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Sedimentary thickness and basement depths of eastern Niger delta, Nigeria, from aeromagnetic data and implications for hydrocarbon prospects

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Abstract

A knowledge of sedimentary thickness and basement depths of a basin is necessary in understanding the structural set up of formations and evaluation of the hydrocarbon potentials of a region. In this work aeromagnetic data, obtained from the Nigerian Geological Survey Agency (NGSA) Abuja, has been interpreted to obtain sedimentary thickness, structural faults and intrusions including the basement depths of the eastern Niger Delta, Nigeria with the implications for hydrocarbon prospecting. Results from magnetic attribute analysis, total horizontal derivative operations, spectral analysis and source parameter imaging reveal the following: the study area is magnetically heterogeneous; the magnetic intensities range for the region is from – 46.2 nT to 160.3 nT, with residual magnetic intensity values of -15 nT to 13 nT revealing sediments with low magnetic rocks in the southwestern and southeastern parts of the study area and magnetic rocks and basement intrusions in the northwestern, northeastern and central parts of the study area; sedimentary thickness range from 96.5 m to 6601.5 m hosting faulted anticline and syncline structural bodies good enough for hydrocarbon formation and trapping and a maximum depth to basement of 6601.5 m. The sedimentary thickness and structural types, influenced by the basement intrusions, make the region a hydrocarbon potential area and it is recommended that prospecting in the southern and northern parts of the study area should be intensified.

Keywords: Aeromagnetic data; Basement; Hydrocarbon; Sedimentary thickness and Niger Delta

1. Introduction

Majority of the subsurface information on the Niger Delta area are obtained from seismic data of the tertiary deltaic hydrocarbon bearing sequence [1; 2]. Information on the underlying basement structures of the basin from other geophysical methods is sparse. As has been shown by literature, the potential method of which the magnetic method is one, can give good subsurface information on the sedimentary and basement structure of a region and is useful in understanding the structural composition and hydrocarbon potential of any overlying sedimentary section. Additionally, a knowledge of the basement structure is vital in understanding the sedimentary hydrocarbon bearing sequence in a basin. For the Niger delta, which is a difficult terrain, aeromagnetic data is ideal for these purposes as it covers a wider area including inaccessible regions on land and sea.

The underlying principle of the magnetic method is based on dipolar fields or variable directions which are time dependent and the method is based on the measurement of the geomagnetic field caused by contrast in soil or rock magnetization. Although, it is a major tool for search for mineral bearing ore bodies, the method can be used for mapping features in igneous, metamorphic and sedimentary regions with possible targets of dikes, faults, syncline and anticline structures and other features including sedimentary depths [3]. Ideally, the method gives subsurface information from

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which the depth to basement can be determined making it possible to locate and define the extent of sedimentary thickness. Interpreted data is capable of delineating hydrocarbon trapping structures with the sedimentary sections which oftentimes are graphic and structural features on the basement surface [2].

In this work, aeromagnetic data obtained from the Nigerian Geological Agency (NGA) Abuja, has been used to determine the sedimentary thickness and structural framework within the eastern Niger Delta with implication for hydrocarbon prospectively determination by analytically methods.

The Niger Delta (Figure 1) lies within latitudes 5^{o} 00 to 8^{o} 00 E and longitudes 4^{0} 00 to 8^{0} 00N, [4] while the study area lies between latitude 6^{o} 00 to 8^{o} 00 E and longitude 4.3^{o} 00 to 6^{o} 00 N. This region is within the oceanic section of the Abakiliki–Benue suture of the much larger Southern Nigeria Basin. It is bounded on the west and east by the basement of the Cameroon volcanic mountains, in the north by the Anambra basin, Abakiliki uplift, Afikpo syncline and Calabar flank [5].

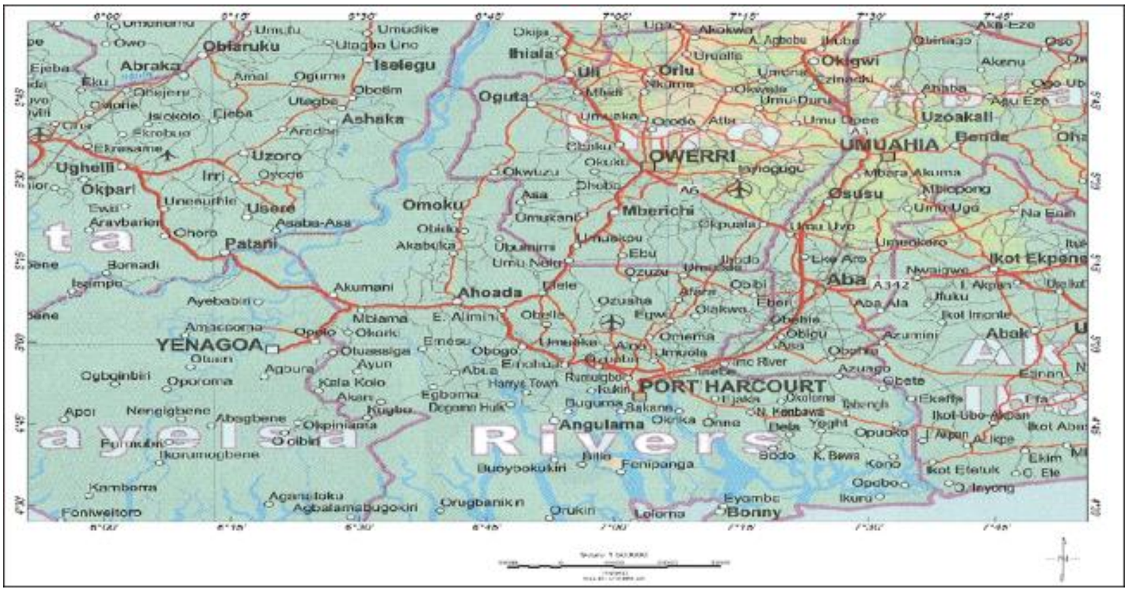

Figure 1 Niger Delta showing the study area [6]

Odumodu [6] explains the Tertiary Niger Delta as an area of approximately 75,000 km^2 consisting of regressive classic succession, which attains a maximum thickness of 12 km^2 with the siliclastic system prograding across pre-existing continental slope into the deep-sea during the late Eocene and still active today. It is a tripartite formation. The topmost formation is the Benin formation which is underlain by the Agbada formation that is further subdivided into upper, middle and lower units. The base formation is the Akata formation [6; 7; 8] and is made up of uniformly dark gray over-pressured marine shales with sandy turbidites and channel fills ranging from late Eocene to recent. The thickness of this formation is about 2,000 m at distal part of the delta to 7000 m beneath the continental shelf and thrust belts in the offshore Niger Delta [9]. This formation is considered as the main source rock for hydrocarbons in the Niger delta.

2. Material and methods

The aeromagnetic data for this work was obtained from the Nigeria Geological Survey Agency, Abuja. The data was acquired along NW-SW flight lines at 500 m spacing, 2 km tie lines and 80 m terrain clearance. The data recorded as sheets consists of twelve sheets covering the towns of Kwale, Abo, Okigwe, Afikpo, Patani, Ahoada, Aba, Ikot-Ekpene, Oloibiri, Degema, Port-Harcourt and Opobo, all in the eastern Niger delta basin of Nigeria. These sites cover an area of about 49, 284 square km. The data interpretation was carried out by first, gridding [10] using 100 m grid cell of the Oasis Montaj Software. Then the regional and residual anomalies were separated using a first order polynomial operation for the regional anomaly [11] after reduction to equator operation to reposition data as if collected on the equator [12] before improvement of data by enhancement of data [13; 14]. TMI maps [15] for the whole region, the regional anomaly and residual anomaly were produced analysis. Finally, analytical signal analysis [16], total horizontal derivative operation [2] and source parameter imaging [17] operations were carried out to interpret data.

3. Results and discussion

The TMI base map (Figure 2) for the study area reveals that the magnetic intensity values for the region ranges from – 46.2 nT to 160.3 nT indicating magnetic heterogeneity. The northeastern, northwestern and central parts of the study area have high magnetic susceptibility suggesting the presence of magnetic rocks and basement intrusions. The southwestern and southeastern parts have low magnetic susceptibility suggesting the presence of sediments with little or no magnetic rocks. The regions of intermediate and low magnetic susceptibility values found in the north-eastern, north-central, south-western and south-eastern parts of the study areas are indications of the presence of sediment deposits.

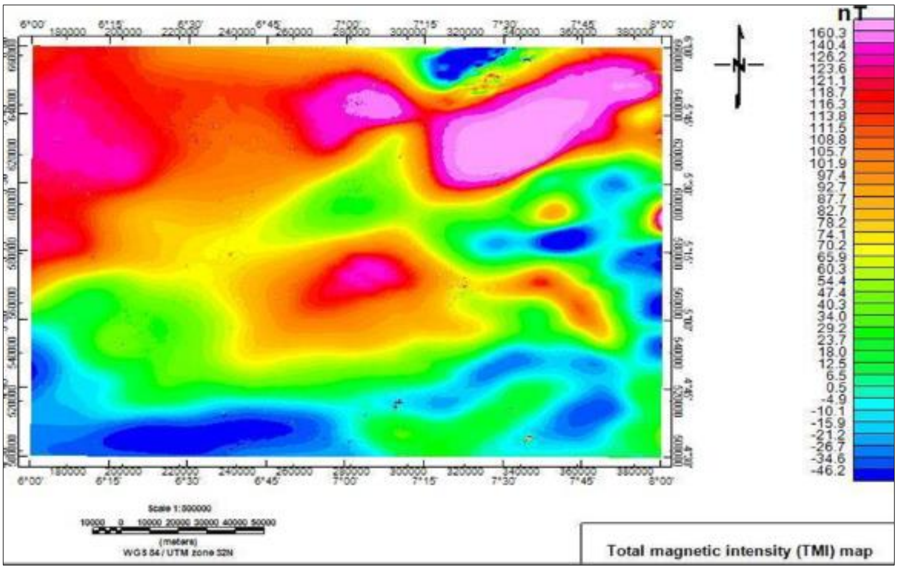

Figure 2 Total Magnetic Intensity (TMI) Map of the Study Area

The residual TMI map (Figure 3) shows the shallow (short wavelength) but high frequency magnetic anomalies of the study area with magnetic intensity ranges from – 15.3nT to 13.3nT. A major part of the study area is made up of sediments with high magnetic minerals due to its high magnetic intensity values especially in the northeastern and southeastern parts of the region. The residual edges and contacts of anomalies are highlighted.

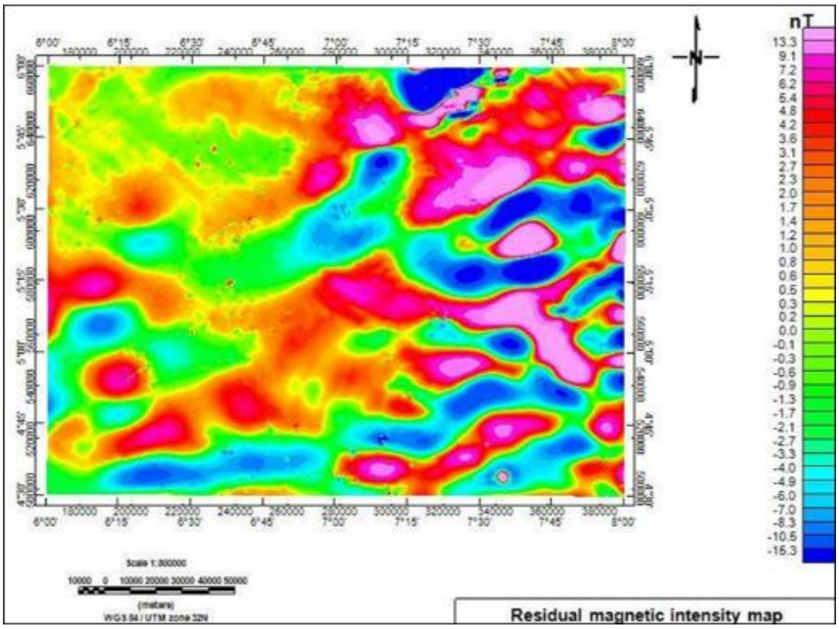

Figure 3 Residual Magnetic Intensity Map

The regional TMI map (Figure 4) shows the deep (long wavelength) seated magnetic anomalies within the study area and the anomaly boundaries. The magnetic intensity values range from -114.7 nT to 153.5 nT. The high magnetic intensities are from the basement rocks that contain high magnetic minerals especially in the northern and northwest parts of the study area. In this case, the residual anomalies are clearly suppressed leaving the high magnetic signatures of the regional bodies in the study area.

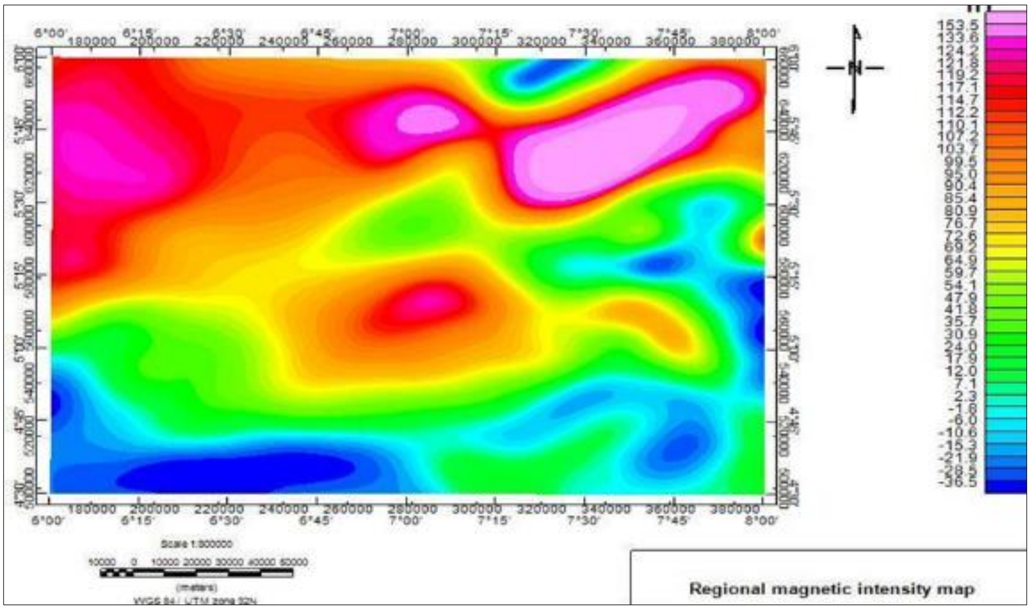

Figure 4 Regional TMI map of the Study Area

The total horizontal derivative map or horizontal gradient map (Figure 5) reveal the regional fault lines, fractures, contacts and edges of anomalies in the study area. The presence of these structural features is suggestive of tectonic events that have existed over time. These regional structural features are clearly pronounced in the NE and SE sections of the study area. The structural features such as fault lines could be possible paths for hydrocarbon migration.

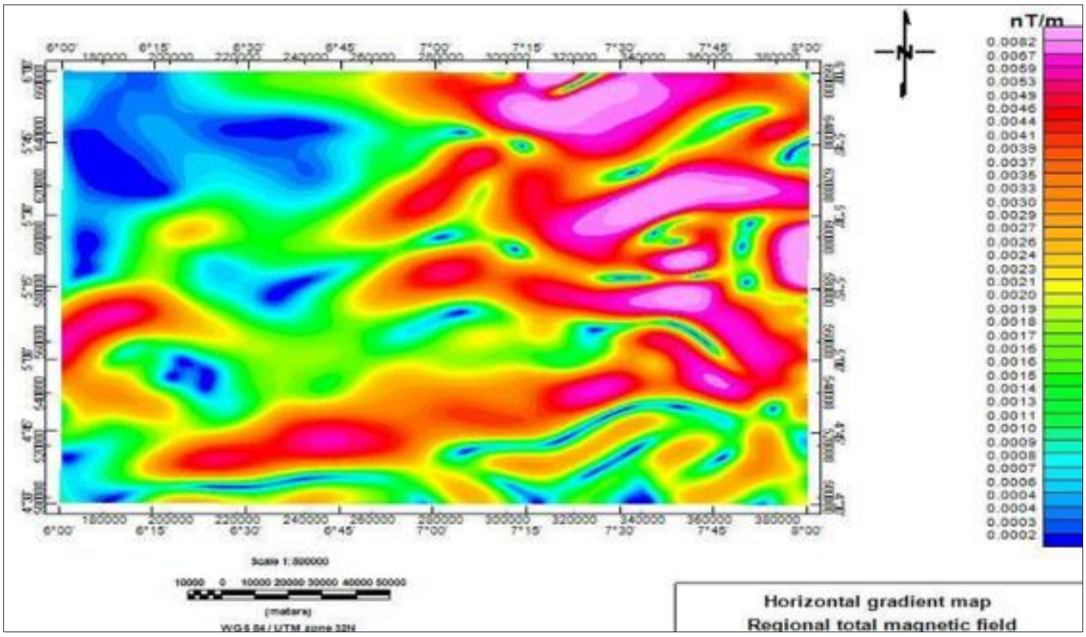

Figure 5 Regional Total Horizontal Derivative Map of the Study Area

The residual total horizontal derivative map from the residual TMI map (Figure 6) exposes more the causative residual structural features of the region. The area is characterized by many faults and fractures systems especially in the north, northeast, southeast and southwest parts of the study area. These fault lines are possible pathways for hydrocarbon migration and eventual accumulation in the presence of a possible seal. The magnetic intensity ranges from 0.00007nT/m to 0.00646nT/m. The presence of high magnetic intensity (0.00169nT/m to 0.00646nT/m) in the northeast and southeast parts of the study area is suggestive of the existence of some magnetic minerals in sediment deposits due to possible intrusions.

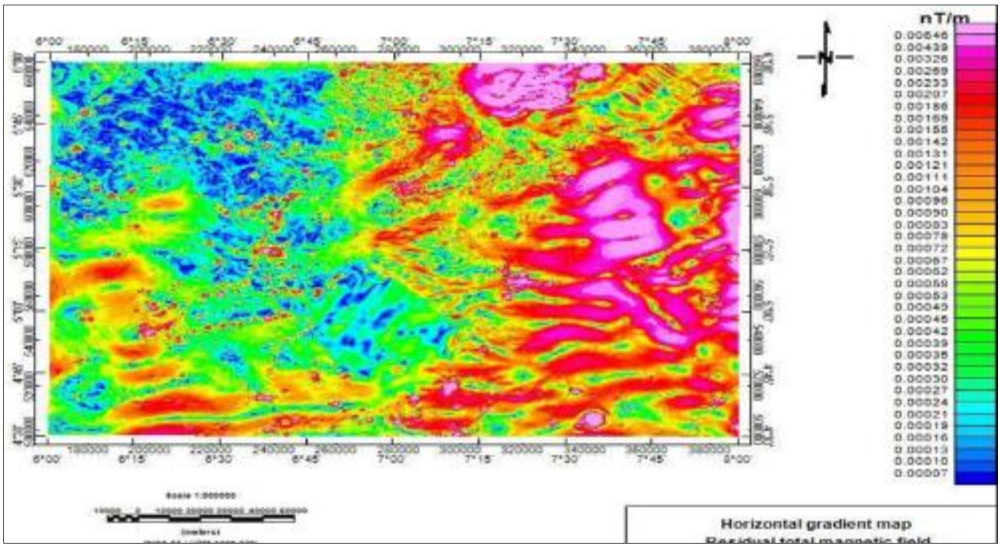

Figure 6 Residual Total Horizontal Derivative Map

The Analytical Signal map (Figure 7) highlights the presence of faults, intrusion of basement rocks and sedimentary thickness in the study area. The magnetic intensity varies from 0.006nT/m to 0.0270nT/m. The presence of magnetic rock minerals is clearly seen in the northeast direction with a magnetic intensity range of 0.0089nT/m to 0.0270nT/m. The area is also characterized by decreasing magnetic susceptibility southward and westward; this suggests that these areas are made up of sediments with low magnetic minerals.

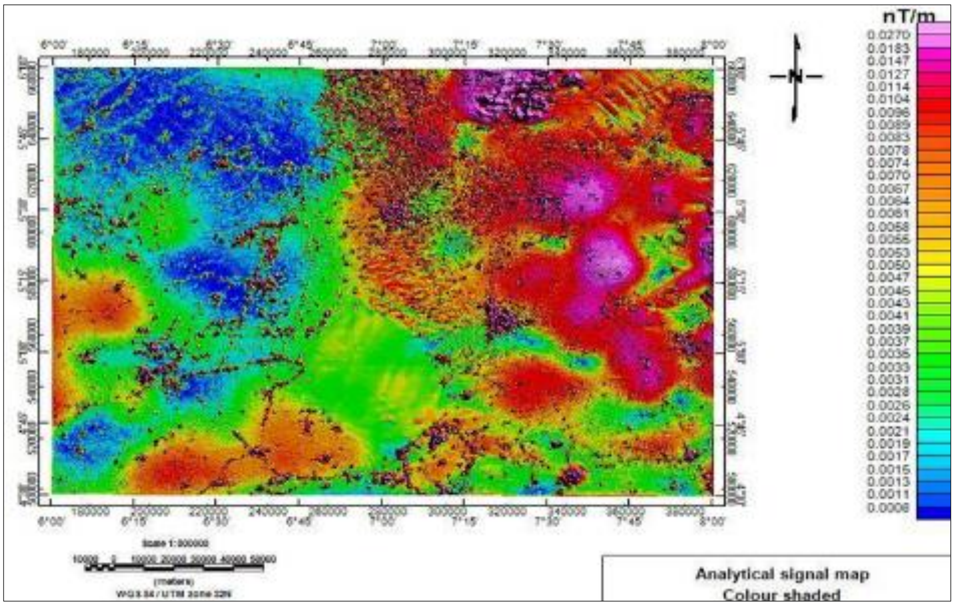

Figure 7 Analytical Signal Map of the Study Area

Furthermore, the Source Parameter Imaging Map (Figure 8) reveals the depth to magnetic sources or the depth to the basement of the study area. The depth to magnetic sources of the study area ranges from 96.5m to 6601.6m with the basement rocks (red to magenta) typical of 1547.0 m to 6601.5 m. The sediment thickness ranges from 96.5 m to734.6 m with coarser sediments suggestive of sandstone range from 849.6m to 1419.8 m. From the SPI map, the cluster of red and magenta is indicative of the existing basement topography of the study area in a north south direction. The basement structure in the southern part of the study area suggests an intrusion of basement rocks. This may be due to tectonic activities which could generate a fault system in the thick sediment above it.

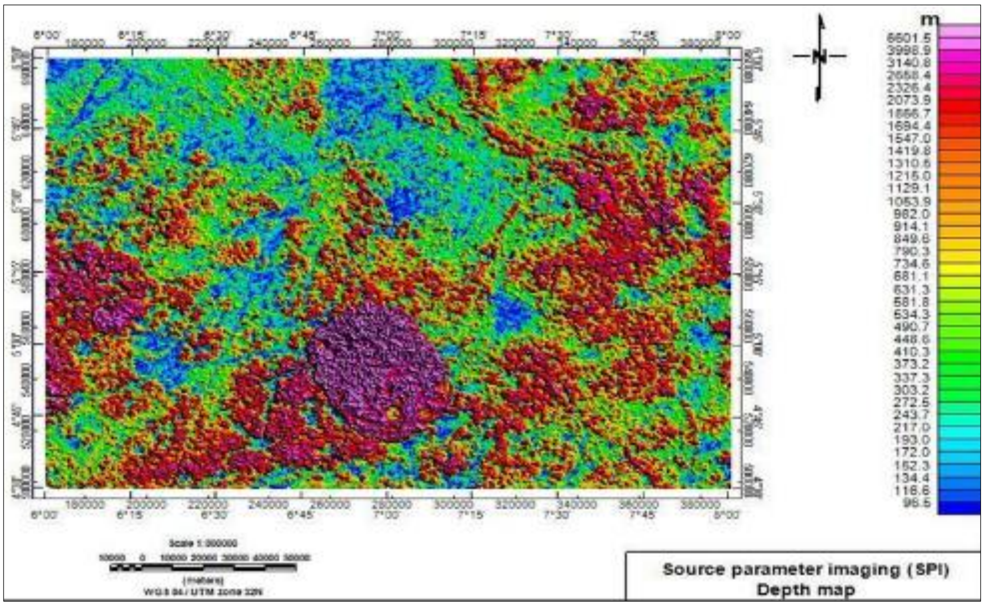

Figure 8 Source Parameter Imaging map of the Study Area

4. Conclusion

In this study, the results reveal heterogeneous magnetic susceptibility values for the study area. Magnetic sediment deposits are found in most parts of the study area. Thick sediment sequences occasioned with faults, factures and contacts exist especially in the southern parts of the study area and are suggestive of the possible generation, migration and trapping of hydrocarbons under suitable conditions of temperature and pressure. The basement rock for the region lies farthest at a depth of 6601.5 m from the surface.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors affirm that there is no conflict of interest.

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