Journal of Basic Physical Research ISSN: 2141-8403 Prints, 2141-8411 Online
Vol.12, Issue 2, October, 2024, pp. 115 - 123. Available online at https://journals.unizik.edu.ng/jbpr/

IDENTIFICATION OF DEPTH TO BASEMENT OVER UGEP AND ENVIRONS, CROSS-RIVER STATE, NIGERIA USING SLOPE METHOD ANALYSIS OF AEROMAGNETIC DATA

[1]Chinwuko, A. Ifeanyi, [2]Usman, A. Ojonugwa, [3]Okeke, S. Okechukwu, and [3]Okonkwo, C. Chukwunonso
[1]Department of Applied Geophysics, Nnamdi Azikiwe University, Awka
[2]Department of Physics/Geology/Geophysics, Alex Ekwueme Federal University, Ndufu-Alike Ikwo, Ebonyi State, Nigeria
[3]Department of Physics, Federal College of Education Umunze, Nigeria

Abstract
The study aimed at the identification of depth to basement over Ugep and environs, Cross River State, Nigeria, using slope method analysis of aeromagnetic data. The study area covers an estimated area of 55 km by 55 km squared between latitudes 5º30'N to 6º00'N and longitude 8º00'E to 8º30'E. The data involved were processed and interpreted using the Surfer-32 software. Seven profiles were taken on the residual anomaly map, which shows the anomalies present. Peter's Half-Slope method is used to deduce the depth to the basement of the study area. The visual inspection of magnetic maps depicts that the total magnetic intensity ranges from 7820 nT to 8120 nT while the residual magnetic intensity ranges from -140 nT to 160 nT. The area is intensely fractured with major faults trending in NE-SW direction and minor fault tending in the NW-SE direction. The depth to basement obtained using Peter's Half-Slope method ranges from 0.16 km to 4.8 km with an average of 2.05 km across the study area. The basement map generated revealed the basement configuration as well as the sedimentary thicknesses within the study area. The 3D surface plot of the basement map indicates the presence of depression and uplift. The findings of this study suggest that the study area possesses some requisite characteristics for possible hydrocarbon accumulation within the study area, considering the huge sedimentary thickness in the area.
***Keywords**: Anomaly map, Rose Diagram, Lineament, Depression and Uplift.*

Introduction

Commercial oil and gas have recently been discovered in Nigeria's Gongola arm of the Upper Benue Trough and the Anambra Basin as a result of the intensive hunt for hydrocarbons in the Benue Trough and Anambra Basin. These findings have made it necessary to investigate Udi and environs within Anambra Basin, which has gotten the least attention thus far. Given that parts of Anambra Basin are productive, it is imperative that the geology of the basin be re-evaluated (Chinwuko *et al.*, 2023). Therefore, the first geophysical tool to use is a magnetic survey.

Investigating subsurface geology using magnetic anomalies in the Earth's magnetic field that arise from the magnetic characteristics of the underlying rocks is the actual purpose of a magnetic survey. It is possible to conduct magnetic surveys in the air, on land, and at sea. Because aeromagnetic data are constantly available, they should be used to their fullest potential in comparison to other geophysical approaches (Chinwuko *et al.*, 2023, Ugwuoke and Chinwuko, 2023). In any region, including the study area, it is crucial to comprehend the applications of aeromagnetic surveys in relation to hydrocarbon prospectively by mapping the dominant structures and sedimentary thickness (Usman *et al.*, 2024; Chinwuko *et al.*, 2023, Ugwuoke and Chinwuko, 2023; Okonkwo *et al.*, 2021; Ikumbur *et al.*, 2023; Anakwuba and Chinwuko, 2012).

Aeromagnetic data are readily available compared to other geophysical methods; therefore, the need for exploiting its potentials cannot be over-emphasized. Due to the complexity of data acquisition and compiling with the advent of modern technology, magnetic method is by far the most widely used of all geophysical methods (Chinwuko *et al.*, 2012). For exploration purposes, both ground and aeromagnetic data have been used to investigate the presence of mineral deposits in combination with gravity and or other geophysical methods. Therefore, there are need for these economic minerals to be delineated, to ascertain its shape, quantity and quality to make its exploitation economically feasible. Nowadays, Aeromagnetic surveys are very useful for determining the depth to magnetic sources over an area (that is sedimentary thickness of rocks/minerals).

Finally, the study used slope method analysis of aeromagnetic data to determine the depth to basement over Ugep and surrounding areas in Cross River State, Nigeria. By figuring out the sedimentary thickness, the interpretation should provide additional insight into the basin's actual structure. Along with establishing the structural features, it may also provide a true image of the Basin.

Location and Geology of the Area

The study area is bounded by latitudes 5º30'N to 6º00'N and longitude 8º00'E to 8º30'E. It is located within the southeastern part of Cross- River State and covers approximately 3,025 km^2. The area is accessible through major highway, Calabar-Ikom and Calabar-Ikang. Another major accessible route is the recently constructed road by Dangote Nigeria Limited close to Odukpani junction (round about).

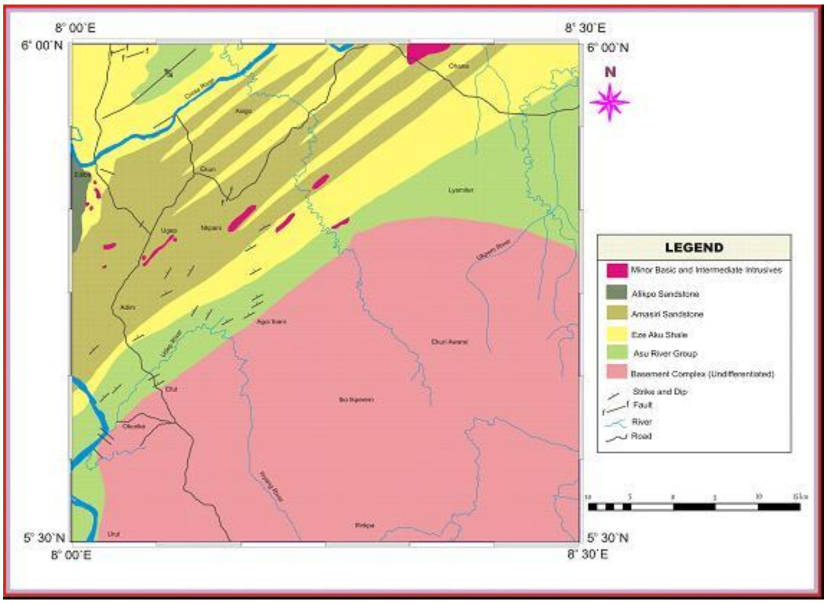


Fig. 1: Geological map of the study area

Geologically, the study area is part of the Calabar Flank which is characterized by crustal block faulting and is bounded by the Oban Massif to the north and the Calabar hinge line delineating the Niger Delta basin in the south. The area is underlain by three main sedimentary facies which include the Asu River Group (Albian –Cenomanian), Nkporo shale and the Eze –Aku Formation (Fig. 1). The oldest rock within the study area comprise of Precambrian basement rocks of Oban massif (Granite, genisses, banded gneisses, biotite, garnet, schist, quartz, diorite and porphyritic granites) according to Nwajide, 2013. These rocks are unconformably overlain by the Asu river group (Albian) which comprises of argillaceous sandy shale, laminated sandstones, micaceous sandstones, minor limestones with an interfingering of mafic volcanic (Nwajide, 2013). It represents the first and oldest cycle of shallow marine to brackish water sediments deposited on the basement complex. There has been reported presence of Cenomanian sediments and Santonian intrusives of dykes and sills extrusives.

Deposited on top of these Asu River Group sediments in the area where the Upper Cretaceous sediments, comprising mostly the Eze- Aku shales. The Turonian Eze – Aku shales consists of nearly 1000m of calcareous flaggy shales and siltstone, thin sandy and shaley limestones and calcareous sandstone indicating the renewal of marine deposition in the Benue Trough (Nwajide, 2013). Finally, the Nkporo Shales are the youngest unit of the Cretaceous sequence and overlies the Eze-Aku shales unconformably. They are Campanian –Maastrichtian in age and are mainly marine in character, with some sandstone intercalations. The Nkporo shale is the basal facies of the late Cretaceous sedimentary cycle in the Anambra basin. In the Calabar Flank, lateral persistent back shale faces can be identified. The sediments are normally associated with siderites and pyrites which are early diagenetic minerals (Nwajide, 2013).

Methodology

The aeromagnetic data of the study area comprises one NGSA data sheet of 1: 100, 000 that have 55x55 km (Sheet- 314 - Ugep) were transformed and displayed using various standard techniques. The methodology involved includes 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 analytical map, lineament map and Rose diagram were produced and interpreted. The Slope Method technique was found to be most suitable for depth to basement estimation in this study, and was adopted for the purpose. Peter's half slope method was used to estimate the depth to the magnetic source body. It is much simpler and faster and provide more depth estimate (Chinwuko *et al.*, 2012 and Ojo *et al.*, 2014). It is a theoretically based graphical approach to magnetic interpretation that uses a rule of thumb to estimate the depth to magnetic source.

According Ojo *et al.* (2014), the magnetic body is then assigned a specific index value ranging from about 1.2 to 2, depending on the objects size. The depth of the object is then obtained by dividing the horizontal distance by the index value. For this study, the depth to the magnetic body is given as:

$$h=1.6p$$

Where, h = Sedimentary thickness or depth to basement
P = distance between the tangency point.

Result and Discussion

Qualitative interpretation

The qualitative interpretation of aeromagnetic data directly illustrates geological information by looking at aeromagnetic maps without any calculations (Anakwuba and Chinwuko, 2012). A visual study of the magnetic maps can be fruitful for preliminary interpretation (Telford *et al.*, 1998). It entails critical examination of the total magnetic intensity, residual anomaly map in conjunction with the analytical map, shaded relief map and rose diagram in order to reveal magnetic signatures, closures and structural lineament within the study area.

Total magnetic intensity map

A 2D Total magnetic intensity map of the study area as shown in (Fig. 2) was generated using the surfer-32 software. It had values ranging from 7820 nT to 8120 nT. The Eastern and South Western part showed closely spaced and clustered contour patterns which could be indicative of igneous intrusion while the North Western portion of the map had sparse contours indicating thick sedimentary covers which means the depth to the basement would be higher here compared to the closely spaced contours in the Eastern and South Western parts which suggests shallow sedimentary thickness. The elliptical contour closures seen in the study area suggest the presence of magnetic bodies. The trend of the contours was in the NE-SW direction. A 3D surface plot of the study area was generated for better visualization (Fig. 3).

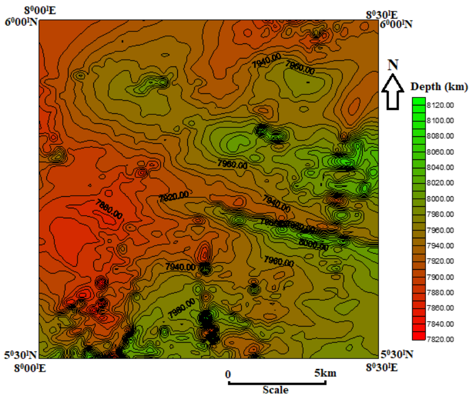


Fig. 2: Total magnetic intensity map of the study area (Contour interval ~10nT)

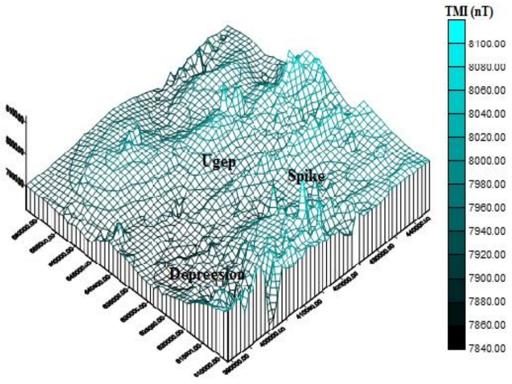


Fig. 3: 3D TMI surface plot of Ugep

Residual map

Visual inspection of the residual anomaly map revealed variation in magnetic field intensity throughout the study area. The residual magnetic intensity values had both positive and negative values ranging from -140 nT to 160 nT. Just like the Total magnetic intensity map, the Eastern and South Western part showed clustered contour patterns indicative of shallow depth to the basement while the widely spaced contours in the North Western portion of the map indicates deeper depth to basement (Fig. 4). A 3D surface plot of the residual map was also generated (Fig. 5).

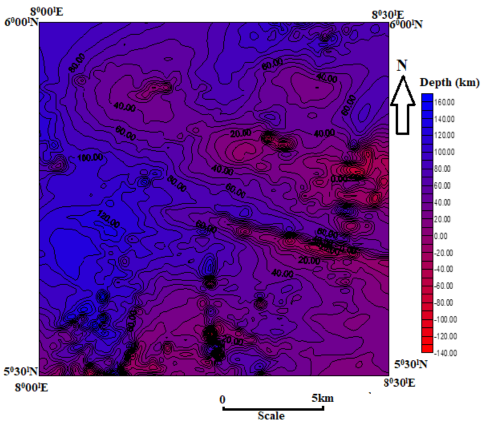


Fig. 4: Residual anomaly map of the study area (Contour interval ~10nT).

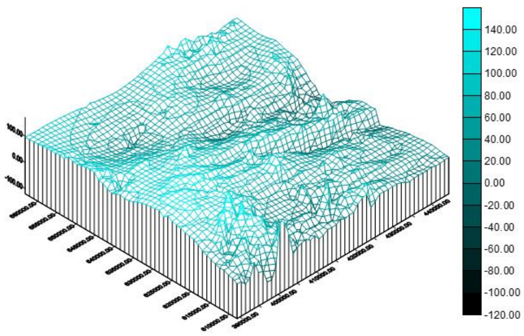


Fig. 5: Residual anomaly 3D plot of Ugep

Analytical map and Rose diagram

The analytical map revealed magnetic lineament\fracture zones in the study area (Fig. 6). Elliptical closures identified on the aeromagnetic maps represents geologic lineaments and their positions are indicated by drawing parallel lines in the direction of flow in the study area. The angle of the lineaments was determined. The major trend of the lineament was in the NE-SW direction while the minor trend was towards the NW-SE direction. More so, the rose diagram was produced using the lineament analysis based on the azimuth direction and frequency of the structural lineaments (Fig. 7). The lineament and statistical values were plotted using the GeoRose software package. The rose (azimuth-frequency) diagram depicts that the major structural trends in the area is in NE-SW with minor NW-SE (Fig. 7).

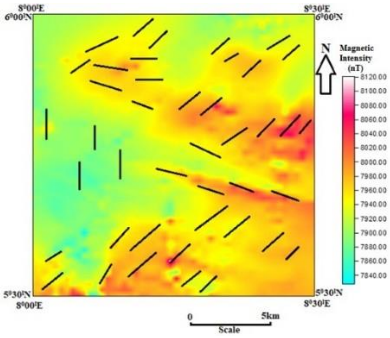


Fig. 6: Analytical map of the study area

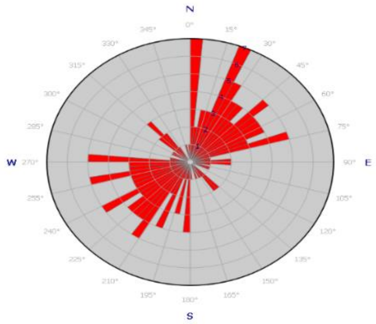


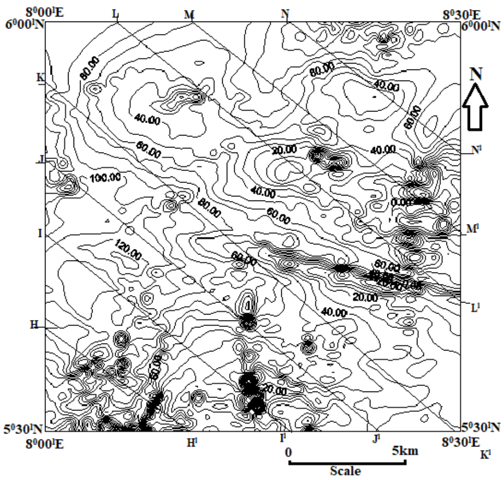
Fig.7: Rose diagram of the study area.

Quantitative interpretation

This involves in depth study of the map. The essence of quantitative interpretation is to obtain information about the depth to magnetic sources, its shape and size, and probably details about its susceptibility. The target during quantitative interpretation is the estimation of the depth to the basement. The graphical method was employed for this interpretation.

Magnetic profile

Depth estimation using Peter's half slope method can be achieved by taking selected profiles along the residual map. The profiles were perpendicular to the direction of the contours. Since the trend of the contours was in the NE-SW direction, the profiles were taken in the NW-SE direction. (Fig. 8). Seven (7) profiles (H-H^l, I-I^l, J-J^l, K-K^l, L-L^l, M-M^l, N-N^l) were drawn on the residual anomaly map of the study area.



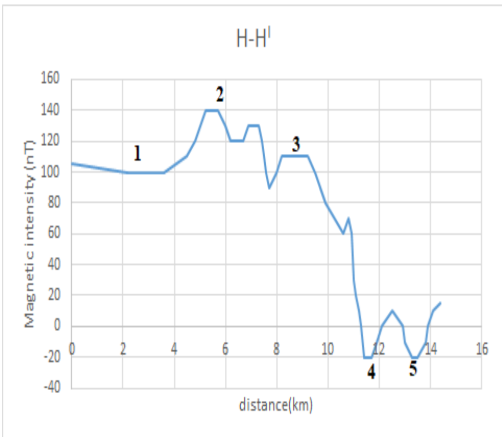


Fig. 8: Residual anomaly map with selected profile lines

Fig. 9: Magnetic profile of H-H^l

Depth to basement estimation using Peter's half slope method

Peter's Half-Slope method was used to estimate the depth to magnetic source body. It is much simpler and faster than other methods. The seven profiles selected revealed thirty (30) anomalous bodies across the profile lines (Fig. 9). The depth to basement obtained using

Peter's Half-Slope method ranges from 0.16 km to 4.8 km with an average of 2.05 km across the study area (Table 1).

Table 1: Estimation of depth to basement

Profiles	Depth (km)
H-H	3.68, 1.12, 1.44, 0.16 and 0.32
I-I	3.20, 1.92, 0.80 and 0.80
J-J	1.92, 1.6, 4.48 and 2.08
K-K	4.0, 4.0 and 3.2
L-L	2.4, 0.8, 0.8, 0.96, 1.6 and 2.4
M-	4.8, 2.08, 0.16, 0.48 and 1.92
N-N	3.04, 1.6 and 3.68

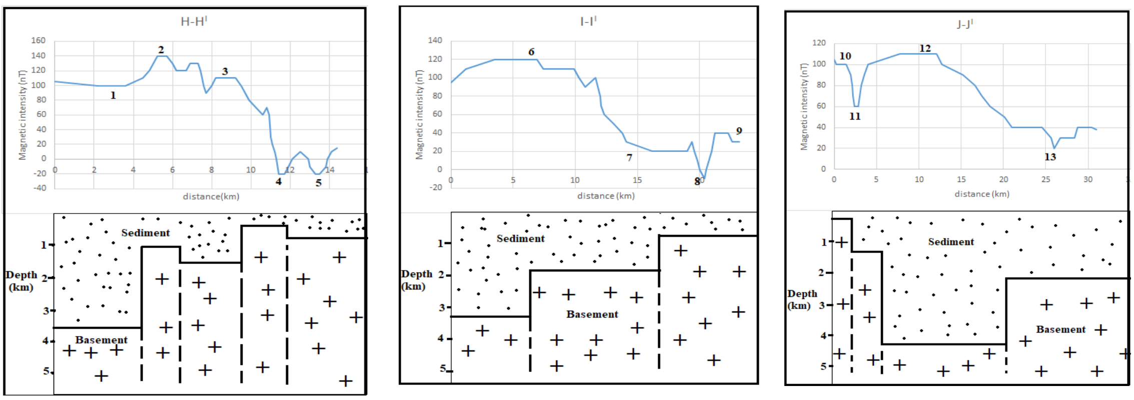
Geologic models

Geologic models for the magnetic anomalies were constructed. The details of the modelling can be seen below:

***Profile H-H^1*:** This profile passes through the southwestern part of the map. The maximum magnetic intensity value along this profile is 105nT and the minimum is -20nT. The depth values along this profile range from 0.16 km to 3.68km (Fig. 10a). The broad part of the curve indicates deeper magnetic source, while the sharp curves indicate shallow sources.

Profile I – I^1: The maximum magnetic intensity value along this profile is 95nT and the minimum value is -10nT. The depth values range along this profile is 0.80km to 3.20km (Fig 10b).

***Profile J-J^1*:** This profile cuts across the north-western, and south-eastern parts of the study area. The maximum magnetic intensity value along this profile is 105nT and the minimum value is 20nT. The depth values range along this profile is 0.1km to 4.48km (Fig. 10c).



(a) Profile H-H^1 *(b) Profile I-I^1* *(c) Profile J-J^1*

Fig. 10: Modeling of anomalies along some selected profiles across the study area

Basement Topography

The computed depths to basement was used to construct both the basement map and the 3D surface map for the basement topography of the area (Fig. 11.). This gives the basement configuration as well as the sedimentary thicknesses within the study area The Northwestern part of the map had greater depth to basement compared to other areas.

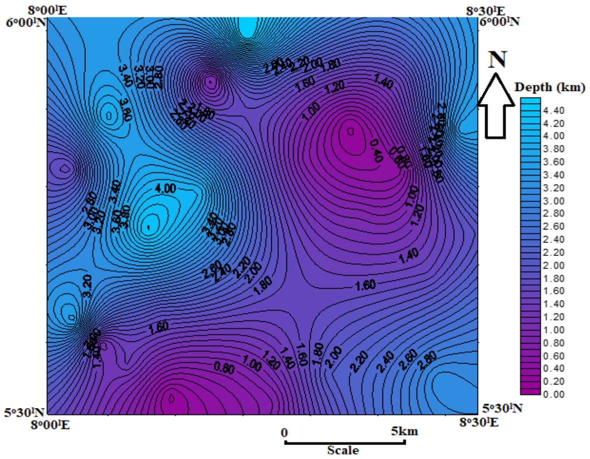


Fig. 11: Depth to basement map of the study area (Contour interval ~0.1 nT).

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 (Chinwuko *et al.*, 2023; Anakwuba and Chinwuko, 2014). 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 2.05 km 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 up to 2.1 km (Table 1). The results also show the variability of the underlying basement depths in the study area being part of Calabar Flank, depicting a basement configuration that has been supported by earlier works such as Okeke *et al.* (2020). Thus, the sedimentary cover within the study area is generally high which increases towards the northern parts and therefore may support hydrocarbon formation (Fig. 12). The 3D surface plot of the basement map indicates the presence of depression and uplift which can favour hydrocarbon formation (Fig. 12). Actually, any hydrocarbon prospective sediment must have a good quality source rock, good reservoir and seal lithologies, favourable regional pathways and trapping mechanisms.

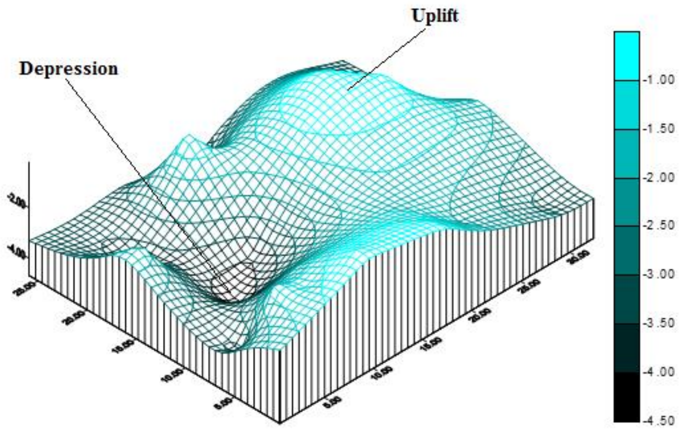


Fig. 12: 3D surface plot for basement topography of the study area.

Conclusions

The following conclusion were drawn after the interpretation:

1. Visual studies of the total magnetic intensity map and residual anomaly map revealed the magnetic intensity values of the study area ranging from 7820 nT to 8120 nT and -140 nT to 160 nT.
2. The area is intensely fractured with major faults trending in NE-SW direction and minor fault tending in the NW-SE direction.
3. Seven selected profiles revealed thirty (30) anomalous bodies across the profile lines.
4. The depth to basement obtained using Peter's Half-Slope method ranges from 0.16 km to 4.8 km with an average of 2.05 km across the study area.
5. The basement map generated revealed the basement configuration as well as the sedimentary thicknesses within the study area.
6. 3D surface plot of the basement map indicates the presence of depression and uplift which can favour hydrocarbon formation.

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 poster presentation at AAPG Annual Convention and Exhibition, Long Beach, California,16p.

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., Benedict, O.M., Obiajulu, O. O., Udoh, A. C., Okeke, G. C., and Umeh, M.C. (2023). Testing the Use of Aeromagnetic Data for the Determination of Depth to Magnetic Bodies in Nkalagu and Environs. Journal of Basic Physical Research, 11 (1): 23-32.

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.

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

Ojo, A.O., Omotoso, T.O., Adekanle, O.J. (2014). Determination of Location and Depth of Mineral Rocks at Olode Village in Ibadan, Oyo State, Nigeria using Geophysical Methods. International Journal of Geophysics, 4: 1-11.

Okeke, S.O., Onwuegbuche, A.A., Chinwuko, A.I., and Okonkwo, C.C. (2020). Interpretation of Aeromagnetic Data over the Nigerian Sector of the Mamfe Basin. Journal of Physics & Optics Sciences, vol, 2, no. 4, pp. 1-6.

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.

Telford, M., Geldart, L.P., and Sheriff, R.E. (1998). Applied Geophysics. 2nd Edn., Cambridge University Press, USA, pp: 113-114.

Ugwuoke, C.C., and Chinwuko. A.I. (2023) Mapping the Subsurface Structures and Sedimentary Thicknesses in Parts of Middle Benue Trough, Nigeria Using Interpretation of Aeromagnetic Data. Journal of Basic Physical Research, 11(1): 77-89.

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.