Petroleum and Coal

Article **Open Access**

Spectral Depth Estimation of the Magnetic Basement in Parts of the Benue Trough Using High-Resolution Aeromagnetic Data: Implication for Hydrocarbon Prospectivity

*I. A. Omenikolo[1, 2] *, A. I. Opara [2], C. N Okereke[2], D. O. Ikoro[2], T. T. Emberga[1], C. C. Agoha[2], and C.N. Nwokeabia[3]*

[1] *Department of Physics/Electronics, Federal Polytechnic Nekede, P.M.B. 1036, Owerri, Nigeria*
[2] *Department of Geology, Federal University of Technology, P.M.B. 1526 Owerri, Nigeria*
[3] *Department of Applied Geophysics, Nnamdi Azikwe University Awka, Nigeria*

Received April 23, 2022, Accepted November 8, 2022

Abstract

Spectral analysis of high-resolution airborne magnetic data of part of Benue Trough was used to estimate the depths of anomalous magnetic sources within the study area. This paper was aimed at the determination of sedimentary thickness of the study area and to infer favourable areas for possible petroleum exploration. Several data enhancement techniques were used to digitally enhance the data to improve the signal-to-noise ratio. The total magnetic intensity was subjected to regional - residual separation using polynomial fitting of the first order, with the residual field revealing magnetic intensity values ranging from -79.8 to -16.5nT. Several clusters of circular magnetic anomaly closures with very clear amplitudes which occur especially in the northern and mid part of the area revealed edges of intrusive bodies. The structures observed within the location from the residual maps revealed dominant trends in the NE-SW and N-S direction. The result of 2D spectral analysis revealed a two-depth model, with the depth to the first layer (D_1) varying from 0.135 km to 0.200 km with an average depth of 0.158 km while second layer depth (D_2) varies from 2.585 km to 4.878 km with the average depth of 3.415 km. This result therefore, indicates that the average basement depth of the study area as deduced from power spectrum inversion is about 3.415km. The mean sedimentary thickness of 3.415km obtained and the near absence of intrusive bodies especially in the northern part of the study area thus reveal favourable conditions for hydrocarbon exploration.

Keywords: *Basement depth; Aeromagnetic data; Spectral analysis; Benue trough; Hydrocarbon exploration.*

1. Introduction

The magnetic method is one of the most common geophysical techniques that is well established and commonly applied for geological mapping, hydrocarbon, and mineral exploration [1-2]. The magnetic method generally measures variations in the Earth's magnetic field and investigates the subsurface geology based on anomalies in the geomagnetic field which are the resultant effects of the magnetic properties of the underlying rocks. It is applied in estimating the depth to magnetic source bodies, sedimentary thickness and to delineate subsurface structures. It is also useful for locating buried magnetic ore bodies due to their magnetic susceptibilities [3]. Aeromagnetic survey is one of the most frequently used airborne geophysical survey and has been recognized as a principal mapping tool for geological bodies that are strongly magnetized [4].

Previous scholars have demonstrated that basement depth and structure can be accurately delineated using airborne magnetic data [5-8]. Spectral analysis is a well-established technique and generally applied in magnetic and gravity surveys for estimating depths to anomalous bodies [5-8]. This is based on the principle that a magnetic force exerted at the surface of a magnetized body produces magnetic signatures at all points. Application of 2-D spectral inversion to the interpretation of potential field data is now usually applied for basement depth determination established [9]. Different studies have therefore carried out magnetic basement estimation using spectral inversion method [10-17]. Ekwok *et al.* [10] assessed the depth to shallow and deep magnetic sources in some parts of southeastern Nigeria, using high resolution airborne magnetic data. Depth estimation methods such as standard Euler deconvolution, source parameter imaging, spectral depth analysis and two dimensional (2-D) forward modeling were also used in the study. The basement depths estimated by Ekwok *et al.* [10] using the different techniques correlated strongly with one another within the study area. Oha *et al.* [18] estimated the depth of magnetic sources and mapped structural features in parts of the southern Benue Trough using high resolution aeromagnetic data. Their study revealed that the study area has very high potential of base ore mineralization and less suitability for hydrocarbon exploration. This finding is based on the abundance of intrusive bodies in the study area.

This study therefore intends to further investigate the sedimentary thickness of the study area and the effects of the observed intrusive bodies on hydrocarbon formation and accumulation using the spectral inversion of high resolution aeromagnetic data.

2. Location and geology of the study area

The study area shown in Figure 1 is part of the Benue Trough, Nigeria and is located in the study area defined by latitudes $6° 00^{1}$- $8° 00^{1}$N and longitudes $7° 30^{1}$- $9° 30^{1}$E. The Benue Trough is a known rift basin in Africa, with an approximate length of 180km and width 130-150km [19]. The trough is divided into three which include the Lower, Middle and Upper Benue trough [20]. The Lower Benue is at the southern portion, the Middle Benue Trough at the central parts while the Upper Benue Trough is located at the northern region. The Lower Benue Trough is classified as a sedimentary basin and consists of a thick sedimentary sequence with the oldest formation been the Asu River Group which are dominantly shales with localized sand stones, silt stones, and limestone [21].

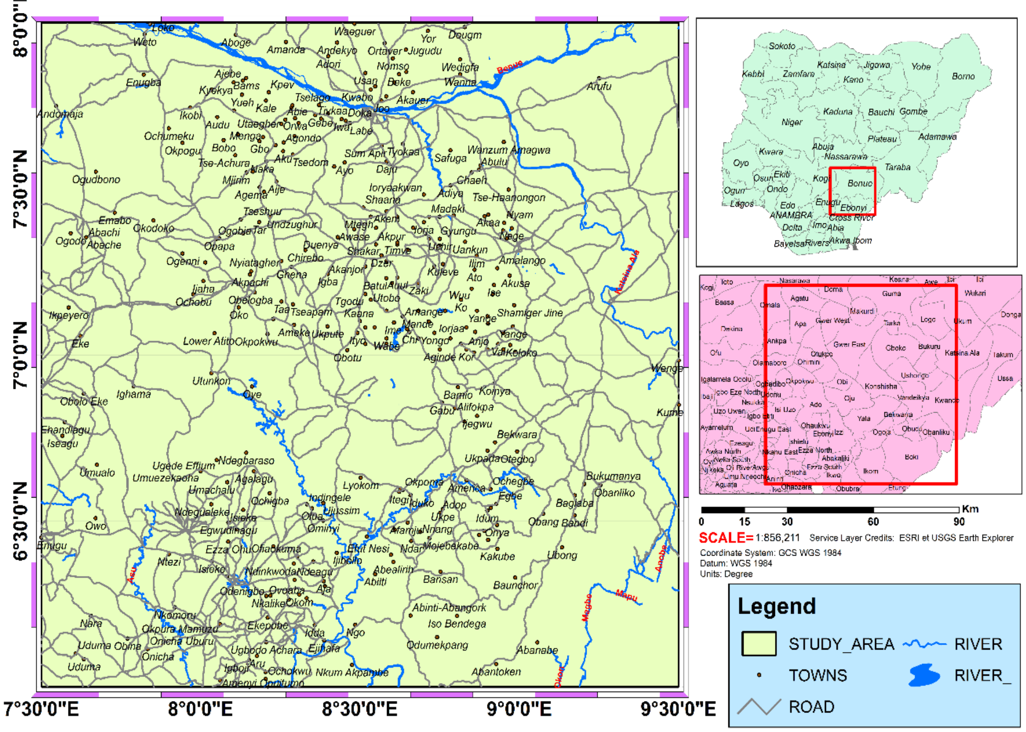

Figure 1. Location map of the study area

The study carried out by Offodile [22], identified several sedimentary formations in the Middle Benue Trough which include the Asu River Group. The Asu River Group is the oldest sediment (Albian in age), is composed of shales, localized sandstone, siltstones and limestone [23]. Other formations are the Keana, Awe, Ezeaku, Awgu and Lafia Formations (Figure 2). The stratigraphic successions in the Benue Trough and the Nigerian sector of the Chad Basin are presented in Table 1.

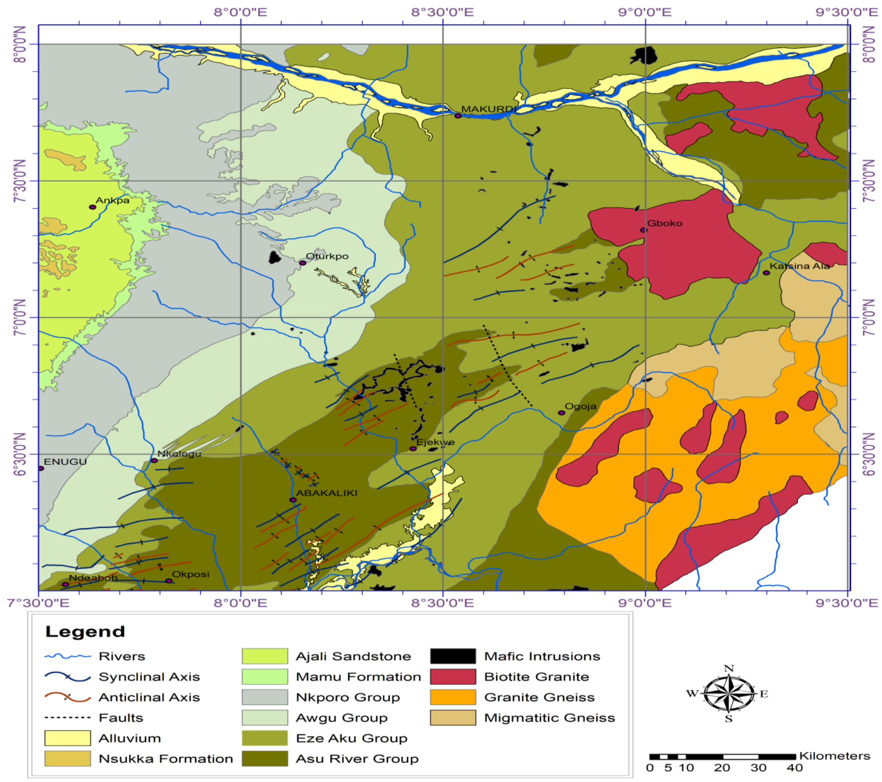

Figure 2. Geologic map of the study area

Table 1. Stratigraphic successions in the Benue Trough and the Nigerian sector of the Chad Basin (Adapted from [24])

AGE		LOWER BENUE	MIDDLE BENUE	UPPER BENUE: Yola sub	UPPER BENUE: Gongola sub	CHAD / BORNU
Quaternary	NIGER DELTA	Benin			Kerri-Kerri	Chad
Pliocene	NIGER DELTA	Benin / Agbada	Volcanics		Kerri-Kerri	
Miocene	NIGER DELTA	Agbada			Kerri-Kerri	
Oligocene	NIGER DELTA	Agbada / Akata		Volcanics	Kerri-Kerri	Hiatus
Eocene	NIGER DELTA	Akata / Nanka	Hiatus		Kerri-Kerri	
Paleocene	ANAMBRA BASIN	Ameke/Imo/ Nsukka				
Maastrichtian	ANAMBRA BASIN	Ajalli/Owelli/ Mamu	Lafia	Hiatus	Gombe	Gombe ?
Campanian	ANAMBRA BASIN	Nkporo/Enugu	Lafia	Hiatus	Fika	Fika ?
Santonian						
Coniacian	Cross River Group	Agbani	Makurdi	Lamja Numanha	Fika ? / Pindiga	Fika
Turonian	Cross River Group	Nkalagu Agala	Awgu Ezeaku/Konshisha/ Wadata	Sekuliye Jessu Dukul	Pindiga / Gongila	Gongila
Cenomanian	Cross River Group	Odukpani	Keana / Awe	Yolde	Yolde	Gongila
Albian	Asu River Group	Mfamosing Abakaliki	Arufu/Uomba/Gboko	Bima	Bima	Bima
Pre-Albian		Basement Complex	Basement Complex	Basement Complex	Basement Complex	Basement Complex

Unconformity; Transitional boundary; Major unconformity (for the Santonian deformation)

3. Materials and method

3.1. Data

The high-resolution aeromagnetic data used for the present study are part of the digital airborne magnetic data acquired between the years 2005 - 2009. The maps were digitized along flight lines with a spacing of 500m and 80m terrain clearance. The acquisition of the data for the study area was done by Fugro Airborne Surveys with the processing and initial interpretations of the data carried out by Paterson, Grant & Watson Limited (PGW). Part of the nationwide grid for the entire study area was made available in Geosoft .xyz format by the Nigerian Geological Survey Agency (NGSA).

The high-resolution aeromagnetic survey for most of the Benue Trough was flown along the NW – SE direction (i.e. perpendicular to the axis of the basin). The geomagnetic gradient was removed from the data using the International Geomagnetic Reference Field (IGRF) formula.,2005. In the present study the interpretation of the digital aeromagnetic data was carried out using the Oasis Montaj Software package. The total magnetic intensity map of the study area was generated by merging the sixteen (16) different aeromagnetic data sheets. The merged aeromagnetic sheet was divided into 32 overlapping sections using a 27.5km x 27.5km spectral window. Regional-Residual separation was carried out using polynomial fitting. Multi-regression least square analysis was used to remove the regional gradient by fitting a plane surface to the data. The expression obtained for the regional field across the study is T(R) was given as

$$T(R) = 7612.158 + 0.371x - 0.248y \quad (1)$$

where x and y are units of spacing of the magnetized data. The regional field values were subtracted from the observed data to obtain the residual magnetic values.

3.2. Method

3.2.1. Spectral analysis

Spectral analysis was employed in the present study to estimate magnetic basement depths across the study area. Spectral inversion typically aids in the estimation of the depths to the magnetic basement and shallow anomalous magnetic bodies [25-27]. The technique involves applying Fourier transform to digitized aeromagnetic data to estimate the energy/amplitude spectrum which is later plotted on a logarithmic scale against frequency thus giving line segments which decreases in slope with increasing frequency. This decrease in slope shows the depth to the magnetic sources [28].

Therefore, given a residual magnetic anomaly map of dimension L×L dimensions digitized at equal intervals, the residual intervals, and total intensity anomaly values can be expressed in terms of double Fourier series expansion which is given by:

$$T(x,y) = \sum_{n=1}^{N}\sum_{m=1}^{M} P_m^n cos\left(\frac{2\pi}{L}\right)(nx+my) + Q_m^n sin\left[\left(\frac{2\pi}{L}\right)(nx+my)\right] \quad (2)$$

Where L is the dimension of the spectral block; $P^n{}_m$ and $Q^n{}_m$ are Fourier amplitude and N, M are the number of grid points along the x and y directions respectively.

Equation (2) can be combined into a single partial wave to give:

$$P_m^n cos\left[\left(\frac{2\pi}{L}\right)(nx+my)\right] + Q_m^n sin\left[\left(\frac{2\pi}{L}\right)(nx+my)\right] = C_m^n cos\left[\left(\frac{2\pi}{L}\right)(nx+my)\right] - \delta_m^n \quad (3)$$

where $(P_m^n)^2 + (Q_m^n)^2 = (C_m^n)^2$ (4)

and δ_m^n is the appropriate phase angle.

Each(C_m^n) is the amplitude of the partial wave. The frequency of this wave is given by $F_m^n = \sqrt{n^2+m^2}$ and is called the frequency of the wave. Similarly, using the complex form, the two-dimensional Fourier transform pair may be written as shown in equation 5&6 [25]:

$$G(U,V) = \int_{-\infty}^{\infty} g(x,y)e^{-j(ux+vy)}dxdy \quad (5)$$

$$g(x,y) = \frac{1}{4\pi^2}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} G(U,V)e^{-j(ux+vy)}dxdy \quad (6)$$

where u and v are the angular frequencies in the x and y directions respectively.

However, this technique is associated with some technical challenges. Some inherent problems in the application of the Discrete Fourier Transform (DFT) includes the phenomenon of aliasing, truncation effect or Gibb's phenomenon and the problem associated with even and odd symmetries of the real and imaginary parts of the Fourier transform. Kearey *et al*. [3], stated that aliasing can be overcome by having the sampling frequency of the digitized magnetic field interval to be at least twice as high as the highest frequency component present in the sampled function. The truncation effect can be reduced by applying a cosine taper to the observed data before Fourier Transform. In this study, the software used in the analysis took into consideration these effects and resolved the stated challenges.

4. Results and discussion

Total Magnetic Intensity Map (TMI) of the study area was generated from the aeromagnetic data using the Oasis Montaj Software version 8.4HJ version. The TMI exhibits the effects of the underneath basement as well as the effects of near surface structures within the study area. Figure 3 which is the TMI map of the study area shows the magnetic intensity values ranging from -89.5 nT -112.0 nT. The study area is characterized by low magnetic intensity values ranging from -89.5 nT to -22.9 nT and high magnetic intensity values ranging from 91.9nT -112.0 nT.

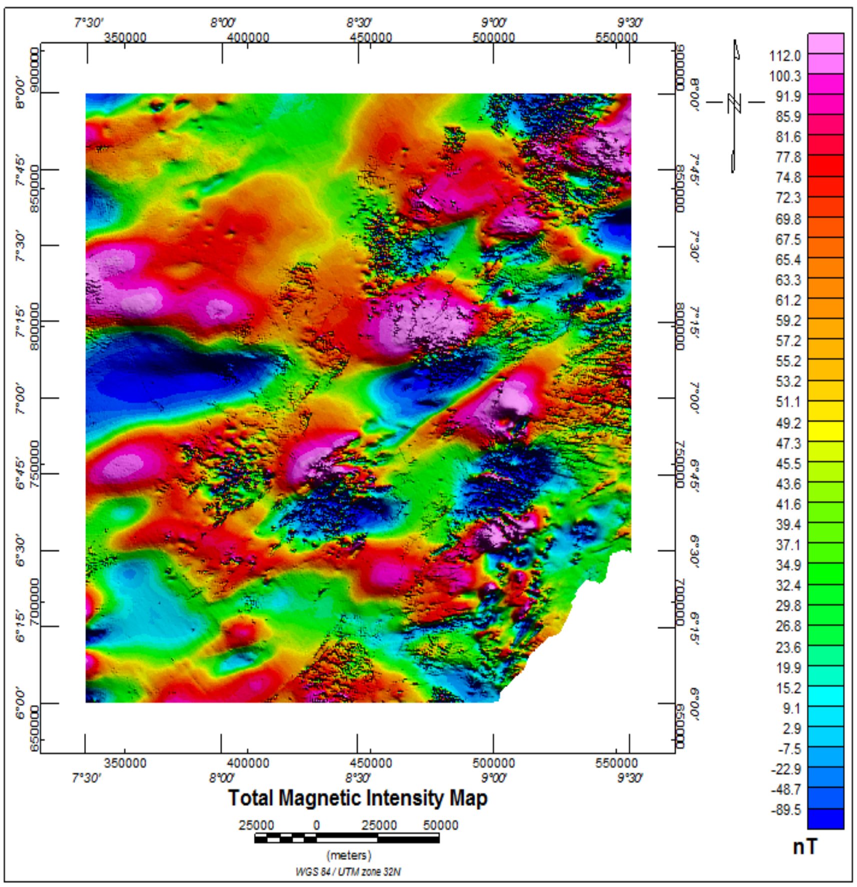

Figure 3. Total Magnetic Intensity (TMI) image of the study area

Several clusters of magnetic closures were observed in the study area which were generally circular and with the NE-SW trends representing intrusive bodies in the area were mapped on the total field map. The several clusters of circular magnetic anomaly closures with very defined trends and amplitudes which occur in parts of the study area revealed edges of mafic/ultramafic intrusive bodies [5]. Across the study area, sections having high magnetic intensities (pink colour) and low (blue colour) magnetic intensity values are spatially displayed on the map. This spatial variation may be because of several factors which include magnetic susceptibility difference, depth variation, extent of strike and change in lithology. The circular closures mapped out in the study area are areas of basic intrusive and are often associated with ore bodies. Magnetic highs were observed around Ankpa, Oturkpo, Markudi while magnetic lows were observed around Ejekwa, Ogoja, Gboko, Katsina-ala.

4.1. Reduction to equator

Reduction to equator is usually employed in the low magnetic latitudes to place the peaks of magnetic anomalies over their sources and resolve problems associated with low latitude magnetic data. In low-latitude areas, pole reduction is difficult since some bodies have no detectable magnetic anomaly at zero magnetic inclination [29]. This enhancement becomes vital in other to correct for the effect of latitude and realign the anomalies to have their peaks symmetrically centered over their corresponding sources since the study area is located within the magnetic low latitude area. The RTE map of the study area is characterized by high, medium and low magnetic anomalies depicted by red, green and blue colors respectively. Figure 4 showed the RTE (inverted image) which appears to be a better enhancement image. The RTE map showed positive magnetic intensity values as high as 584.439 nT which dominated the western and southeastern parts of the study. However, towards the northeastern and northwestern portions, it is characterized by low magnetic intensity values of -406.877 nT (marked by bluish to green colours). In a low latitude magnetic region specifically below the equator, which the study area falls into, a low magnetic peak value represents typical anomalous signatures.

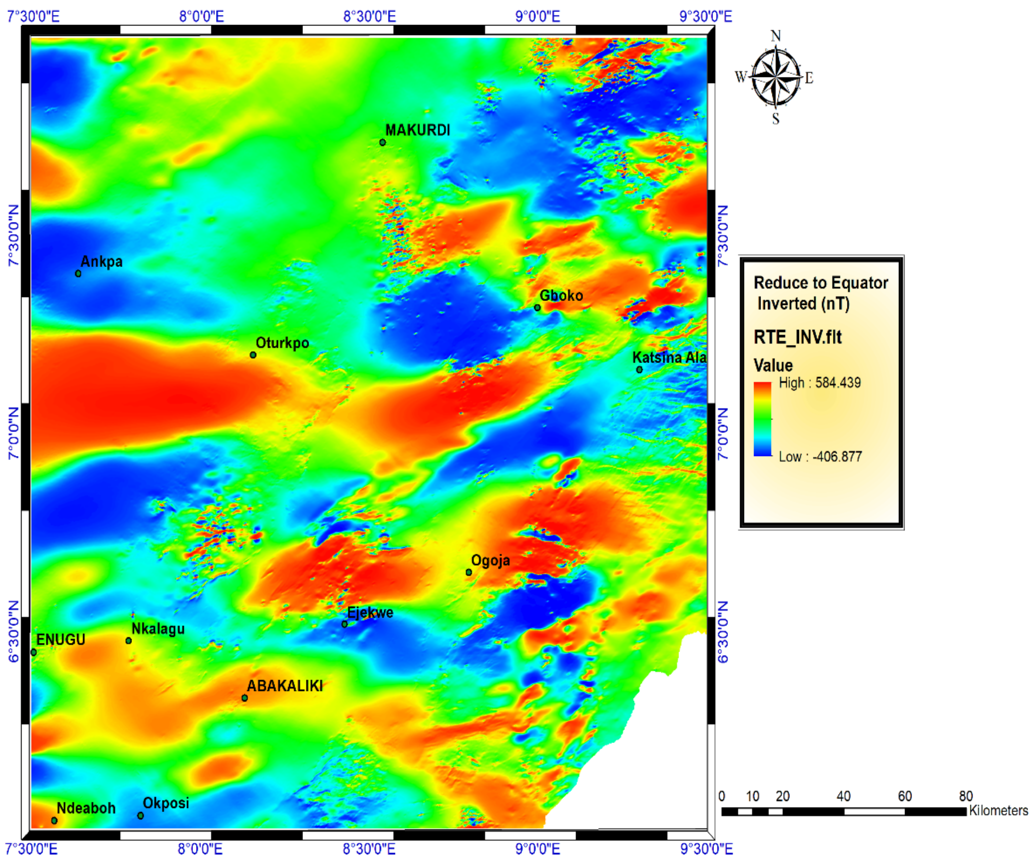

Figure 4. RTE_inverted image of the study area

The first-degree residual is shown in Figure 5. Very low residual magnetic intensity values ranging from -79.8 to -16.5nT were observed around Katsina- ala, Ndeaboh, Abakiliki, Ejekwe, Ogoja, Gboko. These areas coincided with the areas underlain by the Asu River Group, Eze

Aku Group, Biotite Granite. These areas of low residual magnetic intensities can be qualitatively interpreted as zones of low magnetization, which implies the non-existence of underlying shallow to near surface magnetized bodies. The major magnetic highs in the study area were however observed around Oturkpo, Nkalagu and Markudi areas and coincided with the underlying Nkporo and Eze Aku Groups. These areas are depicted with purple coloration and have residual magnetic intensity values between 37.5 to 66.0nT. These areas of high residual magnetic intensities can therefore be qualitatively interpreted as zones of high magnetization, which may indicate the existence of underlying shallow to near surface magnetized bodies.

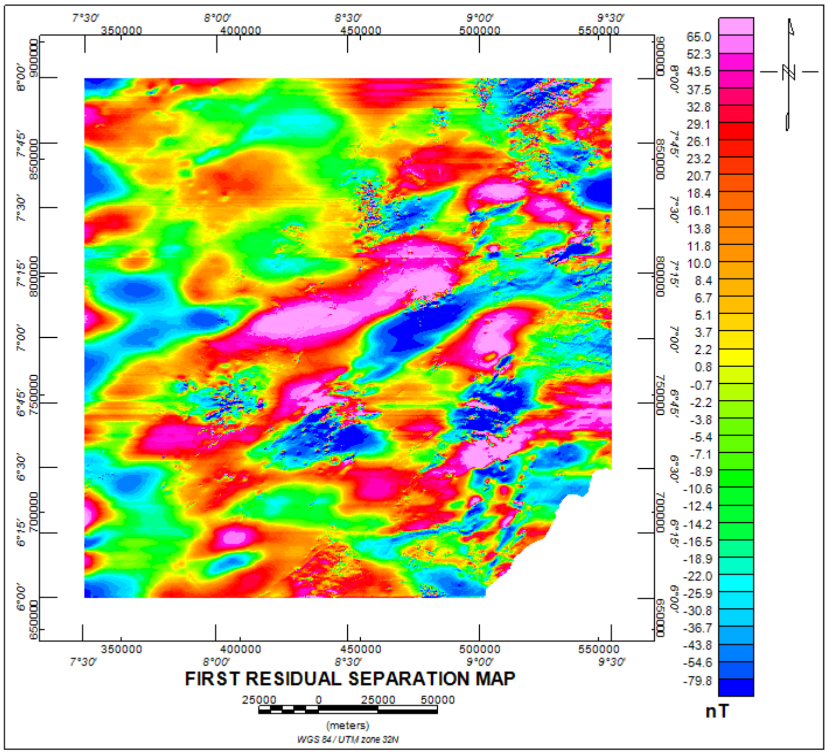

Figure 5. First Residual magnetic intensity map of the study area

The lineaments extracted across the study area from ASTER images revealed two groups of linear features trending in the NE-SW, NW-SE directions with the prevalent structural trends being in the NE-SW direction. This agrees with the findings of [30], that areas affected by the Pan African Orogeny are characterized by NNW-SSE to NNE-SSW trending structures with varying degrees of intrusive bodies, while the lower Cretaceous area of Nigeria are characterized by NE-SW oriented shear zones and fractures controlled by volcanism. The interpreted lineaments of the study area are presented as a lineament map (Figure 6 & 7). The study area shows that more lineament traces were identified in areas where basement outcrops are closer to the surface. The lineament trends were observed to have corresponded to the positions and directions of the paleo-toceanic fracture zones within the study area, which includes the St Paul's and Romanche Fracture Zones. Lineaments with longer lateral extension revealed trends in the NE-SW, which indicates the direction of the last regional tectonic phase.

The lineaments in the study area were observed to cross-cut each other while some run parallel to each other thus representing cross conjugate systems associated with wrench tectonics. This implies that the faults and fractures are products of extensional, trans-tensional and trans-pressional movements along oceanic fracture zones as African and South American Plates separated [31-32]. It thus revealed that these regions have undergone serious tectonic activities associated with subsequent sedimentary and magnetic basement emplacement [33].

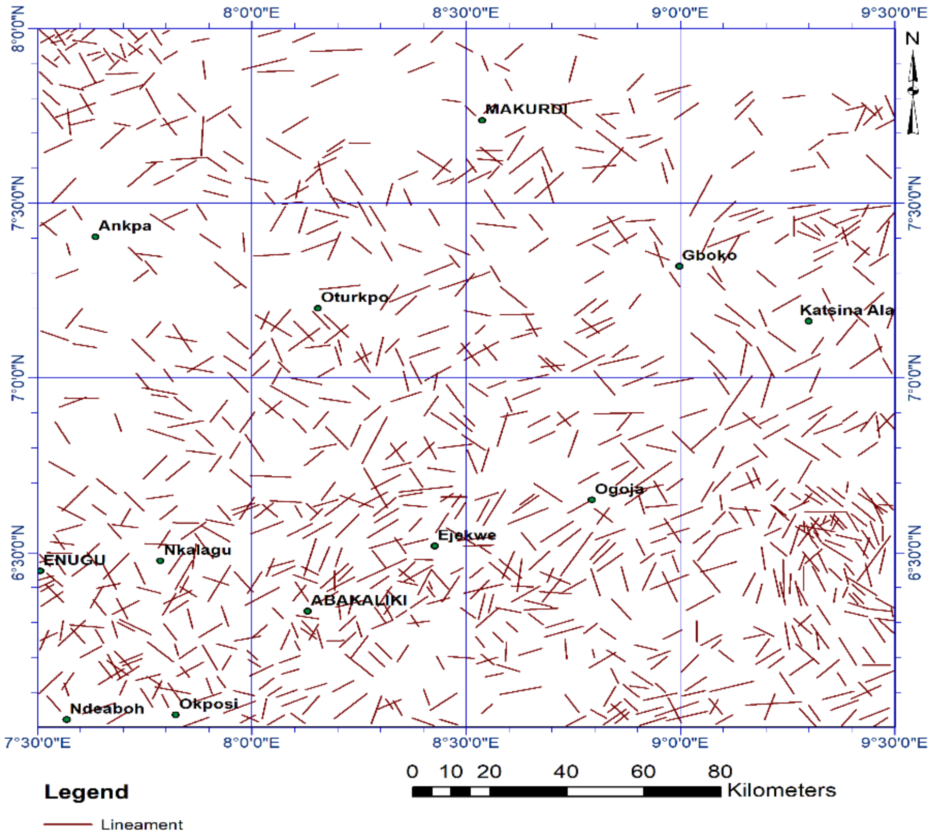

Figure 6. Map of the study area showing surficial lineaments

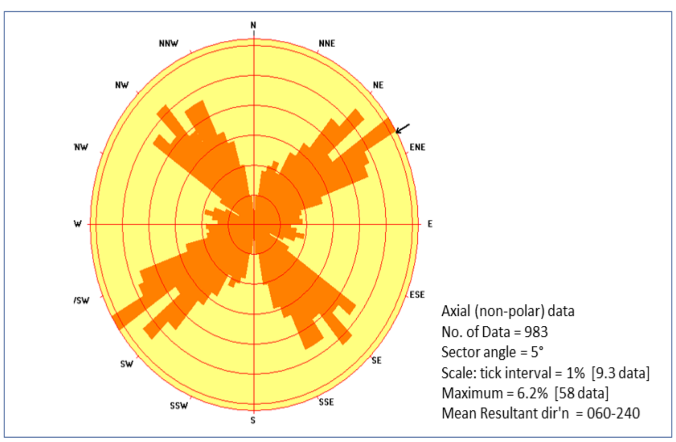

Figure 7. Azimuth Frequency diagram of the lineaments over the study area

Lineament quantification and statistical analysis were carried out with reference to the orientation and frequency of the lineaments. This was done to construct a rose diagram with established structural trends (Figure 7). Rose diagrams were plotted from visually extracted lineaments with the lengths of the rosette blades proportional to the square of the relative frequencies of the lineaments. The rose diagram revealed lineament trend directions of NE – SW, NW – SE, N – S and E – W with the dominant structural trend being in the NE – SW which corresponds to the major lineament trend of the study area. The E-W, NW-SE, and N-S, reflect the old and deeper tectonic trends, why the NE-SW trend reflects the younger tectonic events, because the younger events are more pronounced and tends to obliterate the older events.

Spectral analysis was carried out using the USGS Potential Field software and Spectrum module on Matlab 7.6. To determine the depths of the anomalous magnetic sources, the study area was divided into 32 overlapping sections. The locations of these sections are computed in Table 2. X_1, .X_2 give the limiting longitude values while Y_1, Y_2 give the limiting latitude values. Each of these sections covers a square area of about 27.5km x 27.5km of the data sheet. The spectral plots presented as spectral energies versus frequency plots obtained across the study area are shown in Figure 8. Each of these graphs presents two clear segments due to deeper and shallower sources. The logarithm of the energy spectrum plot produces a straight-line graph with a resultant slope which gives a value of 2z.

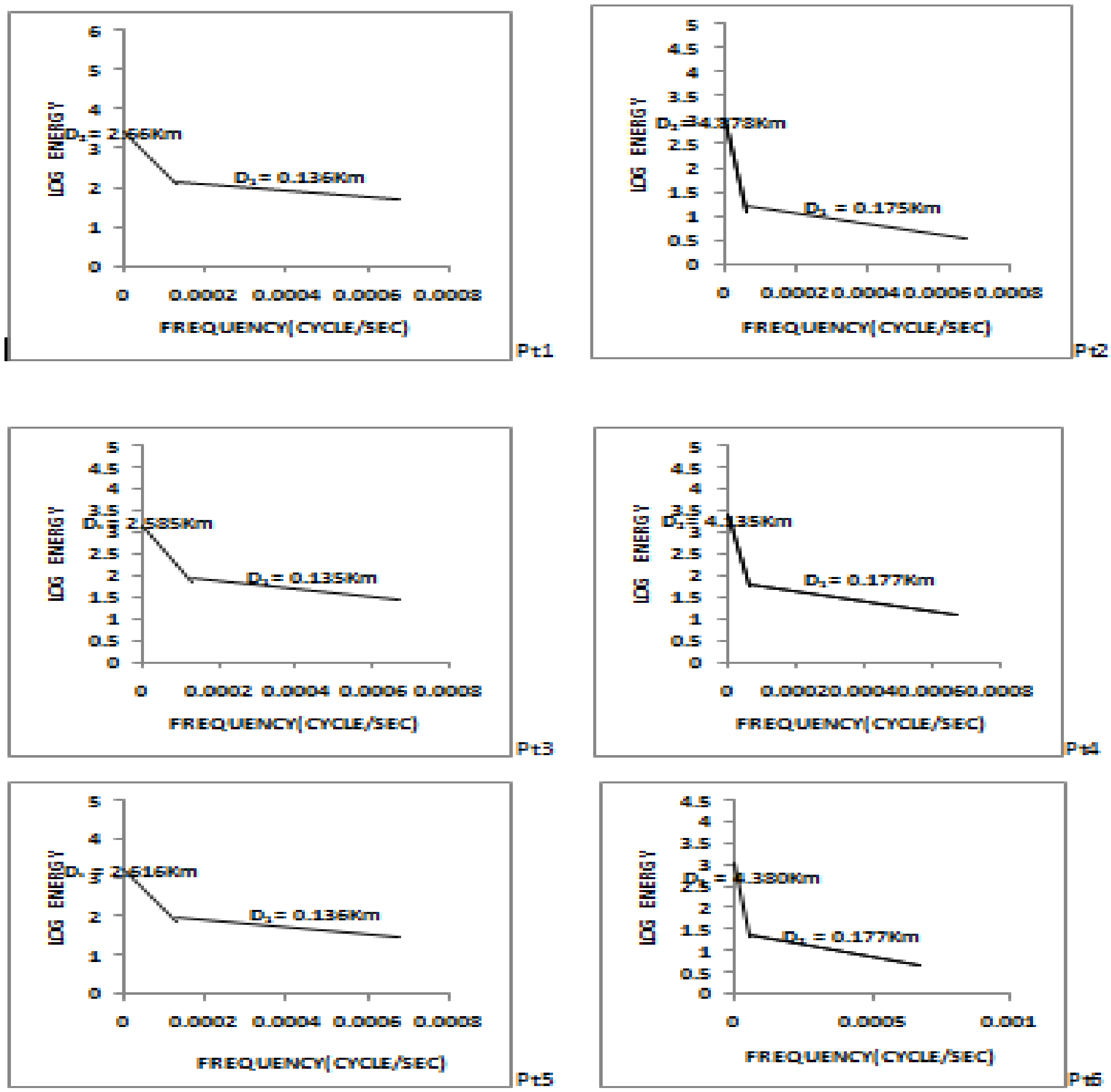

Figure 8. Sample Spectral plots of the aeromagnetic data of the study area

The average depths to magnetic causative sources were estimated from the slopes of the graphs to be D_1 and D_2 as shown in (Table 2). The depth (D_1) is the first depth segment(layer) and corresponds to the shallow magnetic sources while the depth (D_2) is the second depth segment and corresponds to the magnetic basement. Figures 9 and 11 indicates contours of D_1 and D_2 depths which gave the spatial variation of basement depth values across the study area. Basin architecture and basement morphology of the study area were inferred through the use of the 3 –D contour maps of the shallow magnetic depth (D_1) and the magnetic basement depth map (D_2) respectively as shown in figures 10 and 12. The depth to the first layer (D1) in the study area varies from 0.135 km to 0.200 km with an average depth of 0.158 km while second layer depth (D2) varies from 2.585 km to 4.878 km with the average depth of 3.415 km.

Table 2. Depth to the Top of Basement (Sedimentary Thickness) of the study area estimated from spectral analysis

S/N	Spectral Blocks	Longitude		Latitude		Depth(M)	
		X1	X2	Y1	Y2	D1	D2
1	BLK1	7^0 30	8^0 00	6^0 00	6^0 15	0.136	2.660
2	BLK2	8^0 00	8^0 30	6^0 00	6^0 15	0.175	4.878
3	BLK3	8^0 30	9^0 00	6^0 00	6^0 15	0.135	2.585
4	BLK4	9^0 00	9^0 30	6^0 00	6^0 15	0.177	4.135
5	BLK5	7^0 30	8^0 00	6^0 15	6^0 30	0.136	2.616
6	BLK6	8^0 00	8^0 30	6^0 15	6^0 30	0.177	4.380
7	BLK7	8^0 30	9^0 00	6^0 15	6^0 30	0.177	4.308
8	BLK 8	9^0 00	9^0 30	6^0 15	6^0 30	0.136	2.770
9	BLK9	7^0 30	8^0 00	6^0 30	6^0 45	0.175	3.400
10	BLK10	8^0 00	8^0 30	6^0 30	6^0 45	0.136	2.657
11	BLK11	8^0 30	9^0 00	6^0 30	6^0 45	0.136	2.812
12	BLK12	9^0 00	9^0 30	6^0 30	6^0 45	0.135	2.784
13	BLK13	7^0 30	8^0 00	6^0 45	7^0 00	0.138	3.000
14	BLK14	8^0 00	8^0 30	6^0 45	7^0 00	0.136	2.851
15	BLK15	8^0 30	9^0 00	6^0 45	7^0 00	0.136	4.653
16	BLK16	9^0 00	9^0 30	6^0 45	7^0 00	0.136	2.871
17	BLK17	7^0 30	8^0 00	7^0 00	7^0 15	0.176	3.626
18	BLK18	8^0 00	8^0 30	7^0 00	7^0 15	0.177	3.526
19	BLK19	8^0 30	9^0 00	7^0 00	7^0 15	0.136	2.655
20	BLK20	9^0 00	9^0 30	7^0 00	7^0 15	0.200	2.618
21	BLK21	7^0 30	8^0 00	7^0 15	7^0 30	0.175	3.325
22	BLK22	8^0 00	8^0 30	7^0 15	7^0 30	0.177	4.426
23	BLK23	8^0 30	9^0 00	7^0 15	7^0 30	0.136	2.756
24	BLK24	9^0 00	9^0 30	7^0 15	7^0 30	0.136	2.934
25	BLK 25	7^0 30	8^0 00	7^0 30	7^0 45	0.176	3.513
26	BLK 26	8^0 00	8^0 30	7^0 30	7^0 45	0.177	4.255
27	BLK 27	8^0 30	9^0 00	7^0 30	7^0 45	0.177	3.620
28	BLK 28	9^0 00	9^0 30	7^0 30	7^0 45	0.136	3.022
29	BLK 29	7^0 30	8^0 00	7^0 45	8^0 00	0.176	3.968
30	BLK 30	8^0 00	8^0 30	7^0 45	8^0 00	0.180	4.802
31	BLK 31	8^0 30	9^0 00	7^0 45	8^0 00	0.176	4.020
32	BLK 32	9^0 00	9^0 30	7^0 45	8^0 00	0.177	2.865
	Average					0.158	3.415

This result therefore indicates that the average basement depth of the study area obtained from spectral analysis is 3.415km. The depth to the shallow causative magnetic sources may probably be because of tectonic activities that gave rise to basement rocks intruding into the sedimentary formation. The deeper magnetic sources may be characterized by lateral inversion and basement structural deformations for example faults and fractures [2,6,12,34,35]. The 3D surface plot (Figure 10) clearly shows that the area is generally flat except the points indicated by blue colour from the colour legend bar. The 3D depth to basement view (Figure 12) shows also that the blue colour is the deepest point as indicated by the colour legend bar.

The thickest sedimentary cover occurred at the northern part of the map. The 3-D map shown in Figure 12, thus revealed the basement morphology and the host of the sedimentary fills. It is therefore advisable to undertake hydrocarbon exploration in the northern part of the study area.

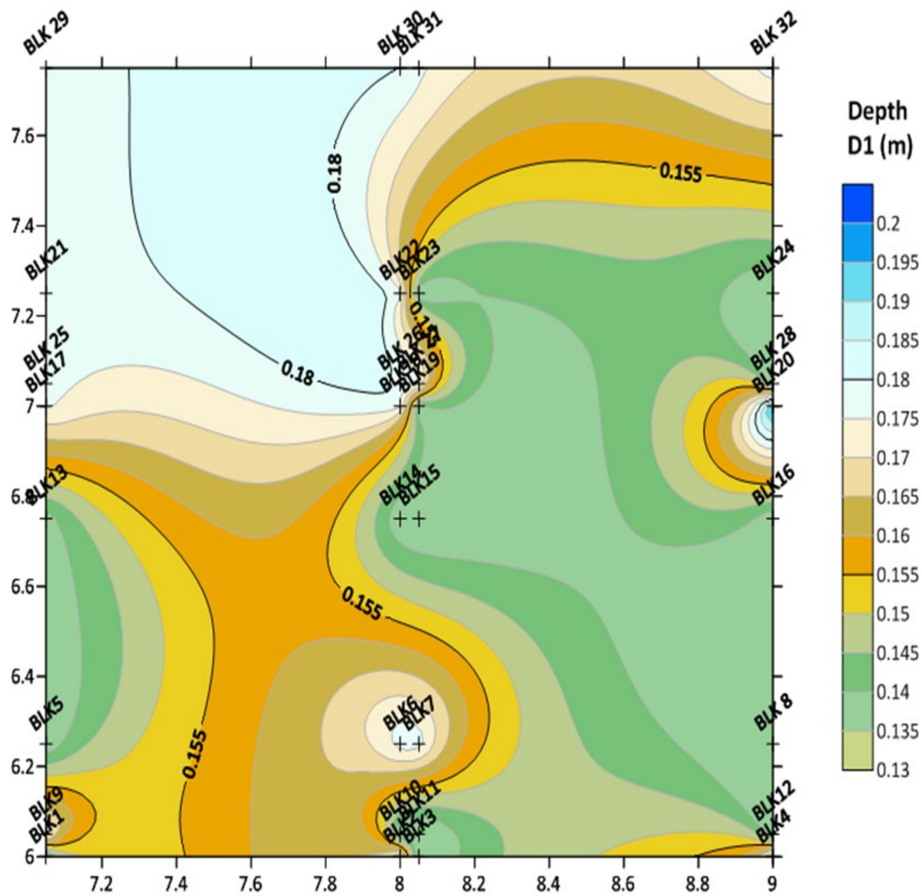

Figure 9. Contour map of the Depth to shallower anomalies (D1)

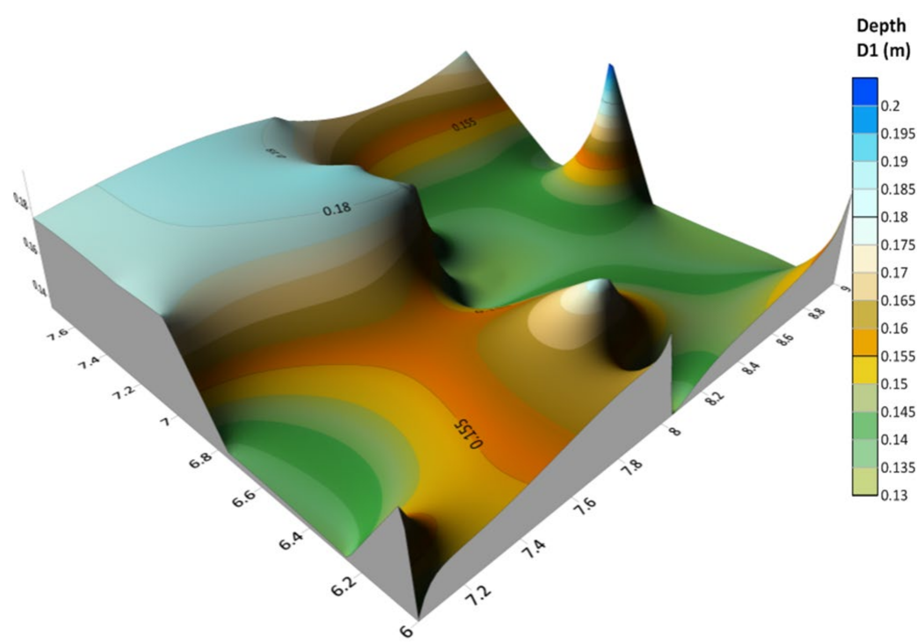

Figure 10. 3D view of the shallow depth of the area

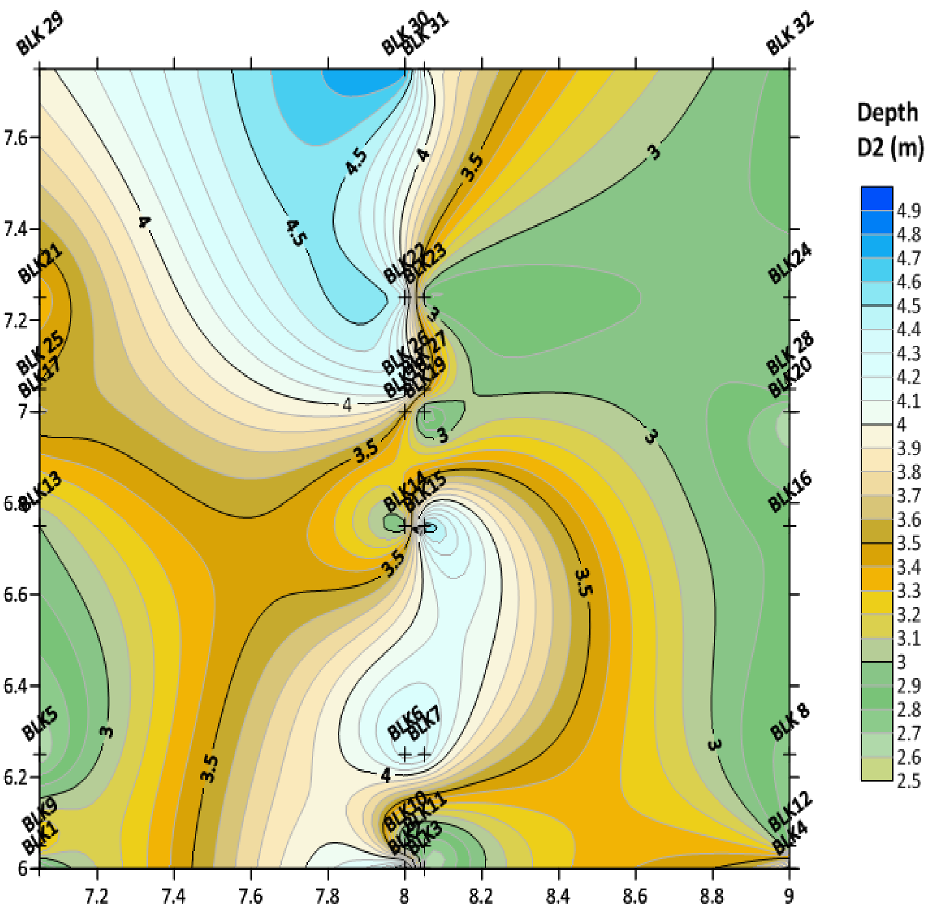

Figure 11. Contour map of the Depth to deeper anomalies (D2)

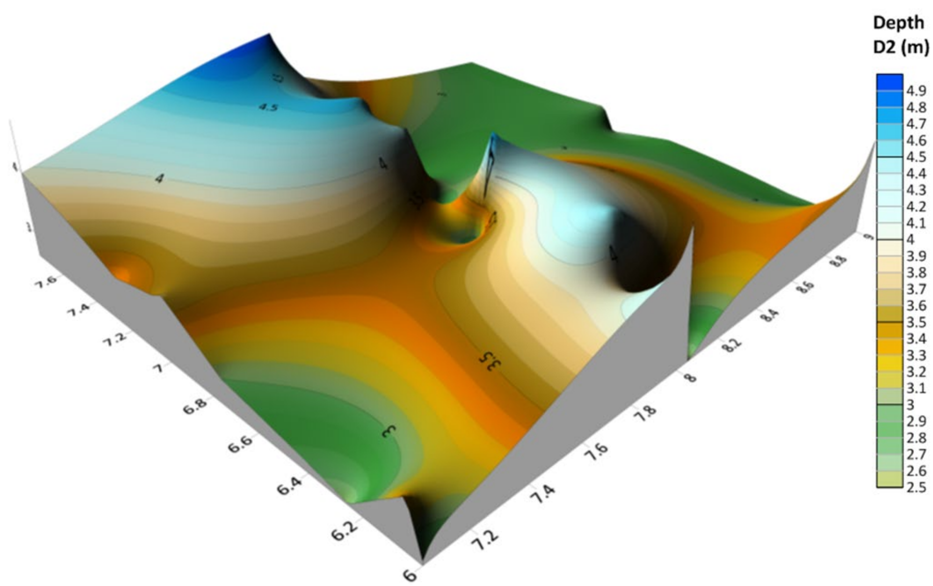

Figure 12. 3D view of the deeper depth (depth to basement or sedimentary thickness) of the study area

4.2. Discussion

The results of the spectral depth determined in the present study agree with the results of some previous researchers that had worked within the area of study. Igwesi and Umego [11], analyzed aeromagnetic data of some parts of Lower Benue Trough using spectral analysis technique to calculate the average depth of causative magnetic sources. The result for the basement depth of the deeper magnetic sources vary between 1.16 km and 6.13 km with an average depth of 3.03 km while, the shallow depth varies between 0.06 km and 0.37 km having an average depth of 0.22 km. This indicates that magnetic intrusive bodies are present within the sediments. Onwuemesi [36] using spectral analysis determined the sedimentary thickness of the Anambra basin to be vary from 0.9km and 5.6km. Nur [37] analyzed the sediment thickness over Yola arm of the Benue Trough, which ranges between 1500m to 2219 m for deeper source and range from 330m to 414m for shallow source. Alagbe and Sunmonu [38] obtained using spectral analysis values for depth to magnetic basement ranging from 1.22km and 3.45km while the depth for shallow sources ranges from 0.01km and 1.49km. Umeanoh *et al.* [39] deduced from spectral analysis the depth to magnetic sources which vary between 3.472 km to 6.972 km for the deeper sources, with average thickness of 5.010 km and 1.177 km to 1.834 km for the shallower sources, with an average of 1.047 km.

5. Conclusion and recommendation

Spectral analysis was employed on high resolution aeromagnetic data of parts of the Benue trough with the purpose of estimating the depth to magnetic sources in the study area. The result of the 2-D spectral analysis of the study area has effectively revealed a two-layer depth model. The depth to the first layer (D1) in the study area varies from 0.135 km to 0.200 km with an average depth of 0.158 km while second layer depth (D2) varies from 2.585 km to 4.878 km with the average depth of 3.415 km. This result therefore indicates that the average basement depth of the study area as inferred from spectral analysis is about 3.415km. The depth to the shallow causative magnetic sources may probably be as a result of tectonic activities that gave rise to basement rocks intruding into the sedimentary formation. The deeper magnetic sources may be characterized to lateral inversion and basement structural deformations for example faults and fractures [6,12,28,34,40]. The northern part is the most advisable area to undertake hydrocarbon exploration since the area has a sedimentary thickness range of 2.585 km to 4.878km and an average sedimentary thickness of 3.415 km thus making the area thick enough for thermal maturation of the available source rocks.

Conflict of interest

There is no conflict of interest to declare by the authors.

Acknowledgement

The authors appreciate with thanks the support of the Management of the Federal University of Technology, Owerri and the Federal Polytechnic, Nekede, Owerri Nigeria, during the period of this study. We appreciate with thanks the data and technical support offered by the Management and Staff of the Nigerian Geological Survey Agency(NGSA).

References

[1] Opara AI, Nwofor VU, Echetama HN, Emberga TT, and Inyang GE. Magnetic Basement Depth and Structure over parts of Bida Basin Nigeria interpreted from 2-D Spectral Analysis and Euler Deconvolution; Australian Journal of Basic and Applied Sciences, 2018;12(9): 1-11.

[2] Ole MO, Opara AI, Okereke CN, Onyenegecha CP, Akaolisa CZ, Okoli AE and Umoh OJ. Estimates of the Curie Point Depth, Geothermal Gradient and Near Surface Heat Flow System of Bida and Environs, Nupe Basin Nigeria from High-Resolution Aeromagnetic Data. International Journal of Energy and Water Resources, 2020; 108 (Springer).

[3] Kearey P, Brooks M, and Hill J. An introduction to Geophysical exploration (Third Edition) Blackwell science Ltd. 2002.

[4] Murphy BS. Airborne geophysics and the Indian scenario. Indian Geophysics UnionJournal,2007;11(1): 1-28.

[5] Ghazala HH. Geological and structural interpretation of airborne surveys and its Significance for mineralization, South Eastern Desert Egypt. Journal of African Earth Sciences, 1993; 16(3): 273-285.

[6] Nwokocha KC, Opara AI, Onyekuru SO, Okereke CN, Emberga TT, Ugwugbu EI, and Ijeoma KC. (2016). Lineament features interpreted over parts of Younger Granite Complex, North Central Nigeria using HRAM and LANDSAT-ETM data. Arabian Journal of Earth Science (AJES), 2016; 3(1): 35-56.

[7] Ofoegbu CO, and Onuoha MK. Analysis of magnetic data over the Abakaliki Anticlnirium of the Lower Benue Trough, Nigeria. Marine and Petroleum Geology, 1991; 8(2): 174 – 183.

[8] Opara AI, Oneyekuru SO, Mbagwu EC, Emberga TT, Ijeomah KC, and Nwokocha KC. Integrating Landsat – ETM and Aeromagnetic Data for Enhanced Structural Interpretation over Naraguta Area, North-Central Nigeria. International J. of Scientific and Engineering Research, 2015; 6(9): 10.

[9] Spector A, and Grant FS. Statistical models for interpreting aeromagnetic data. Geophysics, 1970; 35: 293-302.

[10] Ekwok SE, Akpan AE, Ebong DE, and Eze OE. Assessment of depth to magnetic sources using high resolution aeromagnetic data of some parts of the Lower Benue Trough and adjoining areas, Southeast Nigeria. Advances in Space Research, 2021; 67: 2104–2119.

[11] Igwesi ID, and Umego MN. Interpretation of aeromagnetic anomalies over some parts of lower Benue Trough using spectral analysis technique. Int. J. Sci. Technol. Res., 2013; 2:153-165.

[12] Kangoko R, Ojo SB, and Umego MN. Estimation of Basement depths in the Middle Cross River basin by Spectral analysis of the Aeromagnetic field. Nigerian Journal of Physics, 1997; 9: 30-36.

[13] Ofoegbu CO, and Onuoha MK. Analysis of magnetic data over the Abakaliki Anticlnirium of the Lower Benue Trough, Nigeria. Marine and Petroleum Geology, 1991; 8(2): 174 – 183.

[14] Onyewuchi RA, and Ugwu SA. Geological Interpretation of the High Resolution Aeromagnetic Data over Okigwe-Udi Area, Anambra Basin, Nigeria, Using 3-D Euler Deconvolution and 2-D Spectral Inversion Methods. Journal of Geography, Environment and Earth Science International, 2015; 10(1): 1-22.

[15] Opara AI. Estimation of the Depth to Magnetic Basement in Part of the Dahomey Basin, Southwestern Nigeria. Australian Journal of Basic and Applied Sciences, 2011; 5(9): 335-343.

[16] Opara AI, Ekwe AC, Okereke CN, Oha IA and Nosiri OP. Integrating Airborne Magnetic and Landsat Data for Geologic Interpretation over part of the Benin Basin, Nigeria. Pacific Journal of Science and Technology, 2012; 13(1): 556-571.

[17] Udensi EE, and Osazuwa IB. Spectral determination of depth to buried magnetic rocks under the Nupe Basin, Nigeria. Nigerian Association of Petroleum Explorationists Bulletin, 2004; 17(1): 22-27.

[18] Oha IA, Onuoha KM, Nwegbu AN, and Abba AU. Interpretation of high resolution aeromagnetic data over southern Benue Trough, Southeastern Nigeria. J. Earth Syst. Sci. 2016;125: 369–385.

[19] Cratchley CR, and Jones GP. An interpretation of the geology and gravity anomalies of the Benue Valley Nigeria. Oversea Geological Survey London, 1965.

[20] Obaje NG. Origin of the Benue Trough- A critical Review. In: Geology of Nigeria. C.A. Kogbe, (ed). Elizabeth Publishing Co., Lagos, Nigeria. 2004.

[21] Olade MA. Evolution of Nigeria's Benue Trough (Aulacogen): a tectonic model. Geological Magazine, 1975; 112: 575-581.

[22] Offodile ME. The Geology of the Middle Benue, Nigeria; Paleontological Institute, University Uppsala: Uppsala, Sweden,1976;4: 1–166.

[23] Onu NN, Opara AI, and Oparaku OI. Geological interpretation of the aeromagnetic data over the lower Benue Trough and some adjoining areas. 47th Annual International Conference of Nigerian Mining and Geoscience Society (NMGS), Programmes and Book of Abstracts.2011; 43.

[24] Obaje NG. Geology and mineral resources of Nigeria. Berlin: Springer Publishers. 2009; 1–203.

[25] Bhattacharyya BK. Continuous spectrum of the total magnetic field anomaly due to rectangular prismatic body. Geophysics, 1966; 31: 97-121.

[26] Hahn A, Kind EG, and Mishra DC. Depth estimation of magnetic sources by means of Fourier amplitude spectra. Geophysics Prospecting,1976; 24: 287-308.

[27] Spector A, and Grant FS. Statistical models for interpreting aeromagnetic data. Geophysics, 1970; 35: 293-302.

[28] Ofoegbu CO, and Onuoha MK. Analysis of magnetic data over the Abakaliki Anticlnirium of the Lower Benue Trough, Nigeria. Marine and Petroleum Geology, 1991; 8(2): 174 – 183.
[29] Grauch VJ, Bauer PW, and Kelson KI. Preliminary interpretation of high- resolution aeromagnetic data collected near Taos, New Mexico. New Mexico Geological Society, 55th Field Conference, Guidebook, 2004; 244–256.
[30] Umeji AC. The Precambrian of part of the SE Nigeria: A magmatic and Tectonic study. In : P.O. Oluyide PO W.C. Mbonu WC. Oguzie AE. Egbuniwe IG. Ajibade AC, and Umeji AC (Eds.), Precambrian Geology of Nigeria, Geological Survey of Nigeria, 1988; 69-75.
[31] Fairhead JD, Green CM, Masterton SM, and Guiraud R. The role that plate tectonics, inferred stress changes and stratigraphic unconformities have on the evolution of the Westland Central African rift system and the Atlantic continental margins. Tectonophysics, 2013; 594:118–127.
[32] Gaina C, Trond HT, Van Hinsbergen, DJ, Sergei M, Werner SC, and Labails C. (2013) The African plate: a history of oceanic crust accretion and subduction since the Jurassic. Tectonophysics, 2013; 604: 4–25.
[33] Ofoegbu CO. An aeromagnetic study of part of the Upper Benue Trough, Nigeria. Journal of African Earth Sciences,1988; 5: 187 – 192.
[34] Opara AI, Onyewuchi RA, Selemo AO, Onyekuru SO, Ubechu BO, Emberga TT, Ibim DF, and Nosiri OP. Structural and Tectonic Features of Ugep and Environs, Calabar Flank, Southeastern Nigeria: Evidences from aeromagnetic and Landsat-ETM data. Mitteilungen Klosterneuburg, 2014; 64: 33-54.
[35] Opara AI, Nwofor VU, Echetama HN, Emberga TT and Inyang GE. Magnetic Basement Depth and Structure over parts of Bida Basin Nigeria interpreted from 2-D Spectral Analysis and Euler Deconvolution; Australian Journal of Basic and Applied Sciences, 2018;12(9): 1-11.DOI.10.22587/ajbas.2018.12.9.1.
[36] Onwuemesi AG. One dimensional spectral analysis of aeromagnetic anomalies and curie depth isotherm in the Anambra Basin of Nigeria. Journal of Geodynamics, 1997;23(2): 95-107.
[37] Nur A. Analysis of Aeromagnetic Data over the Yola arm of the Upper Benue Trough, Nigeria. Journal of Mining and Geology, 2000; 36(1): 77-84.
[38] Alagbe OA, and Sunmonu LA. Interpretation of aeromagnetic data from Upper Benue Basin, Nigeria using automated techniques. IOSR Journal of Applied Geology and Geophysics, 2014; 2(5): 22-40.
[39] Umeanoh DC, Ofoha CC, and Ugwu SA. Spectral Analysis and Euler Deconvolution of Regional Aeromagnetic Data to Delineate Sedimentary Thickness in Mmaku Area, South Eastern Nigeria. World Scientific News, 2018;109: 26-42.
[40] Obiora DN, Dimgba BC, Oha IA, and Ibuot JC. Airborne and Satellite Geophysical Data Interpretation of the Gubio Area in the Bornu Basin, Northeastern Nigeria: Implication for Hydrocarbon Prospectivity. Petroleum and Coal, 2020; 62(4): 1504-1516.

To whom correspondence should be addressed: . Dr. A Omenikolo, Department of Physics/Electronics, Federal Polytechnic Nekede, P.M.B. 1036, Owerri, Nigeria, E-mail: omenikoloalexander@gmail.com