Aeromagnetic Investigation of the Subsurface Sturctures in Parts of Niger Delta, Nigeria

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DOI: https://doi.org/10.51584/IJRIAS.2026.11010006

Received: 29 December 2025; Accepted: 09 January 2026; Published: 20 January 2026

ABSTRACT

The geophysical interpretation of Aeromagnetic data over the study area bounded by longitude 4°00′–5°00′ and latitude 5°30′–6°30′ provides crucial insights into the subsurface geological configuration, with significant implications for hydrocarbon exploration. Reduced-to-Equator (RTE) map reveals magnetic values ranging from 32,869.16 nT to 33,037 nT, reflecting the influence of subsurface lithology and tectonic structures. High magnetic intensities in the East–central and South Western part of the map, often correlate with the presence of ferromagnetic minerals, such as magnetite-rich mafic and ultramafic rocks, suggesting potential igneous intrusions or lithological boundaries, the lower magnetic zones, illustrated in blue west–central part of the map, indicate nonmagnetic sedimentary units, deep basement rocks, or zones of weathering and alteration. The high magnetic intensity closures observed within the basin are likely associated with the underlying basement rocks or with igneous intrusions that may have penetrated the sedimentary sequence. Depth estimation techniques such as Euler Deconvolution utilize a structural index (SI = 1) to delineate linear geological features like faults and dykes, with clustered solutions indicating complex basement architecture. Source Parameter Imaging (SPI) analysis estimates source depths exceeding 3.0 km, confirming the presence of thick sedimentary basins critical for hydrocarbon maturation. Spectral analysis indicates basement depths between 8.7 and 11.6 km, with deeper zones concentrated centrally and southeast part, aligning with potential depocenters. The First Vertical Derivative (FVD) map indicates the passage of the paleo-fracture zone through the area. This is also indicated in the discontinuity shown in the Total Magnetic Intensity (TMI) map. These datasets improve the geological interpretation of the region, reveal structurally controlled sedimentary basins, and help outline prospective zones for hydrocarbon exploration and development within the Niger Delta.

Keywords: Aeromagnetic survey, Paleo-fracture zone, Total Magnetic Intensity, Reduced-to-Equator, Spectral analysis.

INTRODUCTION

The Niger Delta, located in southern Nigeria, is one of Africa's largest and most economically important sedimentary basins. It hosts substantial petroleum resources that have sustained Nigeria's economy for decades. Understanding its subsurface architecture is crucial for optimizing hydrocarbon exploration and sustainable field development.

Aeromagnetic investigation is a non-invasive geophysical technique that measures spatial variations in the Earth's magnetic field caused by contrasting magnetic susceptibilities of subsurface rocks. In sedimentary environments such as the Niger Delta, where seismic imaging can be limited by thick alluvial cover, aeromagnetic surveys provide valuable regional insight into basement topography, fault systems, and structural controls on sedimentation.

Previous studies by [1] and [5] have demonstrated that integrating aeromagnetic data with gravity and seismic information improves geological models of the Niger Delta. However, gaps remain in understanding how magnetic signature trends and basement morphology influence hydrocarbon generation and entrapment. This research addresses these gaps through a comprehensive aeromagnetic interpretation of selected areas within the eastern and central Niger Delta.

Geological Setting of the Niger Delta

The Niger Delta Basin developed during the Late Cretaceous rifting that separated the African and South American plates in the late Jurassic era that gave birth to the development of massive continental margins of West Africa and the Benue Trough [7]. Marine sedimentation began to evolve in the early Tertiary times [2] and over the years has prograded a distance of more than 250 km from the Benin and Calabar flanks to the present delta front, controlled by syn-sedimentary faults, folding and subsidence with sediment supply mainly from the Niger, Benue and Cross Rivers accumulating up to 12, 000 m thickness in some regions [4].

The basin comprises three major lithostratigraphic units: the Akata, Agbada, and Benin formations. The Akata Formation, at the base of the Delta, is of marine origin and is composed of thick shale sequences (potential source rock), turbidite sand (potential reservoirs in deep water), and minor amount of clay and silt. Thin sandstone lenses occur near the top particularly near contact with the overlying Agbada Formation. Beginning in the Paleocene and through the Recent, Akata formation formed during low stands when terrestrial organic matter and clays were transported to deep water areas characterized by low energy conditions and oxygen deficiency [8]. It is believed to have been deposited in a front of the advancing delta and ranges from Eocene to Recent. Little of the formation has been drilled, therefore, only a structural map of the top of the formation is available. It is estimated that the formation is up to 7,000 metres thick [2].

Deposition of Agbada Formation, the major petroleum-bearing unit, began in the Eocene and continues into the Recent. It is parallic in origin, indicated by coarseness of the grains and poor sorting. The formation consists of paralic siliciclastics over 3700 metres thick and represents the actual deltaic portion of the sequence. Major hydrocarbons are fund in the intervals between Eocene and Pliocene age. In the lower Agbada Formation, shale and sandstone beds were deposited in equal proportions, however, the upper portion is mostly sand with only minor shale interbeds [6].

The Benin Formation, which outcrops within the Niger Delta constitutes the critical lithologic unit within the study area. It is made up of sands and sandstones with clay intercalation representing the youngest continental deposits and forming important aquifers. The Benin formation extends from the West across the whole of Niger Delta area and Southward beyond the present coastline. It is an extensive stratigraphic units in the Southern Nigeria sedimentary basin with a thickness of about 1414.3m (4667ft) [6].

Structurally, the delta is dominated by growth faults, rollover anticlines, and diapiric structures created by sediment loading and shale mobility. These features define hydrocarbon traps across the basin. Basement highs and troughs further control sediment thickness and maturation of source rocks [3].

METHODOLODY

High-resolution aeromagnetic data covering approximately 12,000 km² were obtained from the Nigerian Geological Survey Agency (NGSA). The area lies between latitudes 5.09° N–5.70° N and longitudes 6.19° E–6.64° E, encompassing Kwale, Aboh, Patani, and Ahoada, Figure 1.

Data preprocessing involved removal of noise and correction for diurnal and regional magnetic field variations. The following filters and transformations were applied:

i) Reduction to Equator (RTE): To centre anomalies above their sources in this low-magnetic-latitude region.

INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN APPLIED SCIENCE (IJRIAS)
ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue I January 2026

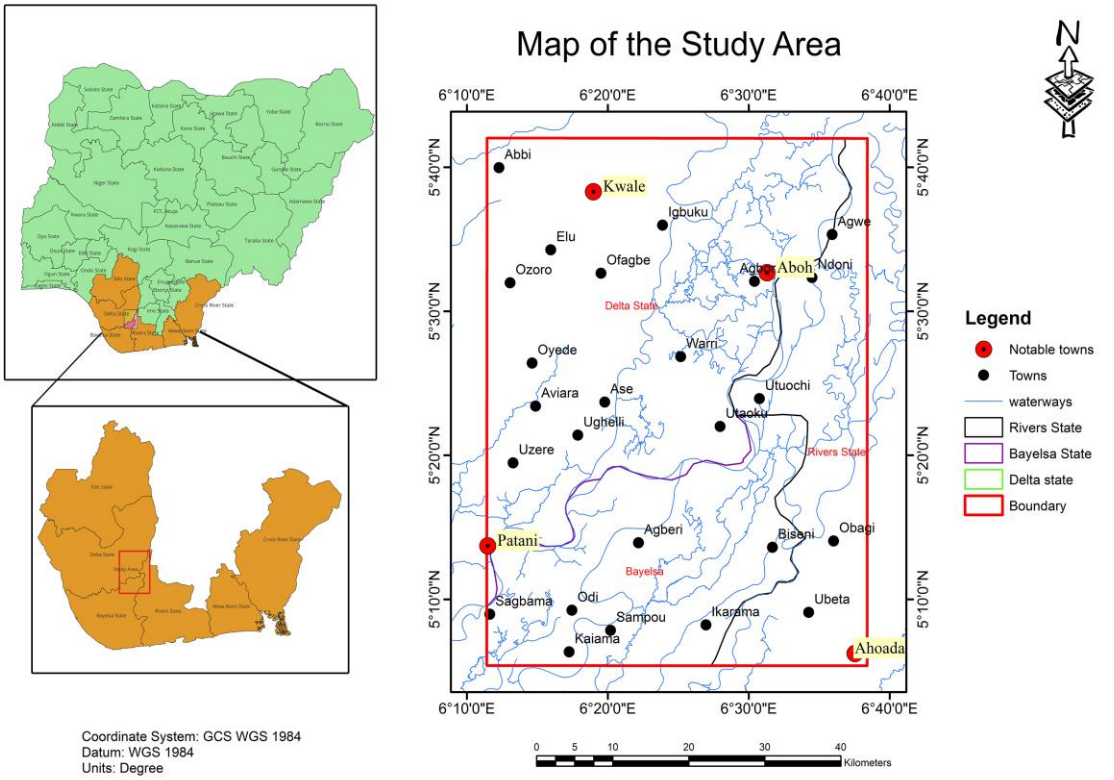

Figure 1: Map of the study area

ii) First-Vertical and Horizontal Derivatives: To enhance shallow features and highlight structural discontinuities.

iii) Spectral Analysis: To estimate average depths to magnetic sources by separating shallow and deep components of the power spectrum.

iv Euler Deconvolution: To obtain localized depth estimates and confirm basement geometry.
All computations were performed using Oasis montaj 9.0 software and standard geophysical interpretation techniques.

The Main Field:

This is the major part of the geomagnetic field. It accounts for about 95% of the total geomagnetic field. This field is not constant with time but the variation is very slow.The magnitude of the total Earth's magnetic field F, its angle of inclination or Dip, I, to the horizontal and the angle it makes with the geographic North called the angle of Declination D, together defined the main magnetic field, as shown in Figure 2. This field, described in terms of the vertical component Z which is positive downward, and the horizontal component H, which is always positive. The X and Y are the components of H considered positive North and East respectively [9].

The elements are related by the equations:

$$F^2 = H^2 + Z^2 = X^2 + Y^2 + Z^2 \quad (1$$

$$H = F\cos I, \qquad Z = F\sin I, \qquad X = H\cos D, \qquad Y = H\sin D \quad (2)$$

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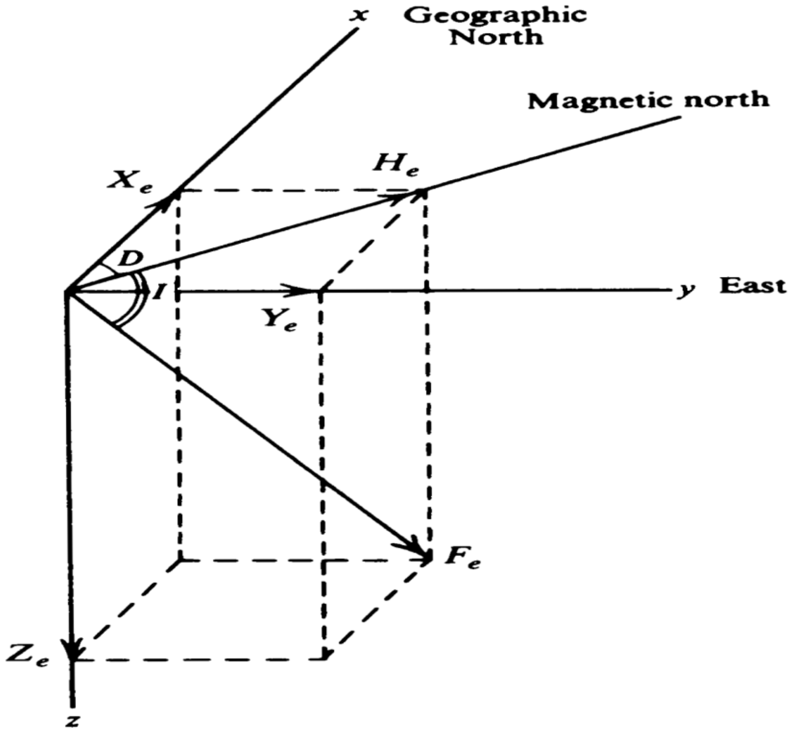

Figure 2: Elements of the Geomagnetic Field [9].

$\tan D = \frac{Y}{X}$, $\tan I = \frac{Z}{H}$ (3)

$\vec{F} = F\hat{f} = F(\cos D \cos I\,\hat{\imath} + \sin D \cos I\,\hat{\jmath} + \sin I\,\hat{k})$ (4)

RESULTS

Reduced to Equator (RTE) Magnetic Map

Figure 3 presents the Reduced to Equator (RTE) magnetic intensity map, which provides an enhanced view of the subsurface magnetic intensity distribution by correcting the inclination and declination of the Earth's magnetic field to simulate measurements taken at the magnetic equator.

The Depth Estimation

Spectral analysis, Figure 4, produced two main depth solutions:

Shallow magnetic sources: 1.0–2.5 km, representing intra-sedimentary volcanic or ferruginous units

Euler Deconvolution map, Figure 5, with a depth ranging from 1000 m to 7500 m a structural index (SI) of 1, which is a widely used geophysical technique

Source Parameter Imaging (SPI) analysis, Figure 6, reveals a significant variation in depth values, ranging from approximately 484.77 meters to 8099.10 meters. Notably, a substantial portion of the magnetic sources lies at depths exceeding 3.0 kilometers. This observation is particularly significant because depths beyond 3.0 km often indicate the presence of thick sedimentary sequences

The deepest basement occurs around Aboh and Patani, suggesting depocentres favourable for hydrocarbon generation. Shallower depths at Kwale and Ahoada indicate structural highs that could serve as traps.

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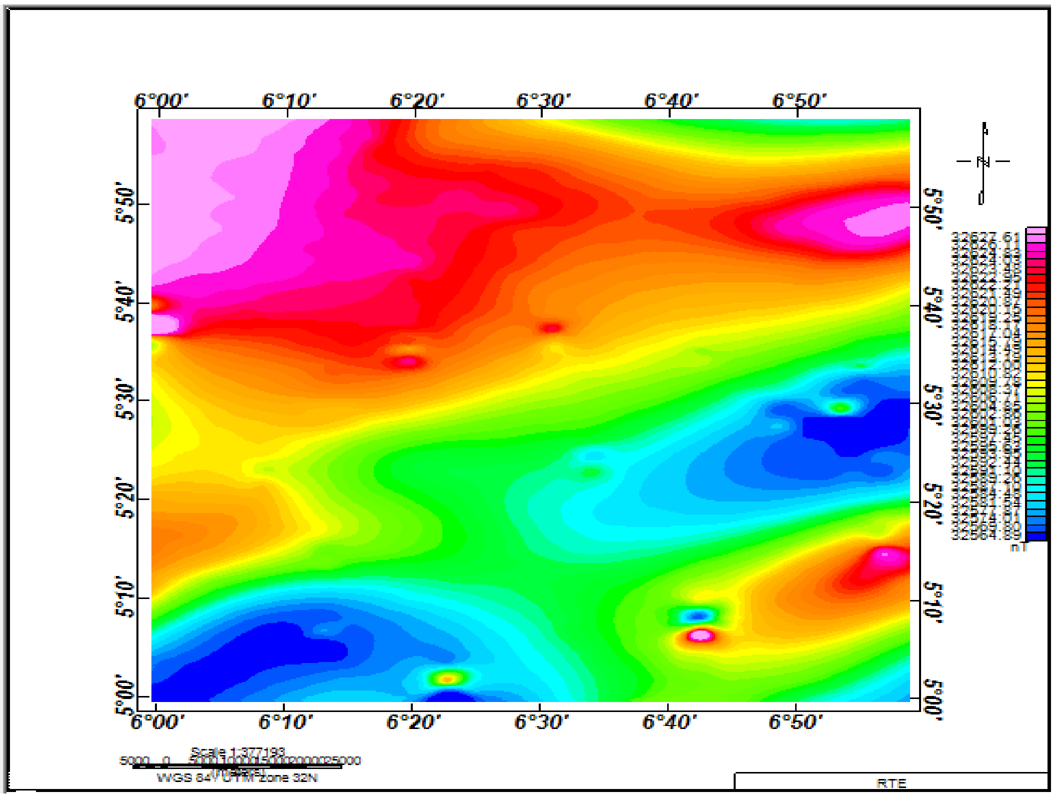

Figure 3: Reduction to Equator (RTE)

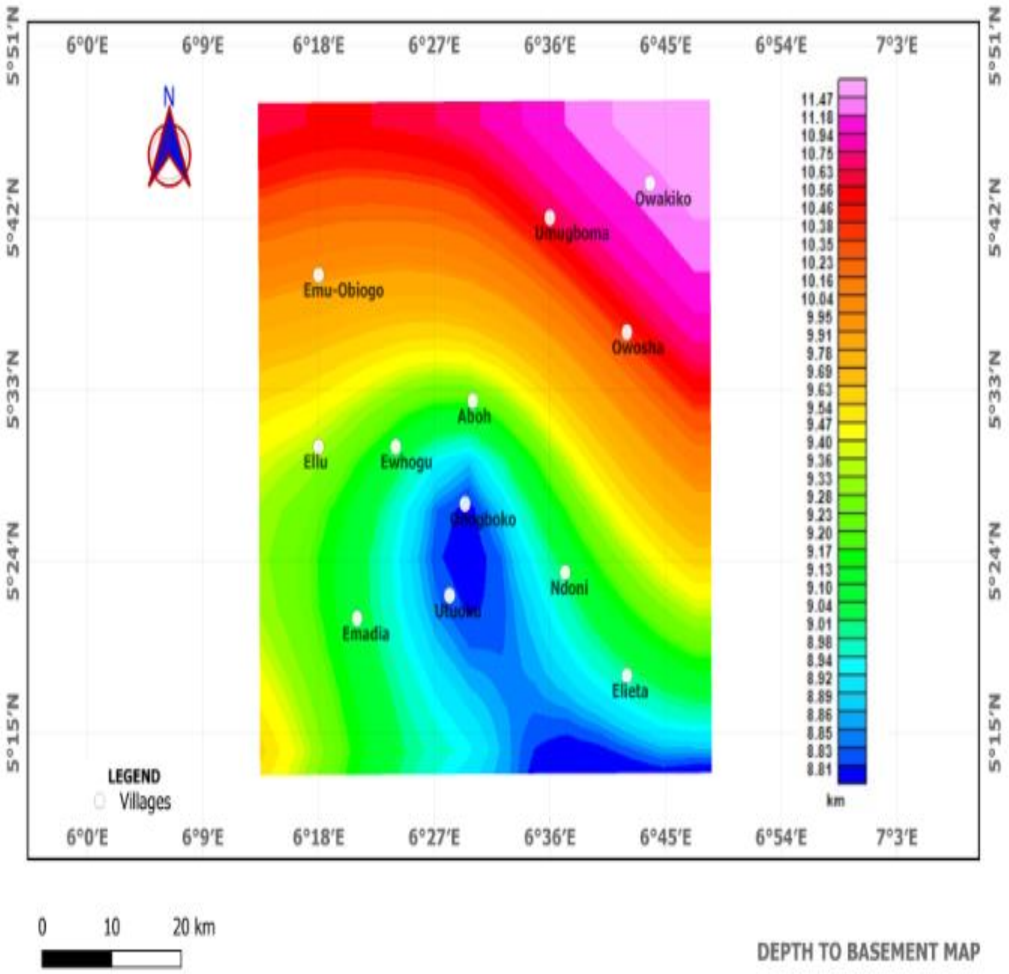

Figure 4: Spectra Analysis

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue I January 2026

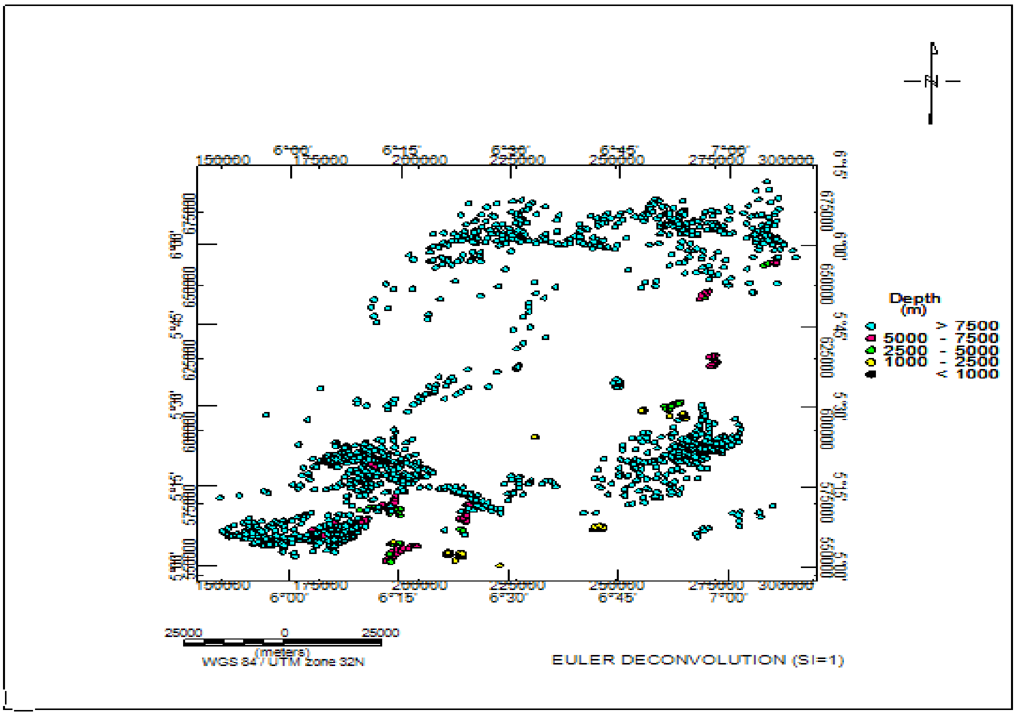

Figure 5: Euler Deconvolution

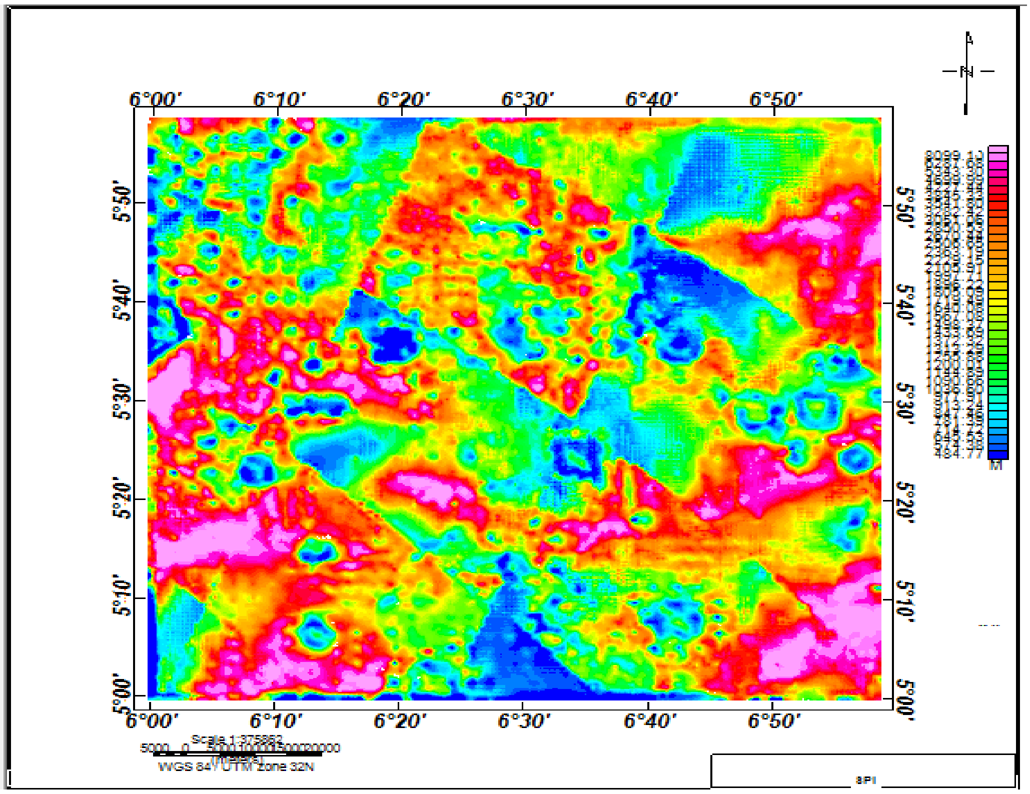

Figure 6: Source Parameter Imaging Map (SPI)

First Vertical Derivative (FVD)

Figure 7, the First Vertical Derivative (FVD) maps reveal numerous linear magnetic discontinuities interpreted as faults or fracture zones. Major lineaments trend NW–SE, parallel to the Benue Trough direction, and NE–SW, consistent with transform-related shears. These faults are likely growth faults associated with syn-sedimentary deformation and are crucial for hydrocarbon migration and trapping.

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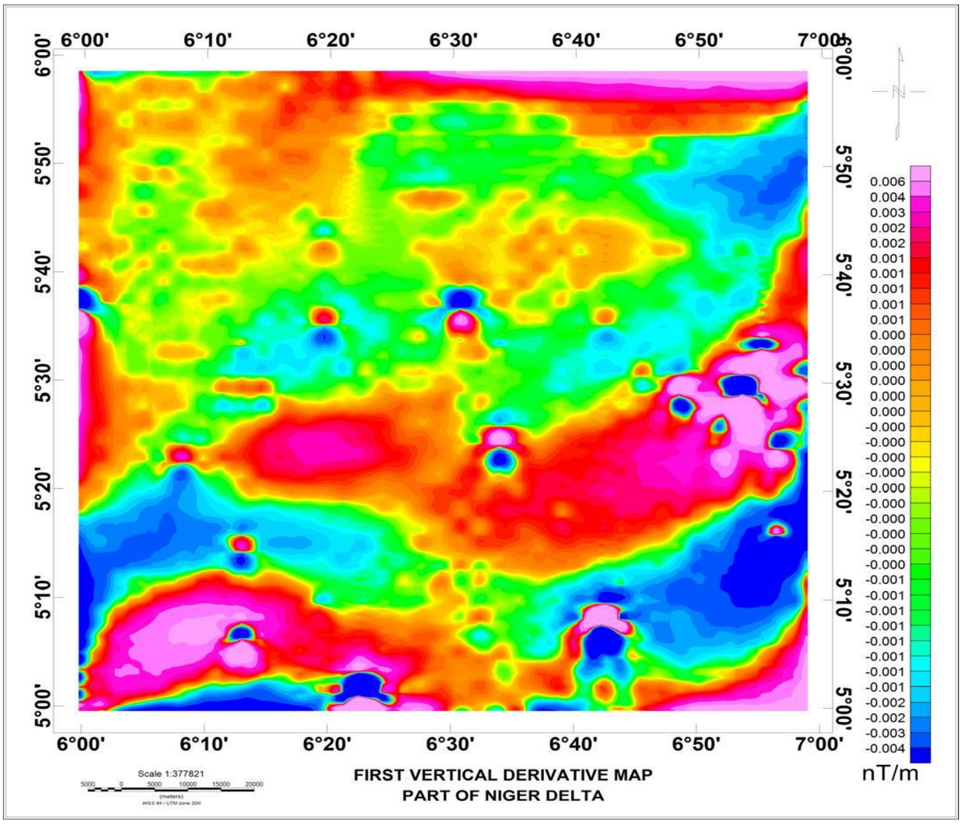

Figure 7: First Vertical Derivative (FVD)

DISCUSSION

The Total Magnetic Intensity (TMI) map was initially utilized in this study to analyze the subsurface characteristics, particularly the thickness of the magnetic layer in the study area. TMI data was further processed using the Reduction to the Equator (RTE) technique.

This transformation adjusts the magnetic anomalies to be centered directly above their causative sources, thereby enhancing the accuracy of interpretation. The RTE map gave a clearer image of the location, geometry, and thickness of the magnetic sources, which is crucial for identifying areas with hydrocarbon potential..

To estimate the depth of magnetic sources more reliably, three depth estimation techniques were applied: Euler Deconvolution, Source Parameter Imaging (SPI), and Spectral Analysis (Energy Spectrum Method).The findings showed that the sedimentary thickness across the study area exceeds 3.8 kilometers, a significant value since hydrocarbon generation and accumulation typically require sedimentary basins with a minimum depth of around 2.5 to 3 kilometers.

The First Vertical Derivative (FVD) map was used to enhance shallow features and delineate geological structures such as faults and folds. This helped in identifying paleostructures within the subsurface. From the FVD analysis, the orientation, length, and possible activity of these ancient structures were determined,

CONCLUSION

The study successfully applied aeromagnetic techniques to evaluate subsurface structures in parts of the Niger Delta Basin. Major findings include:

Dominant magnetic trends oriented NW–SE and NE–SW, reflecting regional tectonic stress regimes.Depth to magnetic basement ranging from about 5 km to 12 km, with thick sedimentary depocentres in Aboh and Patani.Fault systems mapped from derivative filters correspond to growth faults and rollover anticlines critical to hydrocarbon trapping.Paleostructural analysis indicates that basement configuration significantly controls sedimentation and petroleum potential. The integration of aeromagnetic interpretation with other geophysical data is recommended to refine exploration targets and reduce drilling risks. Overall, aeromagnetic surveys remain indispensable for regional structural mapping and resource assessment in the Niger Delta and similar sedimentary basins.

ACKNOWLEDGEMENTS

We sincerely thank the Nigeria Geological Survey Agency for making the data used in this research available and as soon as possible, otherwise this work would not have been possible.

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