

# Aeromagnetic Investigation of the Subsurface Structures in Parts of Bayelsa State, Nigeria

Olorogun D. <sup>1</sup>, Adedokun I. O. <sup>2</sup>, Lawrence J. I. <sup>3</sup>, Udensi E. E. <sup>4</sup>

<sup>1, 2</sup>, Department of Physics, Niger Delta University Wilberforce Island Bayelsa State Nigeria.

<sup>3, 4</sup>, Department of Physics, Federal University of Technology, Minna, Niger State, Nigeria.

## ABSTRACT

The aeromagnetic study presented here covers 4° to 5° N latitude and 5.30° to 6.30° E longitude in the Niger Delta region. The Reduced to Equator (RTE) magnetic map offers a spatial visualization of magnetic field variations, with high-intensity magnetic intensities in the east-central and south-western sectors suggesting the presence of magnetite-rich mafic or ultramafic rocks, while low-intensity zones in the west-central region likely indicate non-magnetic sedimentary layers or deep basement rocks. This differentiation aids in interpreting subsurface lithology's and geological boundaries. Depth estimation techniques, including Euler DE convolution, with depth ranging from 1000 m to 7500 m, Source Parameter Imaging (SPI), and Spectral Analysis, in the study further elucidate the structural and stratigraphic framework. SPI reveals source depths exceeding 3.0 km, suggesting significant sedimentary cover crucial for hydrocarbon generation. Spectral analysis indicates magnetic basement depths ranging from 2.9 km to over 5.3 km, particularly in central and south-eastern sectors, highlighting potential hydrocarbon-rich sedimentary basins. The First Vertical Derivative (FVD) map shows passage of the Charcot paleo-fracture zone through the area. However, there are no outstanding minor fault to indicate that the paleo fracture is still active. These datasets enhance the geological understanding of the region, identify structurally controlled basins, and delineate favourable zones for hydrocarbon exploration and development in the Niger Delta.

## KEYWORDS

Aeromagnetic survey, magnetic basement, structural mapping, Spectral Analysis

## I. INTRODUCTION

Aeromagnetic surveying has become one of the most efficient geophysical techniques for delineating subsurface geological structures in sedimentary basins. Variations in the Earth's magnetic field often correspond to differences in lithology, faulting, or intrusions within the basement. Mapping these variations helps infer the depth, geometry, and tectonic framework of underlying rocks.

Measurements involving the use of magnetic survey are used in evaluating the magnetic field at any point on the Earth's surface. The method is non-destructive and measures the susceptibility contrast of subsurface rocks. By delineating the subsurface structures due to the difference in susceptibility, geologic inferences or interpretations which include delineation of faults, folds, lithology and depth can be made. Determination of depth to

causative magnetic sources or the sedimentary thickness is primarily a topic of research by geophysicists within the study area and environs for many years [26]. The aeromagnetic data has proved to be very useful in delineating the structural architecture as well as the depth to the basement.

Aeromagnetic method has become a very important reconnaissance tool for subsurface structural Characterization, lineament mapping, and mineralization studies. The surveys have provided, for example, preliminary insights by mapping regional and local structural frameworks that control groundwater accumulation, such as fractures, faults, and lineaments, which are difficult to resolve through resistivity method alone. In parts of South-western Nigeria, and have used aeromagnetic data to reveal structural trends, deep-seated fractures, and mineralized veins with direct hydrogeological implications, and at the same time confirming that radiological hazards in such terrains remain below global thresholds. Detection of geological lineaments (geological boundaries, contacts, fractures, and faults) and their orientation can effectively be established by employing geophysical techniques. Amid the airborne techniques, the aeromagnetic technique has been confirmed to have the utmost resolution to the delineation of structural. Remarkable improvements in magnetic data analysis and interpretation, in addition to the geological information, have enhanced the understanding of linear features and their distribution patterns. This has led to a better prospect of accurately mapping structures, detecting mineral and hydrothermal resource deposits.

The Niger Delta Basin in southern Nigeria is a vast sedimentary province formed during Late Cretaceous to Recent time as a result of rifting and subsequent subsidence following the separation of the African and South American plates. The basin is composed of three main lithostratigraphic units, the Akata, Agbada, and Benin Formations, whose interplay controls hydrocarbon generation and accumulation. Bayelsa State occupies a central position in the Delta and contains numerous oil fields that rely on accurate understanding of subsurface structures. Previous aeromagnetic studies in neighbouring areas have mapped the regional basement configuration and major fault zones. However, there remains limited high-resolution coverage focusing specifically on Bayelsa State. This study therefore applies detailed aeromagnetic data processing and interpretation to determine the magnetic basement relief, identify lineaments, and evaluate sedimentary thickness across the area. The ultimate aim is to enhance geological and hydrocarbon exploration models for the region. The aeromagnetic interpretation of the study area has provided a preliminary but coherent framework for understanding subsurface structural controls on groundwater occurrence.

## **II. LITERATURE REVIEW**

### *A. Geological Setting*

The Niger Delta Basin developed on a rifted continental margin during the Late Cretaceous. Its evolution was influenced by pre-existing fractures in the Benue Trough and the South Atlantic transform systems. The Delta comprises thick sequences of marine shale's, sandstones, and unconsolidated alluvial deposits exceeding 12 km in total thickness. The geology of the Niger Delta has been described in detail by various authors and they



### III. STUDIES AND METHODS

#### A. *Data source and coverage*

Aeromagnetic data covering parts of Bayelsa State were acquired from the Nigerian Geological Survey Agency (NGSA). The aeromagnetic data presented are part of the Nigeria's nation-wide high-resolution geophysical data project. The dataset from airborne magnetic survey was recorded at a flight altitude of 80 m and flight-line spacing of 500 m. The study area extends between latitudes 4°45' N and 5°30' N and longitudes 6°00' E to 6°45' E, encompassing approximately 6940 km<sup>2</sup> area.

#### B. *Data processing*

The magnetic method is popularly used because of its ease and cheap approach for detecting near-surface lineament. However, certain rocks have magnetic content to produce reasonable magnetic anomalies. The data interpretation that shows differences of rock magnetization present on a local scale is principally helpful for detecting lineaments (faults and geologic contacts) Data pre-processing and enhancement were carried out using Oasis montaj and Geosoft software packages. Processing steps included:

- [1]. **Gridding and Filtering:** The raw total magnetic intensity (TMI) data were interpolated to a 250 m grid using minimum-curvature gridding. The Reduction to the Magnetic Equator (RTE) filter was also applied to the Total Magnetic Intensity (TMI) data to correct for asymmetry in magnetic anomalies caused by low magnetic inclination (0 – 20°) peculiar to equatorial regions.
- [2]. **Reduction to Equator (RTE):** The RTE transformation re-centres anomalies over their causative bodies to allow a more accurate delineation of subsurface structures the study area lies close to the magnetic equator, RTE so transformation was applied to centre magnetic anomalies directly over their causative bodies.
- [3]. **Spectral Analysis:** Spectral analysis of the aeromagnetic data was conducted to estimate source depths and assess the vertical distribution of magnetized bodies within the study area. The method employs the radial power spectrum technique, wherein the Fourier transform converts spatial magnetic anomaly data into the frequency domain, allowing the slope of distinct spectral segments to be related to the depth of their causative sources. Two-dimensional fast Fourier transform (2D-FFT) was used to separate deep and shallow magnetic components and estimate average depths to basement.
- [4]. **First vertical-derivative:** Derivatives (vertical) are based on the principle that the rates of change of magnetic field are sensitive to rock susceptibilities near the ground surface than at depth. First vertical derivative is physically equivalent to measuring the magnetic field simultaneously at two points vertically above each other, subtracting the data and dividing the result by the vertical spatial separation of the measurement points. The first vertical derivative is employed to enhance magnetic signatures. It pinpoints near-surface magnetic sources by magnifying their anomalies and eliminating regional magnetic trends, making it simpler to identify localized anomalies. Additionally, the FVD is used to detect high-frequency

structures more confidently, particularly if they are covered by high amplitude and low-frequency anomalies.

- [5]. 2D Euler DE convolution: Euler DE convolution is a data enhancement technique for estimating location and depth to magnetic anomaly source. It relates the magnetic field and its gradient components to the location of the anomaly source with the degree of homogeneity expressed as a structural index and is a suitable method for delineating anomalies caused by isolated and multiple sources. The Euler DE convolution is a process of inversion by least squares, from which the anomalous magnetic field values and of one selected structural index aim to solve the Euler equations, generating brief solutions for the depth and Structural Index. Estimating depth to magnetic anomaly using Euler DE convolution involves: Reduction to the pole, calculation of horizontal and vertical gradients of magnetic field data, (in frequency domain), choosing window sizes and Structural Index. The aeromagnetic anomaly map (magnetic signature map) and the Euler solutions helped in identifying the nature, trend and depth of the magnetic source in these locations. This method has been on the increase with the use of Euler DE convolution method. The Euler DE convolution has become a popular choice because the method assumes no particular geological model and has quick means of turning magnetic field measurements into estimates of magnetic source body location and depth. Euler solutions with a structural index of 0 were used to compute localized depths and confirm fault geometries.

#### C. *Interpretation approach*

Interpretation involved visual correlation between filtered anomaly maps and computed depth results. Magnetic lows were interpreted as thick sedimentary zones or depocentres, while magnetic highs corresponded to uplifted basement or igneous intrusions. Lineaments identified on derivative maps were interpreted as faults or fracture zones.

### **IV. FINDINGS AND RESULTS**

#### A. *Total Magnetic Intensity (TMI) Map*

The TMI map, Figure 2, displays magnetic intensity values ranging from about -80 nT to +160 nT. The magnetic anomaly patterns show alternating high and low zones trending NE-SW and NW-SE. The central portion around Yenagoa records relatively low magnetic intensity, indicating thicker sedimentary cover, whereas northern and south-eastern zones near Ogbia exhibit higher intensity due to shallow basement.

#### B. *Reduced to Equator (RTE) Magnetic Map*

Figure 3 shows the Reduced to Equator (RTE) magnetic intensity map. It provides an enhanced view of the subsurface magnetic intensity distribution that corrected inclination and declination of the Earth's magnetic field so as to simulate measurements taken at the

magnetic equator. Reduction to the equator is used in low magnetic latitudes to centre the peak of magnetic anomalies over their sources, enhancing basement architecture including structural lineaments with its orientations thereby making the data easier to interpret without losing any geophysical meaning.

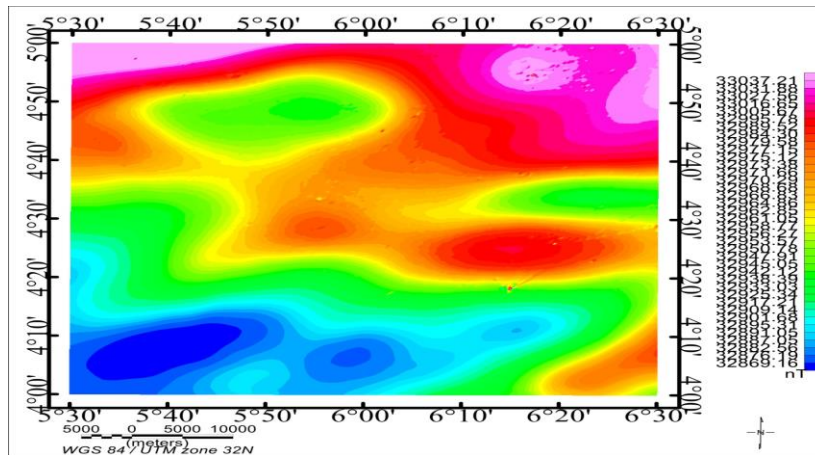


Figure 2: Map of the study area

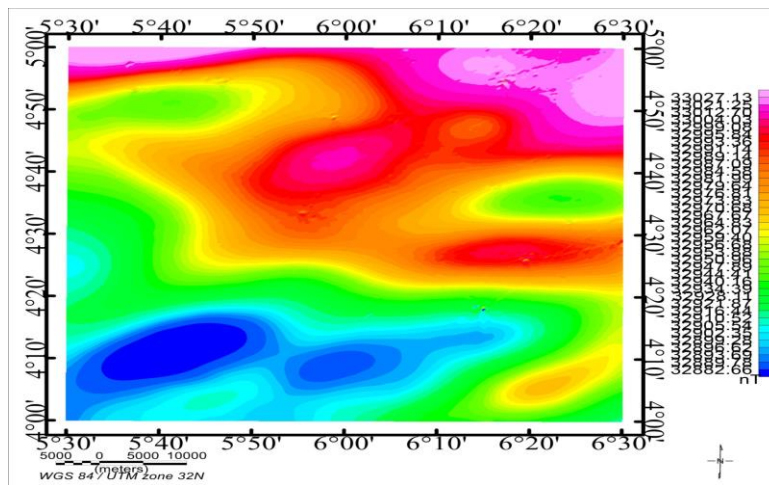


Figure 3: Map of the study area

C. Spectral Analysis Results

Radially averaged power spectra of the residual magnetic field were computed for different sub-areas, Figure 4. Two distinct depth sources were identified: Deep magnetic sources: mean depths between 7.5 km and 12.0 km, representing the magnetic basement surface. Shallow magnetic sources: mean depths of 1.0 km to 2.8 km, attributed to near-surface ferruginous formations or intrusive bodies. The variation in basement depth indicates strong structural control, with deeper sections forming sedimentary depocentres and shallower zones corresponding to basement highs.

D. Euler DE convolution Solutions

Euler depth solutions complement spectral estimates. Depths range from 4.2 km to 11.8 km, aligning well with spectral results, Figure 5. Fault planes derived from cluster trends confirm NE–SW-oriented regional faults and NW–SE cross-faults that subdivide the basin into structural blocks.

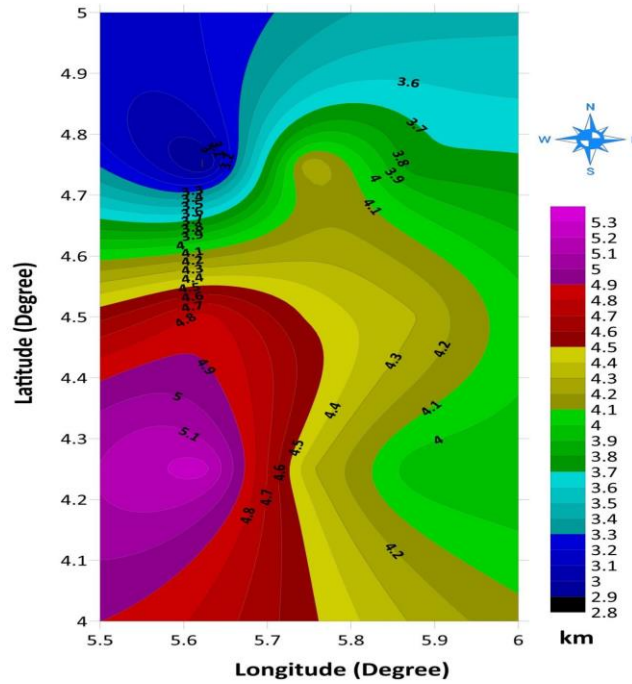


Figure 4: Spectral Analysis Map

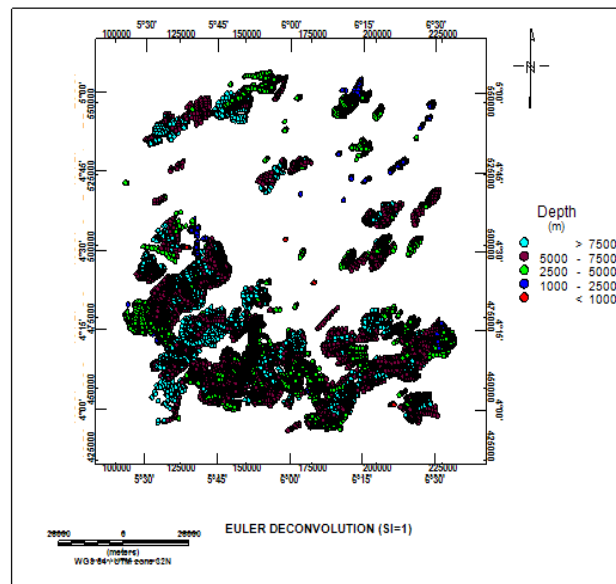


Figure 5: Euler DE convolution Map

### E. Derivative Maps and Lineaments

Figure 6, the First vertical-derivative map enhances short-wavelength anomalies corresponding to near-surface features. Several linear features were delineated, most trending NE–SW, NW–SE, and E–W. These lineaments correspond to basement faults, fracture zones, and possibly igneous dykes. The analytical-signal amplitude map shows strong amplitude zones marking edges of magnetic bodies. The tilt-derivative map reveals intersecting fault trends forming structural closures and potential hydrocarbon traps.

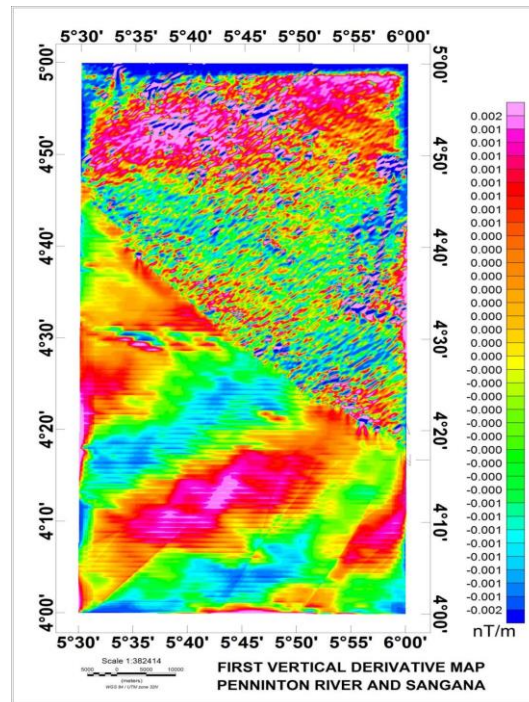


Figure 6: First Vertical Derivative Map (FVD)

## V. CONCLUSION

The aeromagnetic interpretation reveals that Bayelsa State is structurally complex, reflecting multiple tectonic phases associated with the evolution of the Niger Delta. The observed NE–SW and NW–SE magnetic trends correspond to the major fault systems controlling deltaic subsidence and sedimentation. These directions are consistent with the orientation of the continental fracture zones in the underlying Precambrian basement [30]. Tectonic implications and Hydrocarbon potential: The coincidence of magnetic lineaments with mapped surface lineation suggests reactivation of basement faults during delta procreation. The deep NE–SW faults appear to extend through the entire sedimentary column, functioning as zones of weakness for hydrocarbon migration. NW–SE cross-faults act as compartment boundaries, possibly explaining localized variations in oil field productivity across Bayelsa State. Sedimentary thickness exceeding 10 km in the Amassoma and Sagbara areas indicates high geothermal gradients favourable for source-rock maturation. The intersection of NE–SW and E–W faults creates rollover anticlines and structural closures ideal traps for hydrocarbon accumulation. Magnetic basement highs near Ogbia and Kaiama may represent uplifted blocks that served as migration pathways or trap boundaries. The results support earlier seismic interpretations that proposed multiple

petroleum systems within the Niger Delta Basin. Thus, integrating aeromagnetic data with seismic and well logs can refine subsurface models and optimize exploration drilling.

The aeromagnetic investigation of parts of Bayelsa State, Nigeria, has provided a comprehensive view of the subsurface structural framework and basement morphology. The major conclusions are summarized as follows:

Magnetic anomaly trends predominantly NE–SW and NW–SE indicate strong basement structural control consistent with regional tectonic patterns. Depth-to-basement estimates range from about 5 km to 12 km, signifying thick sedimentary sequences favourable for petroleum generation. Derivative and analytical-signal maps delineate numerous lineaments interpreted as faults and fracture zones that serve as hydrocarbon migration pathways. Sedimentary depocentres around Amassoma and Sagbara represent potential targets for further geophysical and drilling investigations. Integration of aeromagnetic results with seismic and gravity data is recommended for robust subsurface interpretation.

## ACKNOWLEDGEMENT

The Authors hereby express our gratitude to the Management of Nigerian Geological Survey Agency for the prompt release of Aeromagnetic data used in this research and which actually made the project possible. We also thank Dr. Francis Omonefe of Department of Geology, Federal University Otuoke, Bayelsa State Nigeria, for providing the map of the study area at no cost or charges.

## REFERENCES

- [1] Abraham, E. M., Lawal, K. M., Ekwe, A. C., Alile, O., Murana, K. A., and Lawal, A. A., 'Spectral analysis of aeromagnetic data for geothermal energy investigation of Ikogosi Warm Spring, Ekiti State, Southwestern Nigeria', *Geothermal Energy*, vol.2, no.1, pp 6. 2014
- [2] Abdullahi, M., Valdón, Y. B., Andrew, F.P. and Idi, Y.B., 'Curie Depth and Surface Heat estimation from anomalous Magnetic blocks in the lower and part of Middle Benue trough and Anambra basin'. *Earth and Planetary Science*.vol. 2, no. 1, 2023.
- [3] Adebayo, O., and Eze, C., 'Application of aeromagnetic data in delineating structural features of the Niger Delta Basin', *Journal of African Earth Sciences*, 179, 2021.
- [4] Ademila, O., 'Aeromagnetic characterization of parts of Ondo and Ekiti States, Southwestern Nigeria', *Environmental and Earth Sciences research Journal*, vol.4, no.3, pp 66 -75.
- [5] Al-Badani, M. A. and Al-Wathaf, Y. M., 'Using the aeromagnetic data for mapping the basement depth and contact locations, at Southern part of Tihamah region, Western Yemen' *Egyptian Journal of Petroleum*, vol.27, pp485-495, 2018.
- [6] Allen; J.R.L., Late Quaternary Niger Delta and adjacent areas. *American Association of Petroleum Geologists Bulletin*, vol. 49, no.5, pp. 547-600, 1965.
- [7] Blakely, R. J., 'Potential Theory in Gravity and Magnetic Applications', Cambridge University Press. 1995.
- [8] Cooper, G.R.J and Cowan, D. R., 'Enhancing potential field data using filters based on the local phase', *Computer Geosciences*, vol.32, pp.1585-1591, 2006.
- [9] Doust, H. and Omatsola, E., 'Niger Delta in Edwards, J. D. and Santogrossi, P. A. (Eds.), *Divergent/Passive Margins Basins*', *American Association of Petroleum Geologists memoir*, vol.48, pp.239-248, 1990.

- [10] Ekpa, B., Anigbo, E., and Ijeoma, C., "Integration of geophysical methods for mapping subsurface structures in the Niger Delta", *Nigerian Journal of Applied Geophysics*, vol.7, no.2, pp.45-59, 2020.
- [11] Ekweozor, C. M. and Daukoru, E. M., "Petroleum source bed evaluation of Tertiary Niger Delta", *American Association of Petroleum Geologists Bulletin* vol.68, pp. 390 - 394, 1984.
- [12] El Dawi, M.G., Tianyou, L., H Shi, and Dapeng, L., "Depth estimation of 2-D magnetic anomalies by using Euler deconvolution method", *American Journal of Applied Sciences*, vol.1, no.3, pp, 209-214, 2004.
- [13] Eze, O. E., Ekwok, S.E., Thompson, C. E., Odey, E. I., Okiwelu, A. A., Abdelrahman, K., Fnaiss M.S., Andráš, P. and Eldosouky, A.M.. "Deciphering aeromagnetic data for sustainable Massif sedimentary and structural insights in Obudu Plateau, Ikom Mamfe embayment and Oban Southeastern Nigeria", *Scientific Reports*, 2025.
- [14] Gilbert, D and Geldano, A., "A computer programme to perform transformations of Gravimetric and aeromagnetic surveys. *Computers and Geosciences*, vol.11 pp.553-588, 1985.
- [15] Gustafson, C., Key, K., and Evans, R. L., "Aquifer systems extending far offshore on the US Atlantic margin", *Scientific Reports*, 9(1), 8709, 2019.
- [16] Isaac, O.A., Auduson, A.E., Ologe, O. and Oladipupo, J.T., "Aeromagnetic characterization of subsurface structures and their hydrogeological significance for groundwater exploration in parts of Lokoja, North Central Nigeria", *Research Square*, 2025.
- [17] Kolawole T., Azeez J., Akande M. E. and Aremu, O. A., "Analysis and interpretation of aeromagnetic data over part of Ibadan, Southwestern Nigeria using advanced interpretation techniques" *Global Scientific Journal*, vol.11, no.4, 2023.
- [18] Knight, R., Smith, R., Asch, T., Abraham, J., Cannia, J., Viezzoli, A., and Fogg, G., "Mapping aquifer systems with airborne electromagnetics in the central valley of California", *Groundwater*, vol.56 no.6, pp.893-908, 2018.
- [19] Lawal, S., and Ojo, K., "Magnetic signature analysis of the Niger Delta basin using high resolution aeromagnetic data", *Frontiers in Earth Science*, vol.10, 1568232, 2022.
- [20] Nabighian, M. N. Grauch, V. J. S. Hansen, R. O. LaFehr, T. R. Li, Y. Peirce, J. W. Phillips, J.D. and Ruder, M. E., "The historical development of the magnetic method in exploration", *Geophysics*, vol. 6, pp.33-71, 2005.
- [21] Nnaemeka, E. K., Obiora, D. N. and Ibuot, J. C., "Structural interpretation and depth to the magnetic basement, using Aeromagnetic data of Nkalagwu and Abakaliki areas, Southeastern Nigeria", *International Journal of Earth Science Geophysics*, vol.7, 54, 2021.
- [22] Pawan, D., Ramprasad, T., Ramana, M. V., Desa, M. and Shailaja, B. "Automatic Interpretation of magnetic data using Euler deconvolution with nonlinear background", *Pure and Applied Geophysics*, vol.164, pp.2359-2372, 2007.
- [23] Reyment, R.A. (1965). "Aspects of the Geology of Nigeria", University Press, Ibadan.
- [24] Rustadi, R., Opik Tauifik, P., and Darmawan, I., "Optimizing groundwater Aquifers potential in the development of irrigation Wells for Agriculture using Geo-Electrical method", *Journal of Engineering and Scientific Research*, vol. 2, no. 1, pp.43-52, 2020.
- [25] Seurey, P, Githiri, J.G., and Ambusso, W. J., "Application of Euler deconvolution and Forward modeling techniques in estimating depth to magnetic structure in Lake Baringo Area, in the Kenyan Rift", *Journal of Applied Geology and Geophysics*, vol. 4, no.3.pp.63-72, 2016.
- [26] Suleiman, T., Okeke, F.N. and Obiora, N. D., Interpretation of aeromagnetic data over some parts of Sokoto Basin, Nigeria, using source parameter imaging and 3D Euler de-convolution methods. *International Journal of Physical Sciences*, 2020.

- [27] Tuttle, M.L.W., Charpentier, R.R. and Brownfield, M.E., "the Niger Delta Petroleum System: Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa. United State Geological Survey", Open-File Report, 7-14, 1999.
- [28] Uwiduhaye, J. D., Ngaruye, J. C. and Saibi, H., "Defining potential mineral exploration from the interpretation of aeromagnetic data in Western Rwanda" *Ore Geology Review*, 128, 103927, 2021
- [29] Whiteman, A.J. "Nigeria: Its Petroleum Geology, Resources and Potential". Graham and Trotham, London. 1982.
- [30] Zubair, A., and Alimi, A. "Structural framework and tectonic evolution of the Niger Delta Basin", *Journal of Petroleum Geology*, vol. 43, no. 1, pp.31-49, 2020.