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MAPPING THE SUBSURFACE STRUCTURES AND SEDIMENTARY THICKNESSES IN PARTS OF MIDDLE BENUE TROUGH, NIGERIA USING INTERPRETATION OF AEROMAGNETIC DATA

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Abstract
The study aimed at mapping the subsurface structures and sedimentary thicknesses in parts of Middle Benue Trough, Nigeria using interpretation of aeromagnetic data. Four aeromagnetic data acquired from Nigerian Geological Survey Agency were merged, displayed and analyzed using various standard techniques including spectral analysis. The result depicts that the study area possess variable magnetic intensity ranging 8480 nT to 8630 nT for total magnetic intensity and -100 nT to 140 nT for residual anomalies. The visual inception of the derivative and lineament maps along with the Rose diagram indicate that the area is intensely fractured with major structures trending in the NE-SW direction while the minor structures trend in E-W and NW-SE path. The spectral analysis result depicts two ranges of sedimentary thicknesses, namely; the shallower thicknesses which vary from 0.52 km to 1.90 km and the deeper thicknesses which vary from 2.00 km to 6.82 km. The results also show the variability of the sedimentary thickness with an average of 3.73 km in the study area being part of Middle Benue Trough depicting a sub-basin configuration. The study concludes that the existence of subsurface lineament structure systems and high sedimentary thicknesses could serve as huge boost for possible hydrocarbon accumulation within the study area.
***Keywords**: Spectral Analysis, Residual Anomaly, Rose Diagram, Lineament and Hydrocarbon Accumulation.*

Introduction

In Nigeria recently, the aggressive search for hydrocarbon in the Benue Trough has led to the discovery of commercial oil and gas in the Anambra Basin and recently in the Gongola arm of the Upper Benue Trough. These discoveries have necessitated for exploration in nearby sub-basins like the Middle Benue Trough which up till now has received least attention. There is therefore great need to re-evaluate the geology of the basin since the same basin outside Nigeria is productive (Lar *et al*., 2023). Hence magnetic survey is the first geophysical tool to start with.

Actually, the goal of a magnetic survey is to investigate subsurface geology on the basis of magnetic anomalies in the Earth's magnetic field resulting from the magnetic properties of the underlying rocks. Magnetic surveys can be performed on land, at sea and in air. Compared to other geophysical methods, the aeromagnetic data are always readily available therefore it is important to exploit the potential of this data. Understanding the aeromagnetic survey applications with respect to the hydrocarbon prospectivity through mapping the prevalent structures and sedimentary thickness is key in any area including the study area (Anakwuba and Chinwuko, 2012; Chinwuko *et al*., 2012; Chinwuko *et al*., 2013; Chinwuko *et al*., 2014; Ikumbur *et al*., 2013; Okoro *et al*., 2021).

Consequently, spectral analysis has proved to be a powerful and convenient tool in the processing and interpretation of potential field geophysical data. It seeks to describe the frequency content of a signal based on a finite set of data. Its advantage is that the spectral domain expressions of the anomalies are generally vastly simple as compared to the expressions of the anomalies in the space domain. Furthermore, the noise associated with potential field data generally has high frequency and by restricting the interpretation to low frequencies,

considerable improvement in the interpretation is possible (Chinwuko *et al*., 2012; Ikumbur *et al*., 2023; Okonkwo *et al.*, 2021; Olasehinde, 1991).
Finally, this research focuses on the mapping of subsurface structures and sedimentary thicknesses in parts of Middle Benue Trough, Nigeria using interpretation of aeromagnetic data. The expected result of the interpretation will throw more light on the configuration of the basin itself by determining the sedimentary thickness. It will also establish the structural features and possibly obtain a real view of the Basin. Finally, the findings shall attempt to evaluate the petroleum prospectivity and delineation of prospect areas for petroleum exploration within the study area.

Location and Geology of the Area

The study area falls within the Middle Benue Trough, which is a sedimentary basin that is part of the three major sub-divisions of Benue Trough, Nigeria with the other two as Upper and Lower Benue Trough border. The geographical coordinates of the study area lie between $9^0 30^1$ and $10^0 30^1$ E of longitude and between $7^0 30^1$ and $8^0 30^l$ N of latitude, covering an area of approximately 12,100 km^2. The major towns are Wukari, Ukum, Zaki-Biam, Sankara, Kado, Abako, Donga, Ibi, Bantaji and Sayi (Fig. 1).

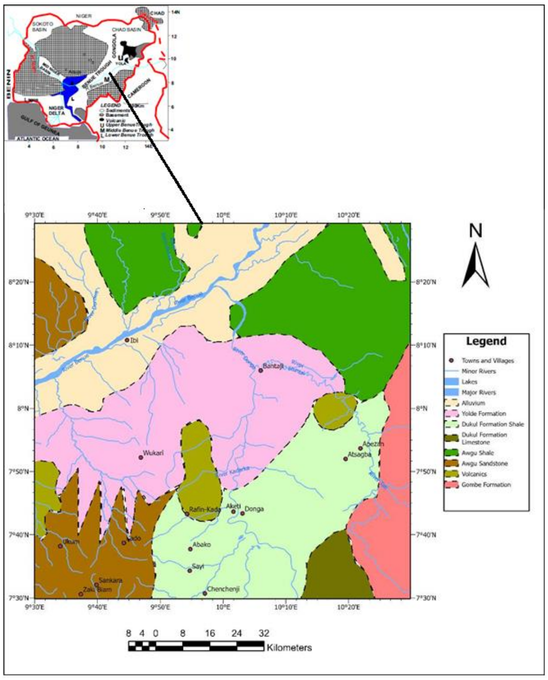


Fig. 1: Geological map of Benue Trough showing the study area (After NGSA, 2020)

Geologically, in the work of Obaje (2009), it was discovered that the Middle Benue Trough comprises of six stratigraphic successions that are dated within the Upper Cretaceous (Fig. 1). The first is the Asu River Group (ARG) which is made up of Albian materials of Arufu, Uomba and Gboko Formations which consist of the lithologic composition of limestones, shales, micacous siltstones, mudstones and clays. Overlying on top of the ARG is the Ezeaku Formation which is attributed to the beginning of marine transgression in the Late Cenomanian. The sediments are made up mainly of calcareous shales, micaceous fine to medium friable sandstones and beds of limestones which are in places shelly (Obaje, 2009).

Following the Ezeaku Formation is the Awe Formation which was deposited as transitional beds during the Late Albian to Early Cenomanism regression. The formation consists of whitish medium to coarse grained calcareous sandstones, carbonaceous shales and clays. Next is the Keana Formation which has resulted from the Cenomanian regression which deposited fluviodeltaic sediments. The formation consists of cross-bedded, coarse grained feldsparthic sandstones, occasional conglomerates, and bands of shales and limestones towards the top. Furthermore, the deposition of the Awgu Formation marks the end of marine sedimentation in this part of the Benue Trough. The formation is made up of bluish-grey to dark-black carbonaceous shales, calcareous shales, shaley limestones, limestones, sandstones, siltones, and coal seams. Finally, the Lafia Formation is the youngest formation in this area. The formation was deposited under continental condition (fluviatile) in the Maastrichtian and lies unconformably on the Awgu Formation (Obaje, 2009). It is lithologically characterized by ferruginized sandstones, red, loose sands, flaggy mudstones, clays and claystones.

Methodology

The aeromagnetic data of the study area comprises four NGSA data sheets of 1: 100, 000 that have 55x55 km per data sheet (Sheets- 233 - Ibi, 234 -Bantaji, 253 -Wukari and 254 - Donga) were transformed and displayed using various standard techniques. The methodology involved includes integration of the four aeromagnetic data (sheet), production of magnetic anomaly map, generation of structural maps, analysis and modelling of magnetic anomaly data. The derived maps were subjected to various transformation and enhancement procedures. The purpose of these procedures was both for enhancement and assessment of consistency of the various categories of anomaly and features. The first horizontal derivation maps, tilt derivative maps, lineament map and Rose diagram were produced and interpreted. The spectral analysis technique was found to be most suitable for sedimentary thickness calculation in this study, and was adopted for the purpose. The spectral analysis is represented mathematically according to Onwuemesi (1997) as shown below;

$$Y_{i(x)=} \sum_{n=1}^{N} \left[a_n \cos\left(\frac{2\pi n x_i}{L}\right) + b_n \sin\left(\frac{2\pi n x_i}{L}\right)\right] \qquad (1)$$

Where: $Y_i(x)$ = Reading at x_i position; L = length of the cross-section of the anomaly;
n = harmonic number of the partial wave; N = number of data points
a_n= real part of the amplitude spectrum
b_n= imaginary part of the amplitude spectrum } Partial Amplitude
i = 0, 1, 2, 3, ------------------------, n

Result and Discussion

Aeromagnetic Map

The visual assessment of total magnetic intensity (TMI) and residual anomaly maps of the study area reveal complex pattern of magnetic signatures of both short and long wavelengths (Fig. 2 and Fig. 3). This varying amplitude of the anomaly suggests varying magnetic intensities from different causative sources as established by Okonkwo *et al*. (2021) and Chinwuko *et al.* (2012) which are evident in the northeastern and central parts of the study area. Around Bantaji, Wukari, Apezan and Atsagba areas, the total magnetic intensity (TMI) and residual anomaly maps depict the underlying basement as having high magnetic intensities ranging from 33480nT (8480nT) to 33630nT (8630nT) and -100nT to 140nT respectively (Fig. 2 and 3). There are strong evidences of basement when juxtaposed with the geologic map of the area around Bantaji, Wukari and Apezan areas. Thus, the alignment of closed anomalies within these areas suggests presence of magnetic bodies.

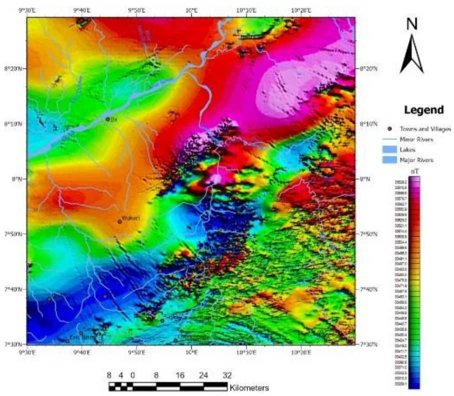


Fig. 2: Total magnetic intensity map of the study area

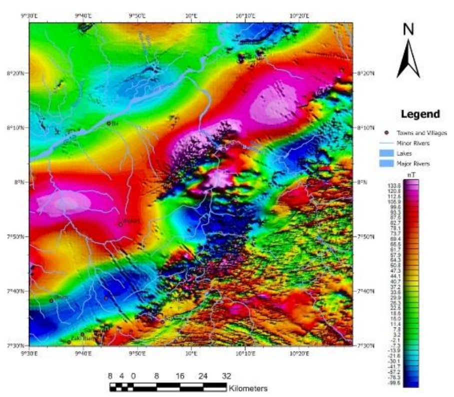
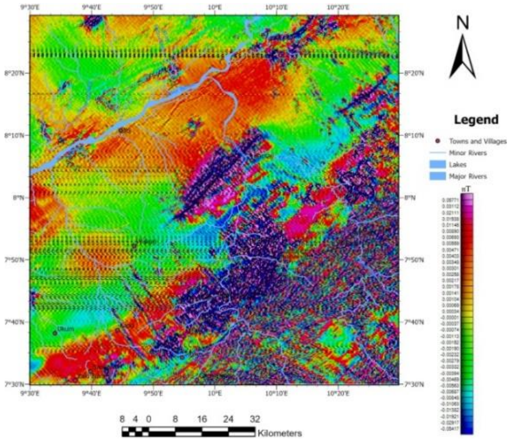


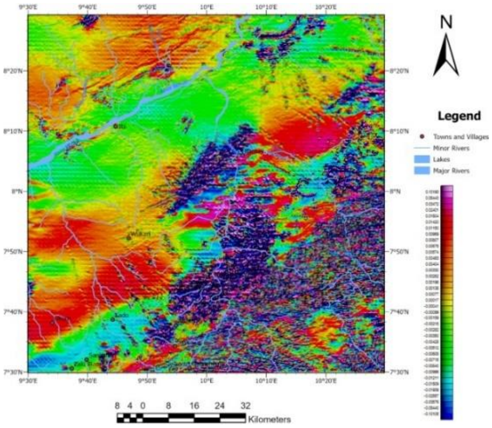
Fig. 3: Residual anomaly map of the study area

Structural Interpretation

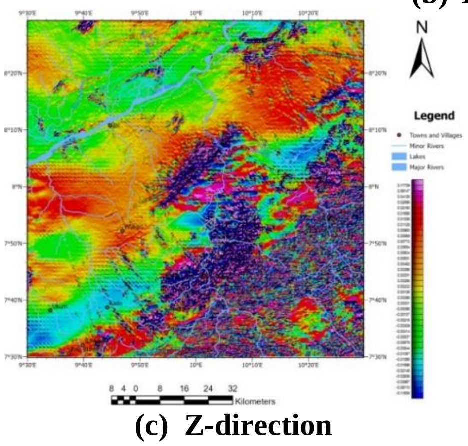
To delineate internal structuration, the original Reduction to Pole (RTP) data were transformed and displayed using various standard techniques. First vertical derivative maps (Fig. 4a-c) shows the set of northeast (NE) to southwest shear fractures as a locally diffuse structure controlling the sedimentary packages on the northeastern to central parts of the study and sheared by intersecting structures within the study area. A tilt derivative map was generated in order to aid enhancement and recognition of anomalies and its attributes (Fig. 5). The map also shows remarkable spatial correspondence between basement structures and sedimentary piles. As indicated on the geology map of Nigeria, the basement and Benue Trough boundaries are sub-parallel limbs of the NE (Pan-African) fold system (Nwajide, 2013) .



(a) X-direction



(b) Y-direction



(c) Z-direction

Fig.4: First Horizontal Derivation Map of the study area

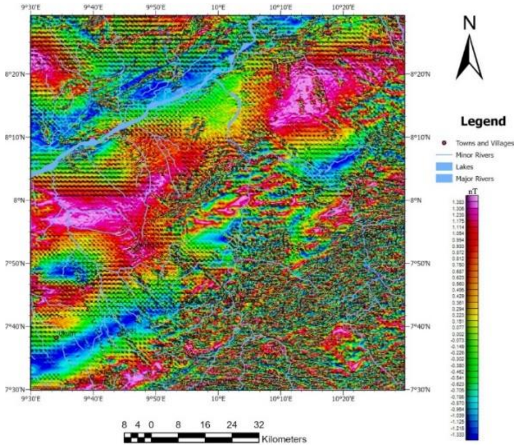


Fig.5: Tilt derivation map of the study area

Lineament Trend Maps

Lineament orientations in the study area were delineated using from all the structural attribute maps obtained from the residual anomaly map. The predominant structural trends were northeast – southwest (NE-SW) with minor E-W and NW-SE trends (Fig. 6). This result is in corroboration with earlier works carried out in the Middle Benue Trough and other portions of the adjoining basement terrains (Chinwuko *et al.*, 2012; Usman *et al.*, 2016; Lar *et al.*, 2023). Juxtaposing these lineaments on the geological map of the study area, it depicts that the structural lineaments were slightly less concentrated in the Createaceous sedimentary rocks compared to the basement complex rocks (granites and biotite gneisses). The high concentration of structural lineament in the area portrays intense tectonic activity that affected the basement complex rocks and its abutting Cretaceous sequences.

Additionally, the generated Rose Diagram (Fig. 7) depicts all the prevalent structural patterns within the study area which attributed in dating some of the events that produced the rocks from which they were formed (Anudu *et al.*, 2012). As a result, NE-SW and NNE-SSW are depicted as prominent trend, whereas, the E-W, and NW-SE are the minor trend in the area (Fig. 7). According to previous works such as Lar *et al*. (2023) and Obaje (2009) propose that the NE-SW within the study area is regarded as Pan-African Orogeny while the E-W and NW-SE may probably have been Pre-Pan-African Orogeny.

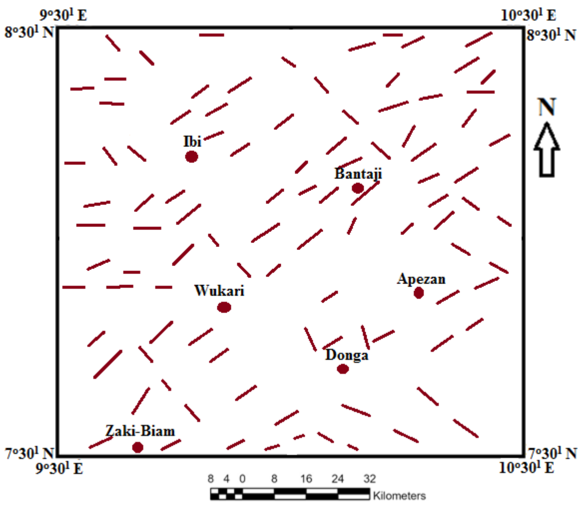


Fig. 6: Magnetic Lineament of the study area

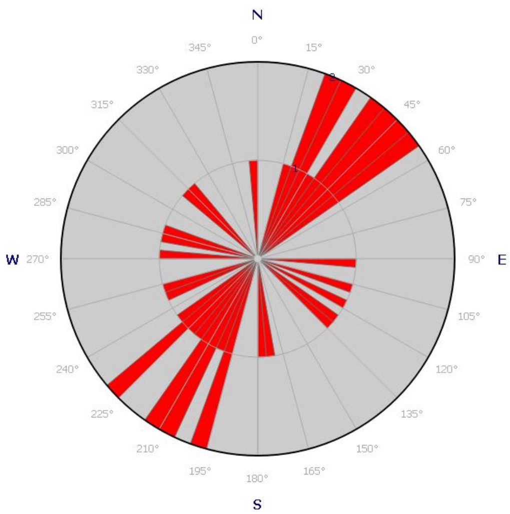


Fig. 7: Trend patterns revealed through Rose Diagram of the study area

Sedimentary Thickness Estimation

The twenty nine magnetic anomalies identified from the selected profiles within the study area (Fig. 8 and Fig. 9) were subjected to spectral analysis in order to obtain the sedimentary thickness in the study area. The spectral analysis result depicts two magnetic sources, namely; the shallower bodies which vary from 0.52 to 1.90 km and the deeper bodies which vary from 2.00 to 6.82 km (Table 1) which conforms to the works by Likkason *et al*. (2013) and Lar *et al*. (2023). Accordingly, the sedimentary thickness distribution map of the study area produced (Fig. 10) reveals higher sedimentary thicknesses in the north and northwestern parts of the study area such as Ibi, Zaki-Biam and parts of Wukari whereas, at other parts of the area such as Bantaji, Apezan and Donga areas have shallower thicknesses.

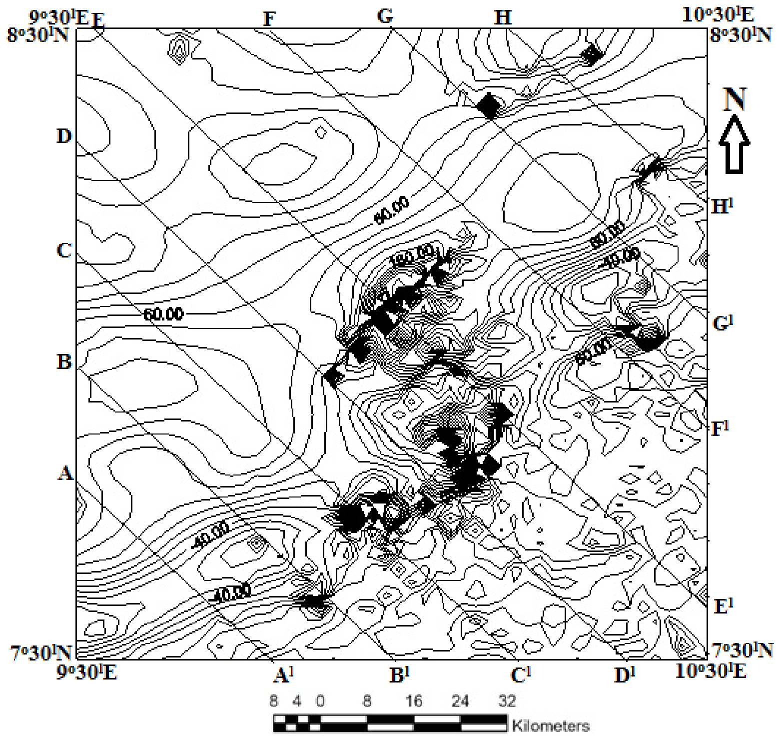


Fig. 8: Selected Profiles on the residual anomaly map of the study area

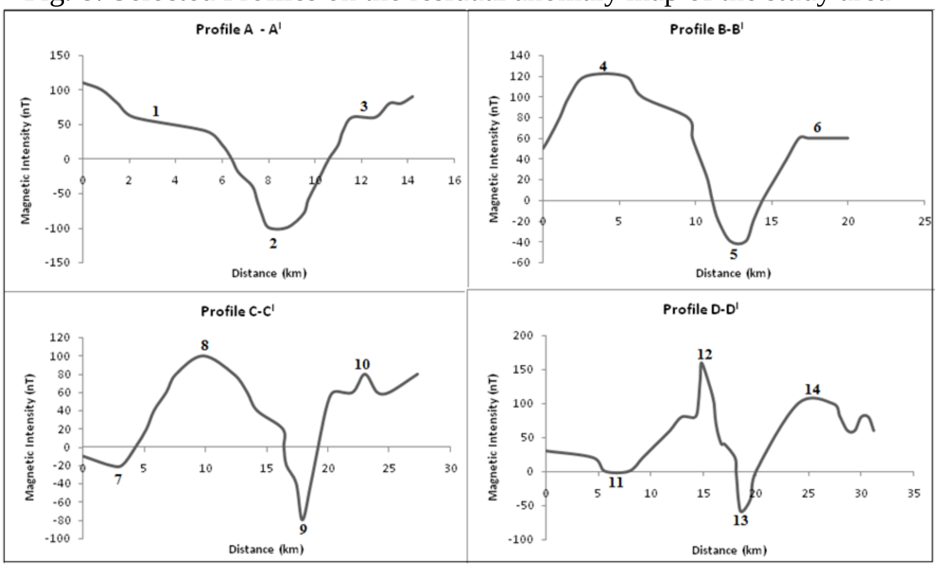


Fig. 9**:** Representative of graphs of profiles within the study area

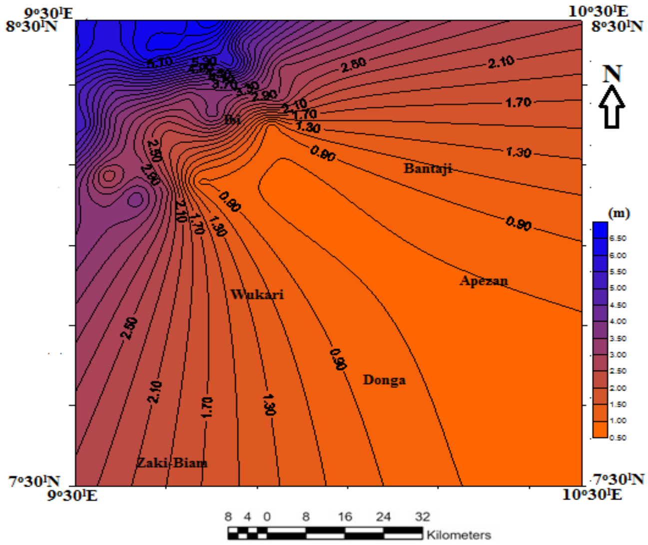


Fig. 10: Sedimentary thickness map of the study area

Table 1: Estimation of Sedimentary thickness using Spectral Aanlysis

Profile Name	*Anomaly Number*	*UTM (X)*	*UTM (Y)*	*Depth (km)*
	1	55500	86000	4.69
A - A	2	57300	84300	2.43
	3	58800	83000	3.71
	4	56000	87600	5.02
B - B	5	58800	85000	3.07
	6	60500	83500	2.71
	7	55500	90000	5.06
C - C	8	57500	88000	3.57
	9	60200	85700	2.24
	10	62000	84000	0.89
	11	55500	92000	6.16
D - D	12	57500	90000	4.24
	13	60300	87300	2.3
	14	82800	65000	0.52
	15	57300	93700	5.71
	16	59300	91700	6.26
E - E	17	61500	89500	3.19
	18	63000	88000	3.46
	19	66000	85000	0.71
	20	60800	92300	6.38
F - F	21	63000	90300	3.75
	22	64400	89000	2.81
	23	66000	87500	0.81
	24	61000	94000	6.07
G - G	25	64000	91300	5.59
	26	66500	89000	2.86
	27	63000	94000	6.82
H - H	28	64500	92500	4.31
	29	66500	91000	2.86
Average				3.73

Furthermore, the real view model of the sedimentary thickness map shows presence of structural features such as peaks (uplifts) and depressions (troughs) within the area (Fig. 11). Around Ibi, Zaki-Biam and parts of Wukari areas, there are visible linear depressions and these areas reveal high sediments than the other parts such as Bantaji, Apezan and Donga areas which have prevalent uplifts (peaks) in conjunction with lower sedimentary thicknesses (Fig. 11). The presence of these peaks (uplifts) suggests that there are numerous intrusive bodies around these areas; as a result, they are more tectonically active than the areas associated with depressional feature (Okonkwo *et al.*, 2021; Ikumbur *et al*., 2023).

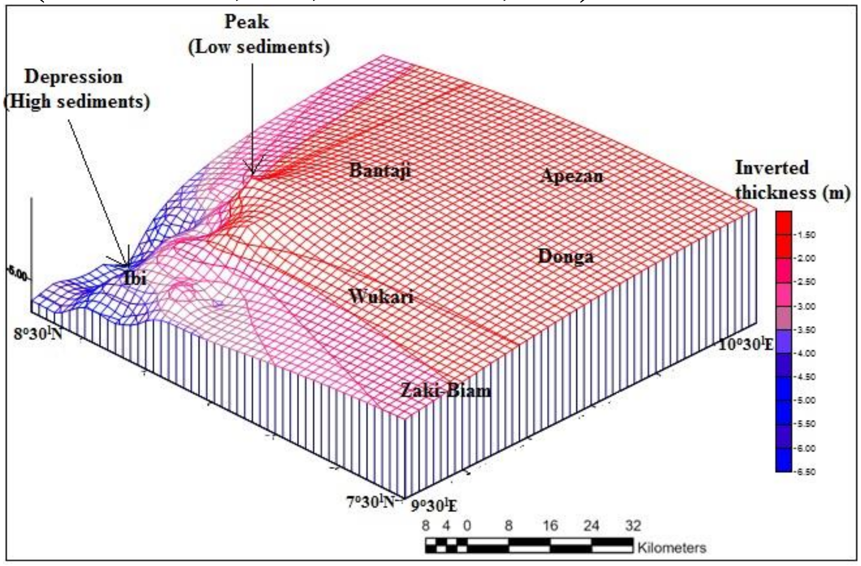


Fig. 11: Real view model of Sedimentary thickness of the study area

Implication of the findings

Prominent magnetic lineament structures trending majorly in the NE-SW direction (Figs. 6 and 7) have been deduced and it conforms to the basement structures of Nigeria. As indicated on the geology map of Nigeria, the basement and Benue Trough boundaries are sub-parallel limbs of the NE-SW (Pan-African) fold system (Nwajide, 2013). The existence of such sub-surface/deep-seated extensive lineament structure systems could serve as pathways for fluid flow such as hydrocarbon, water, and brines within the study area (Chinwuko *et al*., 2012; Lar *et al*., 2023).

In addition, the computed sedimentary thickness revealed an average of 3.73km across the study area conforms to the general standard according to Wright (1985) and Chinwuko *et al*. (2012) for possible hydrocarbon accumulation since the average thickness is above 2.10km (Table 1). The results also show the variability of the underlying basement depths in the study area being part of Middle Benue Trough, ranging from 0.52 to 6.82km depicting a basement configuration that has been supported by earlier works such as Lar *et al*. (2023); Benkhelil (1988). Thus, the sedimentary cover within the study area is generally high which increases towards the northwestern parts and therefore may support hydrocarbon formation. Actually, any prospective sediment must have a good quality source rock, good reservoir and seal lithologies, favourable regional pathways and trapping mechanisms. According to Obaje (2009) and Lar *et al*. (2023), the study possessed some key elements of petroleum system such as source rock (dark shale and limestone of the Asu River Group, Awe, Ezeaku and Agwu Formations); reservoir rock (the sandstones of the Cenomanian Keana, Awe Formations and Makurdi sandstone); and the shales of the basal Ezeaku Formation are possible regional seals.

Conclusions

The study concludes as follows;

1. The magnetic anomaly maps depict the underlying basement as having high magnetic intensities ranging from 8480nT to 8630nT across the study area.
2. The study area is highly structuralized with the generated lineament maps and Rose diagram signifying that the study area is extremely faulted with prominent trends in NE-SW, whereas, the minor trends occur along E-W and NW-SE.
3. The spectral analysis result depicts two magnetic sources, namely; the shallower bodies which vary from 0.52 to 1.90 km and the deeper bodies which vary from 2.00 to 6.82 km.
4. The computed results and models provided information on the wherewithal of interpretation of aeromagnetic anomalies in delineating hydrocarbon potentials across the study area.

References

Anakwuba, E.K. and Chinwuko, A.I. (2012). Re-Evaluation of Hydrocarbon Potentials of Eastern Part of the Chad Basin, Nigeria: An Aeromagnetic Search and Discovery Article #10405. Adapted from extended abstract prepared in conjunction with posterpresentation at AAPG Annual Convention and Exhibition, Long Beach, California, 16p.

Anudu, G.K., Onuba, L.N., Onwuemesi, A.G. and Ikpokonte, A.E. (2012). Analysis of aeromagnetic data over Wamba and its adjoining areas in north-central Nigeria. Earth Sci. Res. Journ., 16 (1): 25 – 33.

Benkhelil, J. (1988). Structure et evolution géodynamique du bassin intracontinental de la Bénoué, Nigeria. Bulletin des Centres de Recherches Exploration—Production Elf-Aquitaine, 12: 29-128.

Chinwuko, A.I., Onwuemesi, A.G., Anakwuba, E.K., Onuba, L.N., and Nwokeabia, N.C. (2012). The Interpretation of Aeromagnetic Anomalies over parts of Upper Benue Trough and Southern Chad Basin, Nigeria. Advances in Applied Science Research, 3 (3): 1757-1766.

Chinwuko, A. I., Onwuemesi, A. G., Anakwuba, E. K., Okeke, H. C., Onuba L.N., Okonkwo, C.C. Ikumbur, E. B. (2013). Spectral Analysis and Magnetic Modeling over Biu – Damboa, Northeastern Nigeria. IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG), 1 (1): 20- 28.

Chinwuko A.I., Usman, A.O., Onwuemesi A.G., Anakwuba, E.K., Okonkwo, C.C. and Ikumbur, E.B. (2014). Interpretations of aeromagnetic data over lokoja and environs, Nigeria. International Journal of Advanced Geosciences, 2(2): 66- 71.

Ikumbur, E.B., Onwuemesi, A.G., Anakwuba, E.K., Chinwuko, A.I., Usman, A.O., and Okonkwo, C.C. (2013). Spectral Analysis of Aeromagnetic Data over Part of the Southern Bida Basin, West-Central Nigeria International Journal of Fundamental Physical Sciences, 3(2): 27-31.

Ikumbur, E.B., Onwuemesi, A.G., Anakwuba, E.K., Chinwuko,A.I., and Usman, A.O. (2023). Evaluation of Geothermal Energy Potential of parts of the Middle Benue Trough Nigeria: Aeromagnetic and Aeroradiometric Approach. Iranian Journal of Geophysics, 16 (4): 37 – 52.

Lar, U.A. , Bata, T. Dibal, H., Yusuf, S.N., Lekmang, I., Goyit, M., and Yenne, E. (2023). Potential petroleum prospects in the middle Benue trough, central Nigeria: Inferences from integrated applications of geological, geophysical and geochemical studies. Scientific African, 19 (e01436): 1-19.

Likkason, K., Singh, G.P., and Samaila, N.K. (2013). A study of the Middle Benue Trough (Nigeria) based on geological application and analyses of spectra of aeromagnetic data, energy sources, Part A: recovery, Utilizat. Environ. Effects, 35 (8): 706–716.

Nwajide, C.S. (2013). Geology of Nigeria's Sedimentary Basins. CSS Bookshop Ltd., Lagos. pp 246 – 247.

Obaje, N.G. (2009). Geology and MineralResources of Nigeria. Springer-Verlag Berlin Heidelberg, 218p.

Okonkwo, C. C., Onwuemesi, A. G., Anakwuba, E. K., Chinwuko, A. I., Ikumbur B. E. and Usman, A. O., (2012). Aeromagnetic Interpretation over Maiduguri and Environs of Southern Chad Basin, Nigeria. Journal of Earth Sciences and Geotechnical Engineering, 2 (3): 77-93.

Okonkwo, C.C., Onwuemesi, A.G., Anakwuba, E.K., Chinwuko, A.I., Okeke, S.O., and Usman, A.O. (2021). Evaluation of Thermomagnetic Properties and Geothermal Energy Potential in Parts of Bida Basin, Nigeria, Using Spectral analysis. Bulletin of the Mineral Research and Exploration, 165: 13-30.

Okoro, E.M., Onuoha, K.M, Okeugo, C.G., Dim, C.I.P. (2021). Structural interpretation of High-resolution aeromagnetic data over the Dahomey basin, Nigeria: implications for hydrocarbon prospectivity. Journal of Petroleum Exploration and Production, 11: 1545–1558.

Olasehinde, P.I. (1991). A spectral evaluation of the aeromagnetic anomaly map over part of the Nigerian Basement complex, unpublished Ph.D Thesis, University of Ilorin.

Onwuemesi, A.G. (1997). One Dimensional Spectral Analysis of Aeromagnetic Anomalies and Curie Depth Isotherm in the Anambra Basin of Nigeria. Journal of Geodynamics, 23 (2): 95-107.

Wright, J. B.; Hastings, D.; Jones, W. B. and William, H.R. (1985). Geology and Mineral resources of West Africa. George Allen and Urwin, London, pp.90-120.