3867

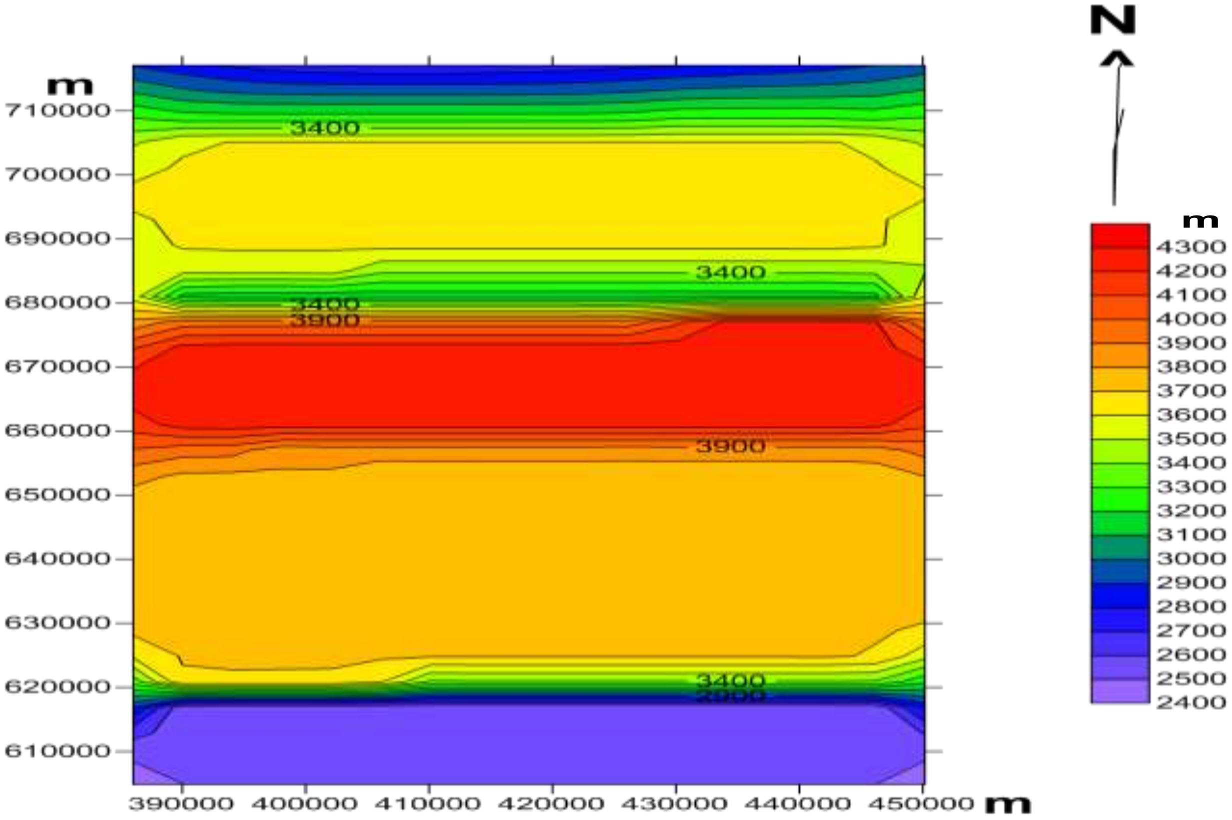

Figure 11. Depth to basement map of the study area (Contour interval 200 m).

Conclusion

Qualitative and quantitative interpretations of the aeromagnetic data over Abakaliki and Ugep areas of the lower Benue Trough have been successfully carried out using the spectral analysis of the data. The basement morphology, relief, and the structural features associated with the basin and their trends have been revealed by this study. The results from the spectral analysis have shown the basement depths over the Ugep area to be thick enough to hold hydrocarbon accumulation prospect. This result is similar to that of Goodhope and Luke (2013) on Structural interpretation of Abakaliki – Ugep using Airborne Magnetic and Landsat Thematic Mapper (TM) Data. It is also in agreement with that obtained by Obi et al. (2010) on aeromagnetic modeling of subsurface intrusive and its implication on hydrocarbon evaluation of the lower Benue Trough. These results therefore demonstrate the applicability of the spectral method of magnetic interpretation in estimating depths to the surface of magnetic basement in a basement complex.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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