Spectral Analysis Determination of Depth to Basement in Parts of Nigerian Sector of Chad Basin using Aeromagnetic Data

M. Akiishi*, P. I. Uloko, T. T. Iortim, G. O. Ankeli and A. Ichagba

Department of Physics, Collage of Education Oju, Benue State

***Correspondence Author**

DOI: https://dx.doi.org/10.47772/IJRISS.2025.908000363

Received: 22 July 2025; Accepted: 28 July 2025; Published: 11 September 2025

ABSTRACT

High resolution aeromagnetic data covering parts of Nigerian sector of Chad basin (latitude 12 ° 00' to13 00' North and longitude 12° 30' to 14° 00' East) have been interpreted qualitatively and quantitatively. Residual-regional separation was carried out by applying polynomial fitting (first order), which was fitted by least square method. First order was used because it is the best regional fit for the data as it reflected the available geological information of the area. The residual magnetic anomaly values obtained were used to produce residual magnetic anomaly map while the regional magnetic anomaly values were used to produce regional magnetic anomaly map. Depth to basement was obtained using spectral analysis. The result indicates that deep depth (D_1) varies between 6.568 and 2.644 km, with an average depth value of about 4.043 km, while shallow depth (D_2) lies between 1.393 and 0,869 km, with an average depth value of 1.065 km. The deeper magnetic anomalies could be due to deep magnetic bodies, while the shallow magnetic sources might be as a result of near surface magnetic bodies, which intruded the area. The average depth to deeper magnetic bodies (D_1) of 4.043 km indicates that the area has the potential for hydrocarbon accumulation; therefore it is recommended that oil (crude) company should be sited in the area, this will provide employment opportunity for the masses.

Keywords: High resolution, aeromagnetic data, Fast Fourier Transform, Enhancement techniques, windowing

INTRODUCTION

Nigeria is blessed with subsurface natural resources, which if harnessed, processed and commercialized could increase her revenue generation. Subsurface natural resource such as hydrocarbon, over the years has been a key determinant of Nigerian economy, since large portion of the country's revenue comes from export and domestic sale of petroleum, gas and minerals resources (Obiora et al., 2021). These are mostly explored in Niger Delta area; hence the fear that soon or later the economic reserve of the country may have a hitch, as the hydrocarbon potentials and mineral deposits of the Niger Delta may be exhaustibly harnessed. On the other hand, it has been presumed by other researchers that Nigerian sector of Chad basin has adequate geologic features that encouraged accumulation of hydrocarbon (Adekoya et al., 2014) but geological features associated to subsurface resource varies with time. In addition, changes in scientific and technology innovations have lead to constant improvement in the geophysical survey techniques Therefore, the search for subsurface resources in this region using different methods of data acquisition, analysis and interpretations can never be over emphasis. Meanwhile some geophysical works had been carried out in Nigerian sector of Chad basin (Akiishi et al, 2020, Adewumi et al., 2017 Sani and Likkason, 2022, Lawal et al., 2020 , Okonkwo et al., 2021, Bonde, et al., 2020a, Bonde et al., 2020b); however most of these works were done in the southern and western parts of the basin. Similarly, much of these works were carried out using lower resolution data and investigated water, geothermal energy and mineral resources only. Finally, majority of these works were carried out using land survey data which may be restricted in some regions such as revering and mountains areas. Thus this might have given results at discrete locations, hence; this work used high resolution data which

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VIII August 2025

could bring out more geological features for analysis. It was also carried out in the northern part of the basin where geophysical studies of this nature have not been done.

Location and Geology of the Study Area

The study area is found in the Nigerian sector of Chad basin, which lies within latitude 12 ° 00' to 13 ° 00' North and longitude 12° 30' to 14° 00' East (Fig. 1). Nigerian sector of Chad basin formed part of the Chad basin which lies within a vast area of central and west Africa at an elevation between 200 and 500 m above sea level and covers an approximate area of about 230,000 km^2 (Ajana et al., 2014). It is the largest area of inland drainage in Africa and extends into parts of the republic of Niger, Chad, Cameroon, Nigeria and Central Africa (Avbovbo et al., 1986, Barber 1865) The Nigerian sector of Chad basin is about one tenth of the Chad basin and has a broad sediment-filled depression spanning north eastern Nigeria and adjoining parts of the republic of Chad. The geological map (Fig. 2), consisting of sheets 44, 45, 46, 66, 67 and 68 reveals the presence of granite, marble, sandstone, limestone and shale.

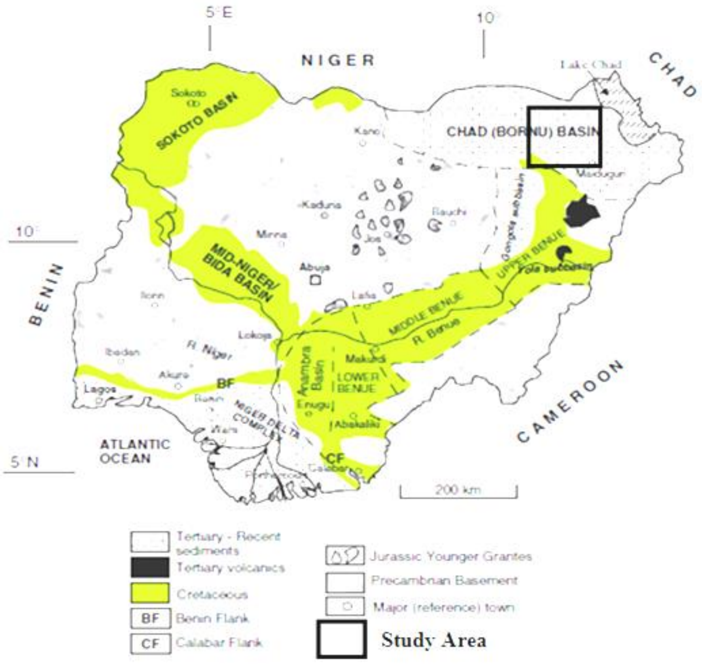

Fig 1: The Map of Nigeria Showing the Location of Chad Basin (Obaje 2009).

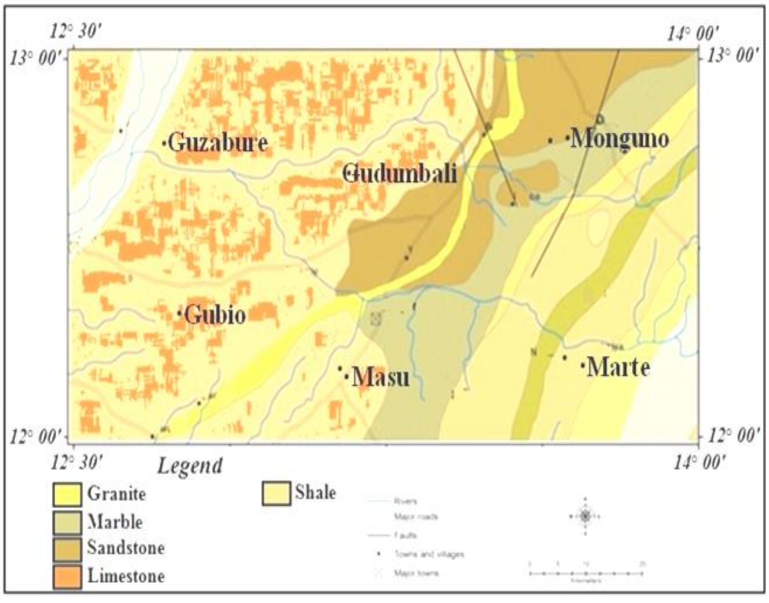

Fig. 2: Geology Map of the Study Area (courtesy: The Nigerian Geological Survey Agency, NGSA Abuja)

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VIII August 2025

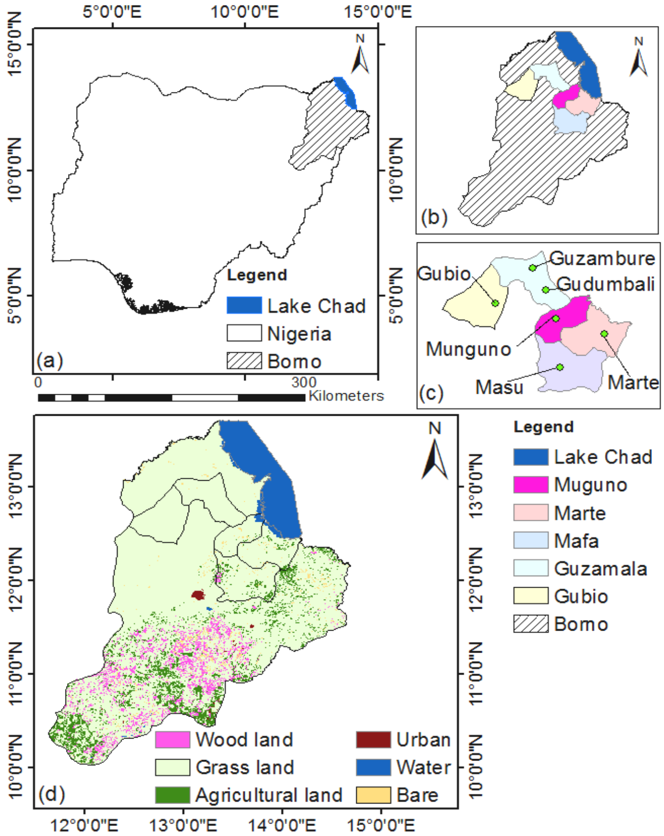

Fig. 3: Digitized (a) Map of Nigeria Showing Borno State (b) Map of Borno State Showing LGA (c) Map of LGA Showing Study Areas (d) Land Cover Map of Borno State.

MATERIALS AND METHOD

MATERIALS

The digital aeromagnetic data were obtained from Nigerian geological survey agency Abuja (NGSA). These airborne magnetic data were measured using a 3 x Scintrex CS2 cesium vapor magnetometer belonging to Fugro Airborne Surveys in 2009. The magnetic survey was flown at 80 m elevation along flight lines spacing of 500 m apart. The flight line direction was 135^{o}, while the tie line direction was 225^{o}. The airborne magnetic data were recorded in digital format (X, Y and Z test file). X and Y represent the longitude and latitude of the study area, while the Z represents the magnetic field intensity measured in nano Tesla. The Earth's main field was removed by applying international geomagnetic reference field (IGRF 2010).

METHODOLOGY

The total magnetic field intensity data were merged in the note book and imported into Oasis Montaj software and subsequently gridded using minimum curvature. These gridded data were further used with the aid of Oasis Montaj to produce the total magnetic intensity map. First order polynomial fitting was applied on the total magnetic field intensity data; hence the regional and residual magnetic fields were separated. The regional magnetic and residual magnetic fields were furthermore used to produce the regional magnetic map and residual magnetic map respectively.

To quantify the depth to basement in the area, 2D spectral depth analysis was used. The process began by calculating the average radial power spectrum over a square window which was obtained by windowing the residual aeromagnetic map with the aid of Oasis Montaj into 24 over lapping spectral windows. The Discrete Fourier Transform is the mathematical tool for spectral analysis and applied to regularly spaced data such as the aeromagnetic data. A Fast Fourier Transform (FFT) algorithm computes the Discrete Fourier Transform

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VIII August 2025

(DFT) of a sequence, or it's inverse. The Fourier Transform is represented mathematically (Onwuemesi, 1997) as:

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

Where $Y_i(x)$ is the reading at x_i position, L is length of the cross-section of the anomaly, n is harmonic number of the partial wave number, N is number of data points, a_n is real part of the amplitude spectrum and b_n is imaginary part of the amplitude spectrum; for $i = 0,1,2,3, \ldots, n$.

The logarithms of the energy spectrum (Log E) are plotted against the domain frequency. Two linear segments are drawn from each graph; and their gradients (m) were used to estimate the deep depth (D1) and the shallow depth (D2) as shown in equations 2 – 4

$$Slope\ (m_1, m_2) = \frac{Log\ (Energy)}{Frequency} \quad (2)$$

$$D_1 = -\frac{m_1}{4\pi} \quad (3)$$

$$D_2 = -\frac{m_2}{4\pi} \quad (4)$$

where, m_1 and m_2 are slopes of the first and second segments of the spectral plot, the negative sign (-) indicates depth to the subsurface.

RESULT AND DISCUSSION

Figure 4 presents result of qualitative interpretation (a) Total magnetic intensity, (b) residual magnetic intensity, (c) Regional magnetic anomaly. The results of the quantitative interpretation using spectral analysis to map the depth to basement are shown in Figures 5 - 8. Meanwhile, Figure 9 shows the 2D Contour maps for both shallow and deep depth to basement. Finally, the 3D map of deep depth showing magnetic basement is given Figure 10

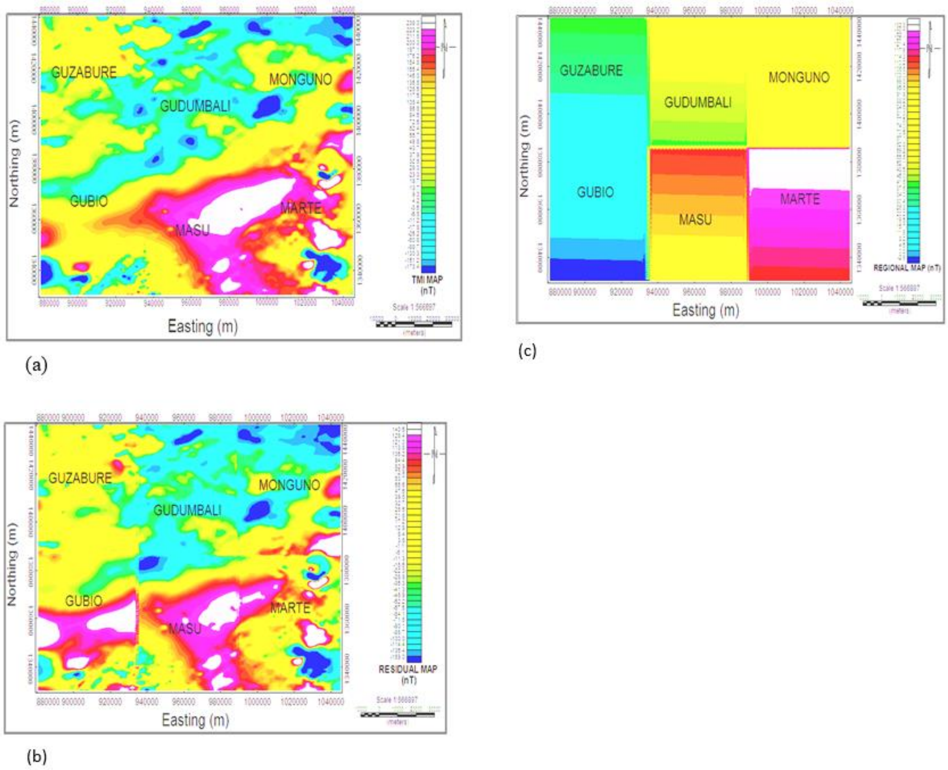

Fig. 4: Maps Showing Results of Qualitative Interpretation of Aeromagnetic Data of Nigerian sector of Chad basin: (a) Total Magnetic Intensity (b) Residual Magnetic Anomaly (c) Regional Magnetic Anomaly

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VIII August 2025

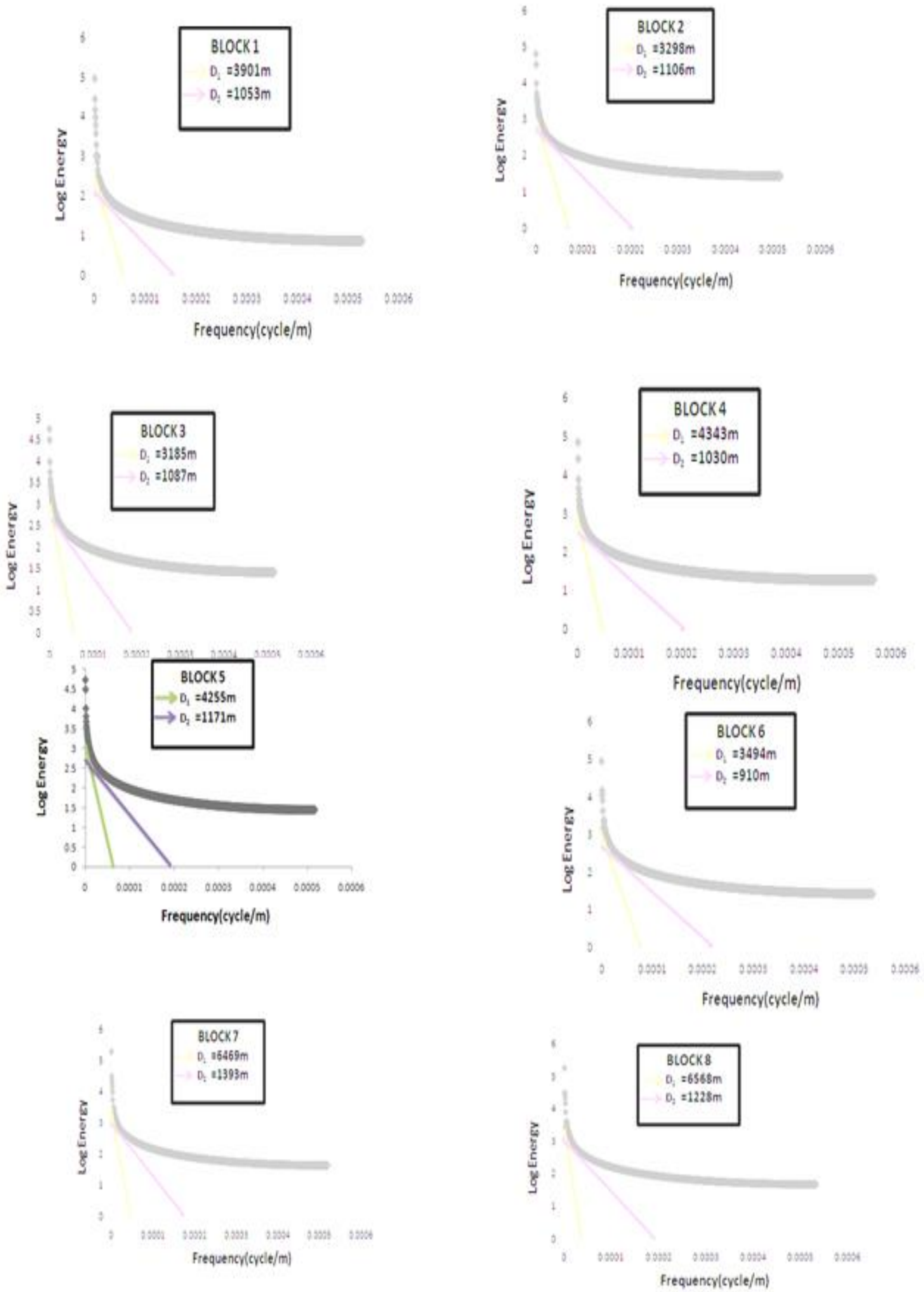

Fig. 6: Spectral plots of Logarithm of Energy against Frequency (cycle per meter) for Cells 1-8

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VIII August 2025

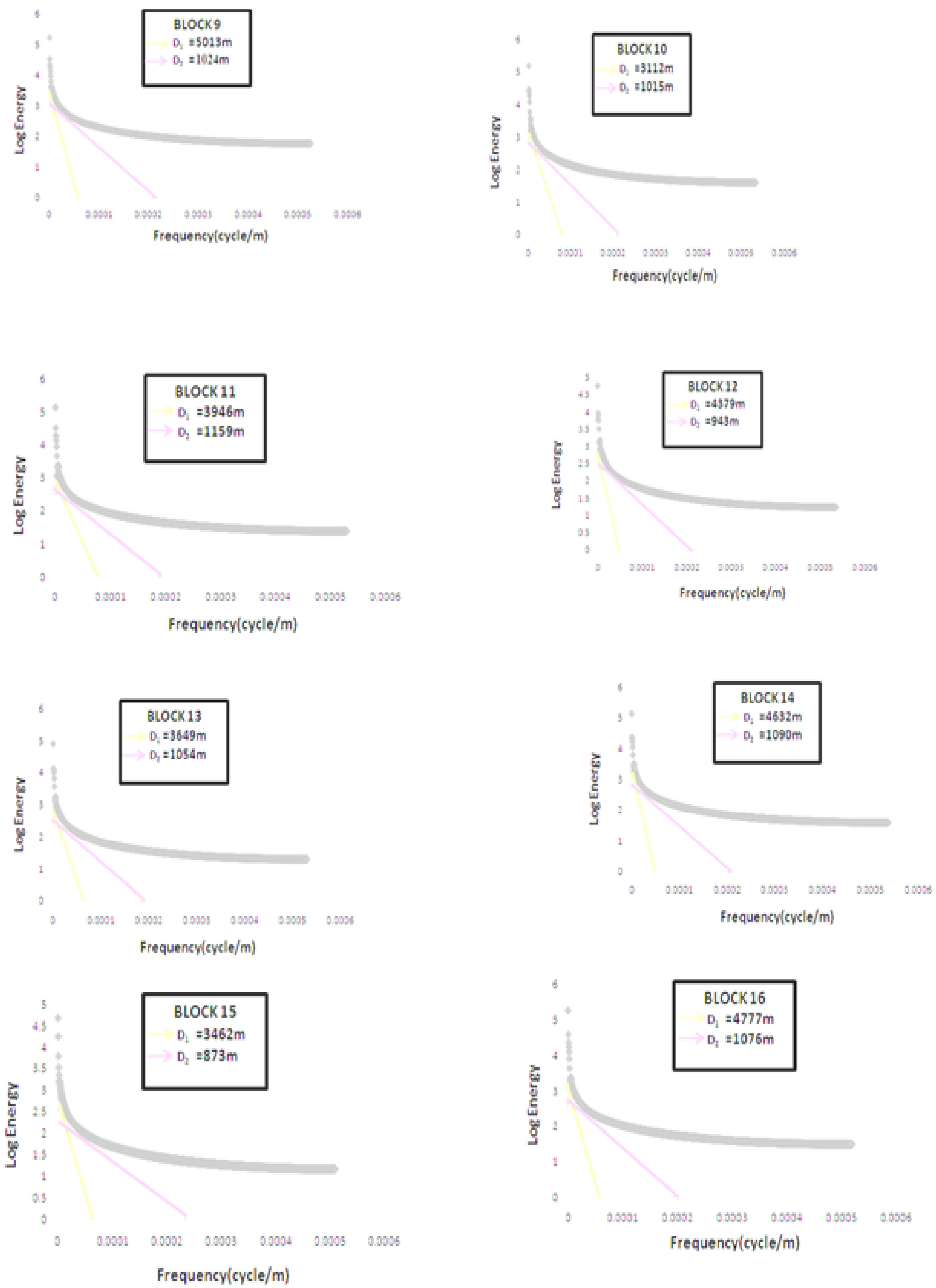

Fig. 7 Spectral Plots of Logarithm of Energy against Frequency (cycle per meter) for Cells 9 -16

INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN SOCIAL SCIENCE (IJRISS)
ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VIII August 2025

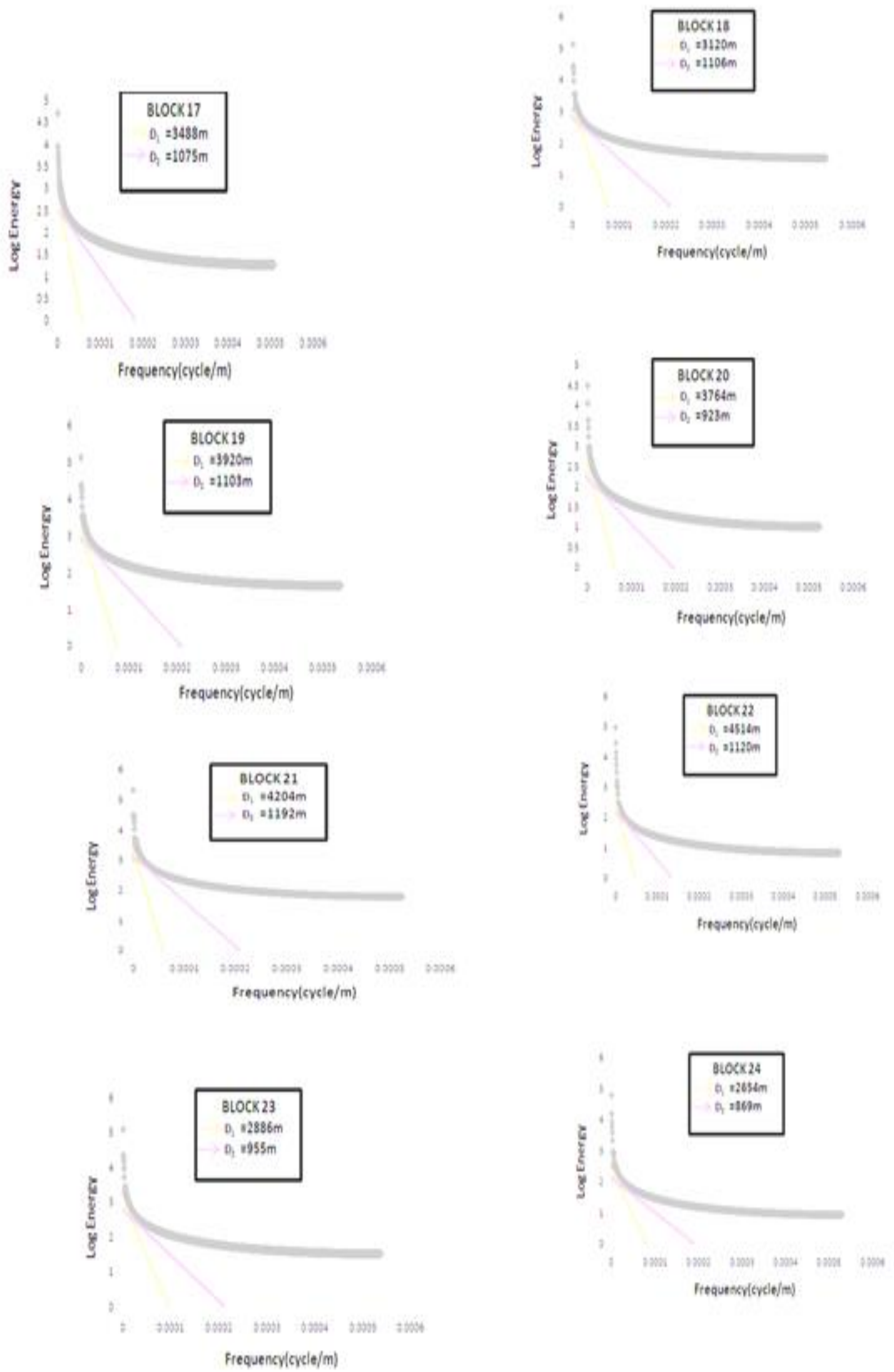

Fig 8: Spectral Plots of Logarithm of Energy against Frequency (cycle per meter) for Cells 17-24

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VIII August 2025

Table 1: Estimated Depths to Magnetic Basement (first and second magnetic layers) for 24 Spectral Blocks and Their Coordinates

S/n	Spectral Blocks	Co-ordinates (m)		Depth Source Value (km)	
	Sections	X(Easting)	Y(Northing)	Deep(D_1)	Shallow(D_2
1	1	894110.3	1344026	3.901	1.053
2	2	921456.0	1344026	3.298	1.106
3	3	948802.0	1344026	3.185	1.087
4	4	976148.0	1344026	4.343	1.030
5	5	1003494.0	1344026	4.255	1.171
6	6	1030840.0	1344026	3.494	0.910
7	7	894110.3	1371412	6.469	1.393
8	8	921456.0	1371412	6.568	1.228
9	9	948802.0	1371412	5.013	1.024
10	10	976148.0	1371412	3.112	1.015
11	11	1003494.0	1371412	3.946	1.159
12	12	1030840.0	1371412	4.379	0.943
13	13	894110.3	1398798	3.649	1.054
14	14	921456.0	1398798	4.632	1.090
15	15	948802.0	1398798	3.462	0.873
16	16	976148.0	1398798	4.777	1.076
17	17	1003494.0	1398798	3.488	1.075
18	18	1030840.0	1398798	3.120	1.106
19	19	894110.3	1426183	3.920	1.103
20	20	921456.0	1426183	3.764	0.923
21	21	948802.0	1426183	4.204	1.192
22	22	976148.0	1426183	4.514	1.120
23	23	1003494.0	1426183	2.886	0.955
24	24	1030840.0	1426183	2.644	0.869
Average Depth				**4.043**	**1.065**

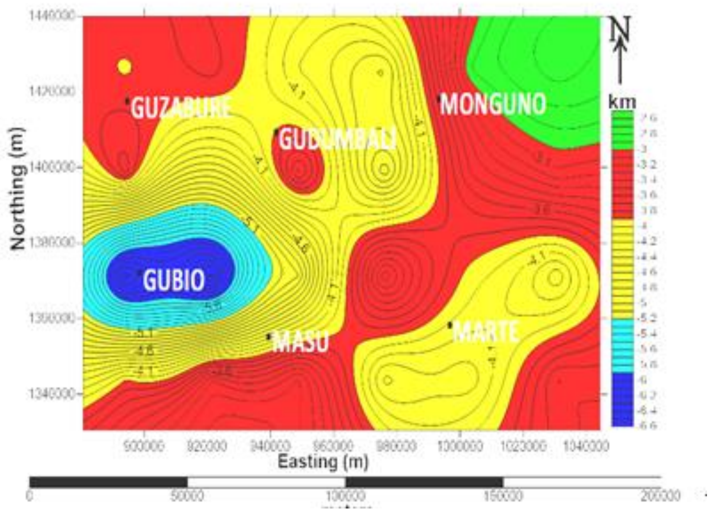

Fig.9: 2D Contour Maps of Depth to Magnetic Basement of the Study Area (a) Deep Depth to the Basement (cont. interval 0.1km); (b) Shallow depth to Basement (cont. interval 0.01km)

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VIII August 2025

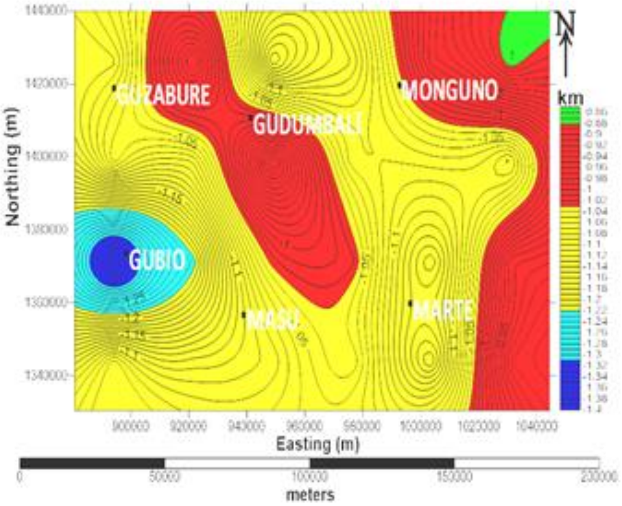

Fig. 10: 3D Map of Deep Depth Showing Magnetic Basement Topography of the Nigerian sector of Chad basin.

DISCUSSION

The total magnetic intensity (TMI) map of the study area reveals ranges of magnetic anomalies, which varies from -170.4 to 238.3 nT (Fig. 4a). High magnetic intensity is observed in the southeastern part of the area (indicated by Masu and Marte) and decreases towards the north. This indicates that the southeastern area could be occupied by shallow magnetic bodies while the central and northern regions could be occupied by deep magnetic bodies. It further shows that the variation in the total magnetic intensity could be as result of variation in depth to magnetic bodies, differences in magnetic susceptibility mineral, lithology, dip and plunge (Obiora et al., 2020, Fajanu et al., 2024). The 2D residual magnetic map (Fig. 4b) of the area identifies residual magnetic anomalies to vary from -169.0 to 140.5 nT. Further observations indicate that the central and northern parts of the area exhibit low residual magnetic anomaly. This could be as a result of low concentration of magnetic materials in the area. The high residual magnetic anomaly experienced at the southeast could be due to high concentration of magnetic mineral or rocks of high magnetic susceptibility. The residual magnetic field was used to bring into focus local features, which tends to be obscured by the broad features of the regional magnetic field. The residual magnetic intensity trend of the area agrees well with that of the total magnetic intensity of the area. It implies that the area is mostly occupied by residual magnetic bodies. This agrees with the work of. Lawal et al., 2022. Similarly high regional magnetic intensity is noticed in the southeast while low regional magnetic is observed in the southwest. The decrease in the regional magnetic intensity from southeastern to southwestern parts of the area, indicate there is a fill of sediments more in the southwestern part than in the southeastern part of the area. The computed depths to basement recorded in Table1 indicates mainly two depth to magnetic sources, the deeper sources which has depth range of 2.644 to 6.568 km with an average depth value of about 4.043 km, while the depth to the shallow sources ranges from 0.869 to 1.393 km with an average depth value of about 1.065 km. The deep depth to magnetic basement map (9a) indicates that the northeast is relatively shallow, while Gubio area is relatively deeper. Similarly, the shallow depth to magnetic basement (Fig 9b) shows that the northeast is shallowest while Gubio area is been deeper. This result is confirmed by the 3D basement topographic map (Fig. 10) which shows the irregular nature of the basement possibly associated with faults that aid the migration and entrapment of hydrocarbons and other mineralized deposit. Hence, the 3D map shows a linear depression with thickest sediments at the southwest region of the area and an elevation with shallowest sediment at the northeastern (Monguno) part of the area.

CONCLUTION

The aeromagnetic data of the area has been interpreted qualitatively and quantitatively. The qualitative interpretation shows that southeastern part of the area experienced both the high residual and regional magnetic

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue VIII August 2025

intensities. The high sedimentary thicknesses (4.043 km) obtained in this work is sufficient enough for hydrocarbon accumulation based on the assertion made by Wright et al. (1985) that the minimum thickness of the sediment required for the commencement of oil formation from marine organic remains would be 2300 m (2.3km). This implies that the area has the potential for hydrocarbon accumulations within the depths of about 2.644 to 6.568 km estimated in this work.

REFERENCES

1. Adekoya, J. A., Ola, P. S., & Olabole, S. O. (2014). Possible Bornu Basin hydrocarbon habitat: A review. International Journal of Geosciences, 5(11), 983–996.
2. Ajana, O., Udensi, E. E., Momoh, M., Rai, J. K., & Muhammad, S. B. (2014). Spectral depths estimate of subsurface in parts of Chad Basin, Northeastern Nigeria. Journal of Applied Geology and Geophysics, 2(2), 58–60.
3. Akiishi, M., & Ankeli, G. O. (2020). Investigation of solid mineral deposit in Gabio, Nigerian sector of Chad Basin using aeromagnetic and aerogravity forward and inverse modeling. International Astronomy and Astrophysics Research Journal, 2(2), 28–40. https://doi.org/10.9734/IAARJ/2020/v2i23057440
4. Avbovbo, A. A., Ayoola, E. O., & Osahon, G. A. (1986). Depositional and structural styles in Chad Basin of Nigeria. Bulletin of the American Association of Petroleum Geologists, 70(12), 1787–1798.
5. Barber, W. (1965). Pressure water in the Chad formation of Borno and Dikwa Emirates, NE Nigeria. Bulletin of the Geological Survey of Nigeria, 35, 138.
6. Bonde, D. S., Udensi, E. E., & Momoh, M. (2020a). Modeling of magnetic anomaly zones in Sokoto Basin, Nigeria. Journal of Applied Geology and Geophysics, 2(1), 19–25.
7. Bonde, D. S., Udensi, E. E., & Momoh, M. (2020b). Delineation of magnetic zones of Sokoto Basin, Northwestern Nigeria using aeromagnetic data. National Journal of Engineering and Science, 4(1), 37–45.
8. Fajanu, A., Damilare, J., Akimola, E., & Tokunbo, S. F. (2024). Hydrocarbon potential evaluation of Chad Basin, Northeastern Nigeria using high-resolution aeromagnetic data. Journal of Nigerian Institute of Physics, 3(2), 24–40.
9. Lawal, T. O., & Nwankwo, L. I. (2022). Evaluation of the depth to the bottom of magnetic sources and heat flow from high-resolution aeromagnetic (HRAM) data of part of Nigerian sector of Chad Basin. Arab Journal of Geosciences, 10(378), 1–12.
10. Obiora, D. N., Ossai, M. N., & Okwohi, E. (2021). A case study of aeromagnetic data interpretations of Nsukka area, Enugu State, Nigeria for hydrocarbon exploration. International Journal of Physical Sciences, 10(17), 503–519.
11. Okonkwo, C. C., Onwuemesi, A. G., Anakwuba, E. K., Chinwuko, A. I., Ikumbur, B. E., & Usman, A. O. (2021). Aeromagnetic interpretation over Maiduguri and environs of Southern Chad Basin, Nigeria. Journal of Earth Sciences and Geotechnical Engineering, 2(3), 77–93.
12. Onwuemesi, A. G. (1997). One-dimensional spectral analysis of aeromagnetic anomalies and Curie point depth isotherm in the Anambra Basin of Nigeria. Journal of Geodynamics, 23(2), 95–107. https://doi.org/10.1016/S0264-3707(96)00037-5
13. Sanusi, Y. A., & Likkason, O. K. (2022). Angular spectral analysis and low-pass filtering of aeromagnetic data over western parts of Nigerian Chad (Borno) Basin, Nigeria. Nigerian Journal of Basic and Applied Sciences, 24(2), 73–78.