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Indications of Hydrocarbon Prospects in the Lower Benue Trough from Aeromagnetic Data

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Abstract

The lower Benue trough has been investigated for indications of hydrocarbon prospect using high resolution aeromagnetic data. Objectively, the study was meant to evaluate susceptibility contrasts related to structure and sedimentary units that could have direct bearing to hydrocarbon formation. Maps of magnetic parameters were generated using Oasis montaj, Surfer 13 and Arc GIS softwares for qualitative and quantitative interpretations. Results of the study reveal that the residual magnetic intensity (RMI) map exhibits distinct elliptical to isolated hemispherical magnetic lows bounded by ridge-like magnetic highs and both trending mostly in the NE-SW with minor E-W trend. These Low magnetic anomalies were delineated in Adani, Enugu-Ezike, Nsukka, Awka, Awgu, Enugu and Nkalagu areas while magnetic highs were delineated in Eha Amufu, Okposi, Igumale, Udi and Ukehe. Magnetic lineaments were mapped and occur predominantly in the NE-SW and NNE-SSW lineament orientations, with minor occurrences in the NW-SE, E-W and N-S lineament orientations. High lineament densities were delineated around Enugu, Udi, Ukehe, Eha-Emufu and Igumale, which suggest that these areas are more deformed than the low lineament density areas in Adani, Enugu-Ezike, Awka, Agwu, Nkalagu and Okposi. Areas of shallow basements depths (< 2000 m), with high magnetic intensities and high lineament densities were mapped in Enugu, Udi, Ukehe, Eha-Emufu and Igumale, suggesting structurally deformed areas with thin sediment cover unfavourable for hydrocarbon formation but with good prospect for mineral deposits and groundwater resource. comparison of SPI map, lineament map, residual magnetic map and the geologic map revealed that large basement depths (> 2000 m) with low magnetic intensities and low lineament densities were mapped in Adani, Enugu-Ezike, Awka Awgu, Okposi and Nkalagu (suggesting structurally less deformed areas with thick sedimentary cover favourable for hydrocarbon formation and accumulation in the lower trough) correlate to parts of the Mamu and Nkporo shale formations and Ajali Sandstones, reported to exhibit characteristics of potential hydrocarbon source rocks for a series of oil/gas and condensate shows found within the Ajali reservoir sandstones and were thus recommended for detailed seismic surveys.

Keywords*: Remote Sensing; Hydrocarbon; Aero Magnetic; Lower Benue Trough.*

1. Introduction

The lower Benue trough has much been studied in the recent past for probable petroleum accumulations. Petroleum exploration in the trough dates back to the early 1930s, following the results of geochemical and geophysical analysis, mapping of surface seeps, sediment alterations and other indications of hydrocarbon presence [1]. It is believed that the trough may have reasonable quantity of hydrocarbon accumulations concealed in deeply buried Cretaceous sediments that satisfy the basic requirement of a hydrocarbon system such as source, reservoir, migration, seal and trap. This is due its proximity to the hydrocarbon-rich Niger delta to the south and the discovery of hydrocarbon in Kolmani River II well in Gongola basin, Chad and Niger republics to the northeast that share similar geologic settings.

The Niger delta and lower Benue trough are genetically related in the generation and accumulation of hydrocarbons in both basins. According to [2], the southern boundary of Anambra Basin coincides with the Northern boundary of the Niger Delta. Petroleum accumulations in

the northern portion of the Niger Delta contains light waxy oils sourced mainly from land plant derived organic matter (OM) disseminated throughout the Eocene source rock units, which could possibly be the scenario in the adjacent trough [3-4].
Several geophysical exploration methods such as gravity, magnetic and seismic have variously been deployed in the search for petroleum in the trough [29]. Of these, the airborne magnetic study has remained the most used geophysical method in the search for petroleum and reconnaissance studies [4-6]. This is because of its cost effectiveness, fast, spatial coverage and resolution. The method maps the thickness, lateral extent and structural texture of the sediments overlying the magnetic basement, which when interpreted could give clues to probable petroleum presence.

The magnetic method depends on the magnetic properties of the rock, depth and geometry of the magnetic source and the external field. Rock magnetism depends on the type and quantity of magnetic mineral in the rock. This determines the magnitudes of the induced and remnant magnetism that varies for the different rock types. Of all the magnetic minerals, magnetite is the most magnetic and of relative abundance such that the magnetism exhibited by a rock under the influence of the earth field is a function of the magnetite mineral content of the rock [7]. Among the different rock types, sedimentary rocks are the least magnetic, igneous the most magnetic and metamorphic is intermediate.

Sedimentary rocks have characteristic low magnetic content or susceptibility and therefore, exhibit uniform magnetic character in contrast to the basement areas. The observed high magnetic anomalies in sedimentary terrains are mostly due to intra-sedimentary intrusive igneous and metamorphic rocks and shallow underlying magnetic basement. Magnetic susceptibility is a fundamental property in magnetic method used for petroleum exploration. Changes in the magnetic susceptibility cause small variations in the magnetic fields of rocks that may indicate the presence of traps and petroleum accumulation as well as intrusives, lava flows and igneous plugs that could provide the geothermal energy needed for the maturation of petroleum source rocks in the sediments [8-9].

The magnetic method rarely maps hydrocarbon directly in the subsurface. This is because the fundamental magnetic property or susceptibility of the rock is not directly sensitive to the presence of hydrocarbons. The analysis of magnetic anomalies gives clues to probable traps due to structure and stratigraphy associated with hydrocarbons accumulation. However, biochemical processes in hydrocarbon bearing sediments result in the alteration of the sediments and accumulation of magnetic minerals diagenetically in the overlying sediment strata by petroleum seepage through faults and micro fractures. This causes local weak magnetic anomalies or aureoles above the hydrocarbon zone, which when isolated from the stronger regional field serves as direct indicators of hydrocarbons (DIH). Temperature gradients, compaction and changes in atmospheric pressure help drive this upward migration [10].

The study area is located at the southeastern part of Nigeria in the lower Benue trough geologic zone, underlain by early to late Cretaceous sediments. It lies between latitude 6°00′N–7°00′N and longitude 7°00′E–8°00′E, comprising of Nsukka, Igumale, Udi and Nkalagu areas and covering a total area of 12,000 square kilometers (Figure 1).

The area is characterized by undulating landforms with mixed biomes. Rainfall is at its peak in June and low in November with average daily temperature of 32^{o}C [11]. The present study is aimed at mapping and delineating structural and lithological features and estimate depth to magnetic basement (thickness of sedimentary pile) from aeromagnetic data for possible indications of petroleum accumulations in the lower Benue trough.

2. Geology of the study area

The study area falls within the Abakaliki and Anambra basins in the lower Benue trough (Figure 2). The lower Benue trough is underlain by thick pile of sedimentary rocks with intra-sedimentary igneous intrusions on the Precambrian basement. The Precambrian Basement Complex is made up of essentially granitic and magmatic rocks which outcrop in the eastern portion of the study area [12]. The stratigraphic sequences of the lower Benue trough range in age from the Aptian to mid Eocene. It is comprised of thick sequence of rocks from earliest to latest such as Asu River Group, Eze-Aku, Awgu, Nkporo Group, Mamu, Ajali, Nsukka, Imo and Bende-Ameki Formations.

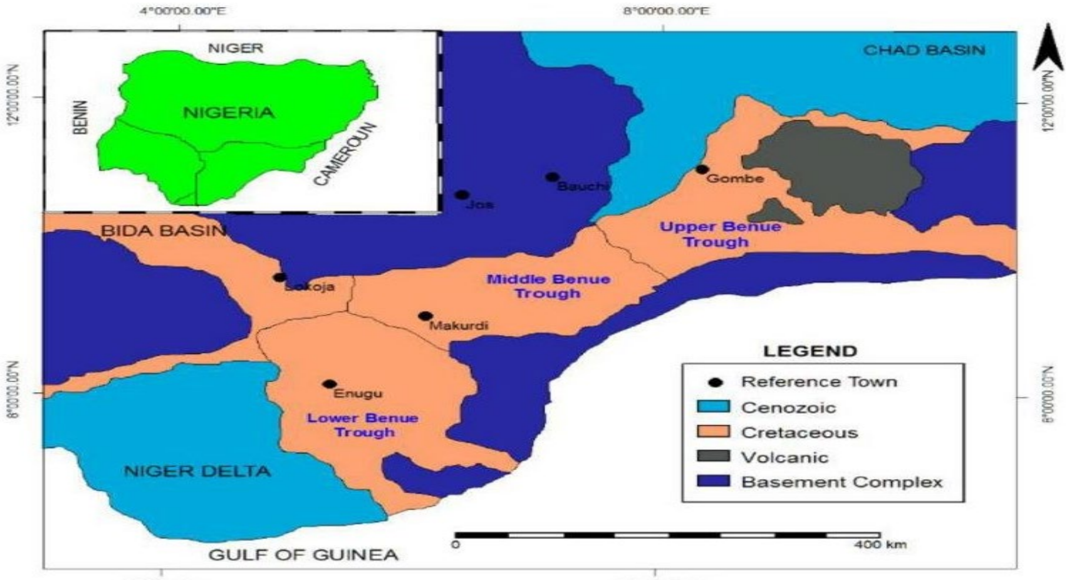

Figure 1. Location map of the study area (after [13-14])

Two petroleum systems Nkporo-Mamu and Mamu-Ajali were identified, while the overlying Nsukka and Imo shale Formations provides the regional seals [15-17]: Nkporo-Enugu and Mamu shale Formations exhibit characteristics of potential hydrocarbon source rocks for a series of oil/gas and condensate shows found within Ajali reservoir sandstones [18-19].

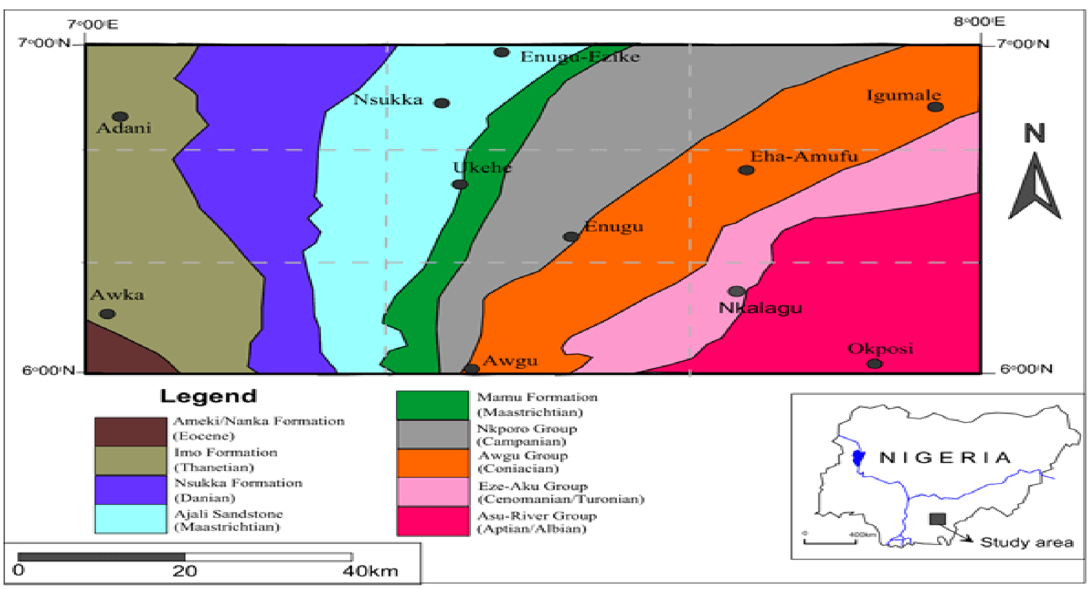

Figure 2. Geology map of the study area (after [20])

The interbedded marine sandstone facies in the Nkporo-Enugu and Mamu shales could provide additional reservoirs in the formations. The lower Benue trough is southernmost part of the Benue trough formed during the separation of the South American from the African continent, as failed arm of the triple junction. The trough is characterized by a dominantly trending NE-SW structural feature with localized forms of E-W, N-S and NW-SE trends. Tectonic and magmatic activities as well as sedimentary depositions in the trough were controlled by this major NE-SW trending fault in the trough [21-22].

3. Method of study

Four sheets of high-resolution aeromagnetic data over Nsukka, Igumale, Udi and Nkalagu areas were obtained from the Nigeria Geological Survey Agency [23]. The data was acquired with nominal flight height of 76m along N-S flight lines with 500m inter line spacing and total magnetic field intensity B (nT) was measured.

The data sheets were subsequently assembled and knitted together using Oasis Montaj and Sulfer 13 softwares to produce the Total Magnetic Intensity (TMI) map of the study area. Data were further processed by the removal of regional magnetic effects through the application of filtering (regional-residual separation) to generate a residual magnetic map of the study. Thereafter vertical and horizontal derivative maps were generated from the residual magnetic intensity grid using Oasis montaj software to enhance shallow geological features and identify geologic boundaries in the study area. Source Parameter Imaging (SPI) for depth to magnetic basement was carried out on the residual maps to determine the thickness of the sedimentary pile.

Subsequently, the filtered images (residual gradients) were then used for the extraction of lineaments which were then merged together, traced and measured clockwise from the North automated by Arc GIS program. The mapped lineaments were statistically analyzed and plotted in the form of rose diagrams, using rockworks software program. Finally, these maps were analyzed visually on the basis of amplitude and shape as well as identification of anomalous boundaries, volcanic zones, lineaments and other regional structures that could be akin to those that are associated with petroleum accumulations.

4. Presentation of results

The results obtained from aeromagnetic data were processed and transferred into information through variety of maps. The maps were characterized for magnetic features, basement lineaments and depth to the magnetic source for indications of hydrocarbon in the lower Benue trough.

4.1. Total magnetic intensity

The TMI map of the study area is characterized by low and medium to high magnetic anomalies with intensity values ranging from -51.05nT to 128.45nT, respectively (Figure 3). The magnetic lows vary from −51.05 nT to 8.23nT and dominate in Enugu Ezike, Nsukka and Awgu, while medium to high magnetic anomalies varies from 13.23nT to 128.45nT mapped at Igumale, Adani, Enugu, Nkalagu, Okposi, Udi and Ukehe areas. The magnetic lows lie parallel and bounded by the medium to high magnetic intensities and both trends approximately E-W. Low and medium to high magnetic intensities are related to local and regional magnetic features in the study.

4.2. Residual magnetic intensity

The residual magnetic intensity (RMI) map exhibits characteristics low and medium to high magnetic anomalous signatures with intensities varying from -52.80nT to 54.11nT (Figure 4). The elongated magnetic lows have intensities varying from -52nT to 2.73nT dominate Adani, Enugu-Ezike, Nsukka, Awgu and Awka areas, while the medium to high ridge-like magnetic anomalies with intensities varying from 4.28nT to 54.11nT are mapped in Enugu, Okposi, Udi and Ukehe. The RMI in contrast to the TMI are dominated by local magnetic features with low magnetic intensities. The low and medium to high magnetic anomalies are parallel to each other and trends dominantly in the NE-SW with minor occurrences in the E-W trend.

These broad areas of low and medium to high magnetic intensities corresponds to sagged and uplifted parts of the underlying magnetic basement, respectively. The alternation between low and high magnetic intensities with steep gradients and elongated anomalous features indicate the presence of faults or contacts that divides the study area into blocks with different magnetization contrasts.

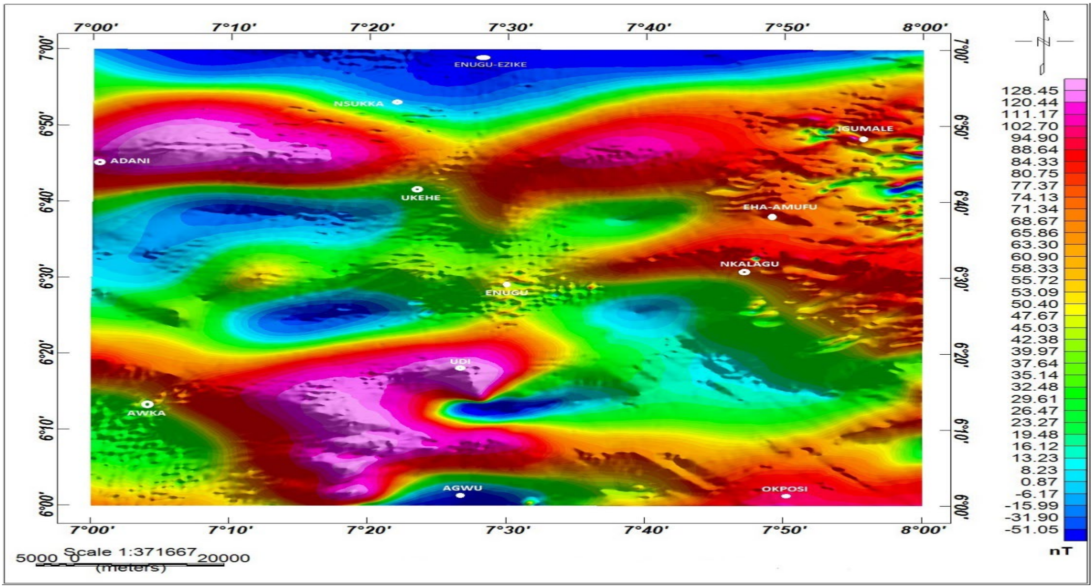

Figure 3. Total magnetic intensity (TMI) map of the study area

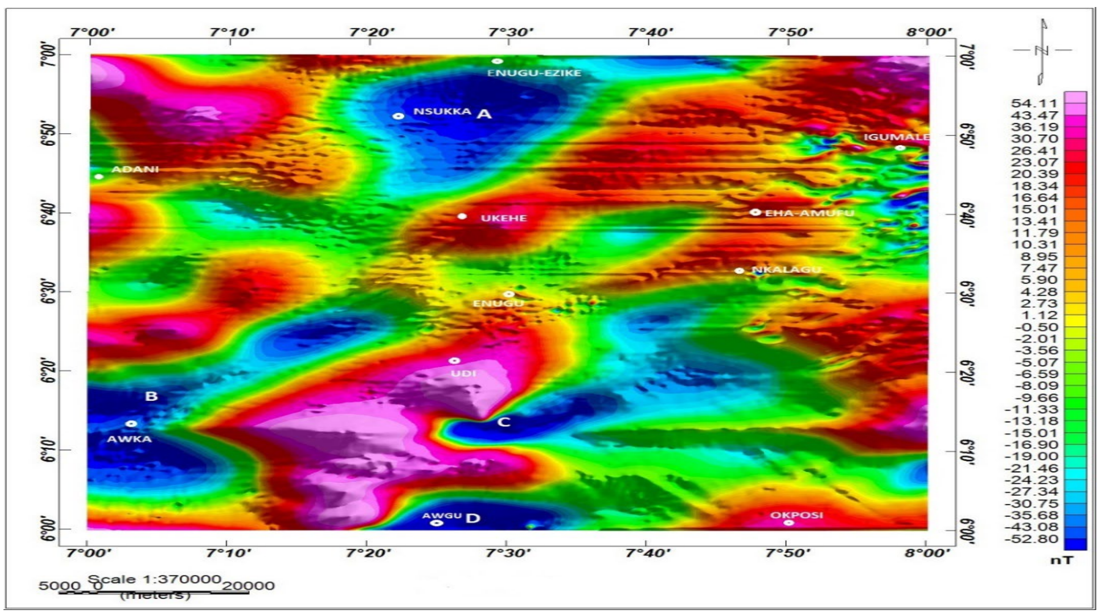

Figure 4. Residual magnetic intensity (RMI) map of the study area

4.3. Source parameter imaging

Source Parameter Imaging (SPI) map displays the depth to magnetic sources in the study area (Figure 5). The map shows significant depth variations across the area with depths varying from -95.5m to -3318.8m. The Nsukka, Ukehe, Enugu, Udi, Igumale, Eha-Emufu and Awka exhibit characteristic shallow to medium depths varying from -95.5m to -1661.2m. Deeper depths to magnetic sources varying from -1661.2m to -3318.9m, occur mostly in the SE of the study.

These depths variations are attributed to the tectonic upwarp and downwarp of the magnetic basement and /or magnetic sources, respectively, in the area. The downwarped Awgu, Awka, Nkalagu and Okposi areas are characterized by thick sediment cover than the upwarped Eha-Emufu, Enugu, Igumale, Nsukka, Udi and Ukehe areas with thin sediment cover.

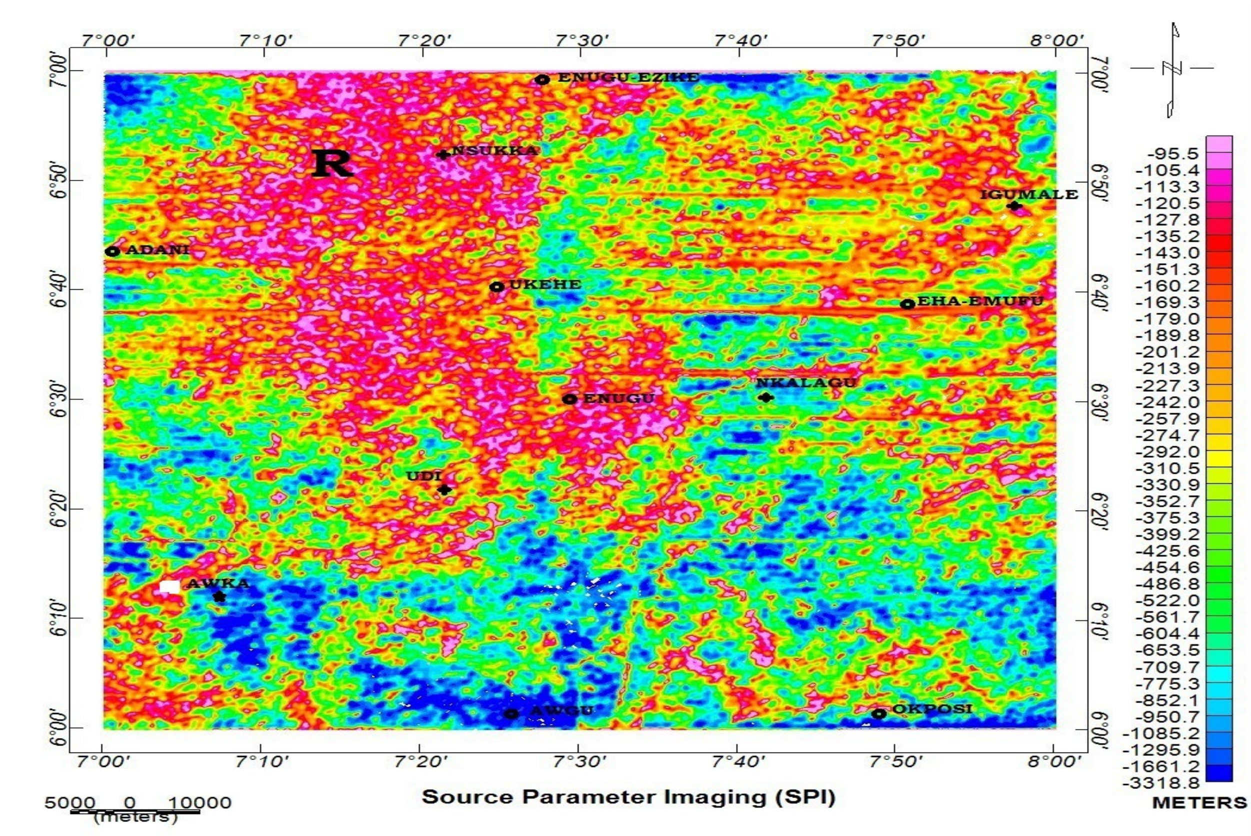

Figure 5. Source Parameter Imaging (SPI) map of the study area

4.4. Magnetic lineament

The magnetic lineament map shows the distribution of lineaments in rocks with different magnetic susceptibilities (Figure 6). The lineament distributions are widespread and densely distributed in Udi, Okposi and W and NE of Enugu and Nkalagu areas, respectively and sparsely distributed in the other parts of the study area. They are characterized by both short and long linears, crisscrossing and intersecting each other and forming fault closures capable of forming traps for probable hydrocarbon accumulations.

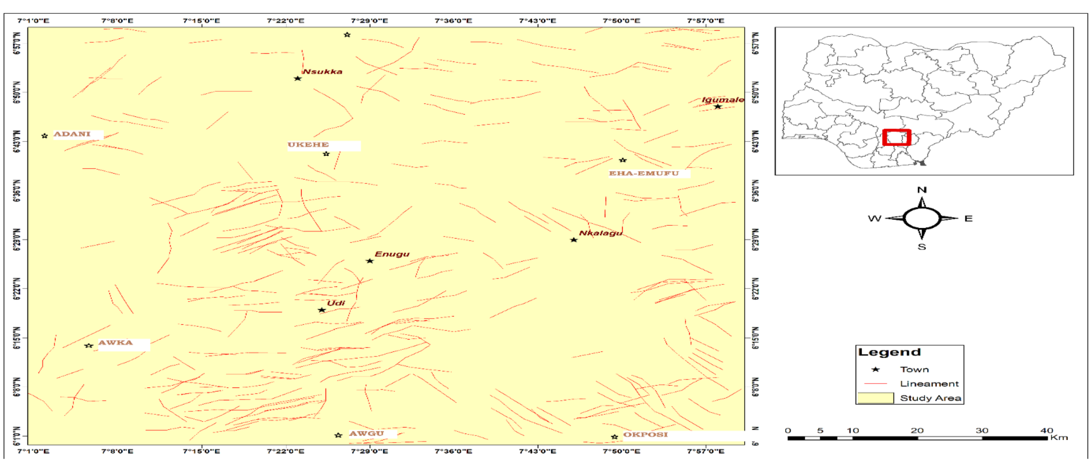

Figure 6. Magnetic Lineament map of the study area

Lineament orientation analysis (Figure 7), revealed that the study area is dominated mostly by NE-SW and NNE-SSW lineament orientations, with minor occurrences of NW-SE, N-S and E-W lineament orientations.

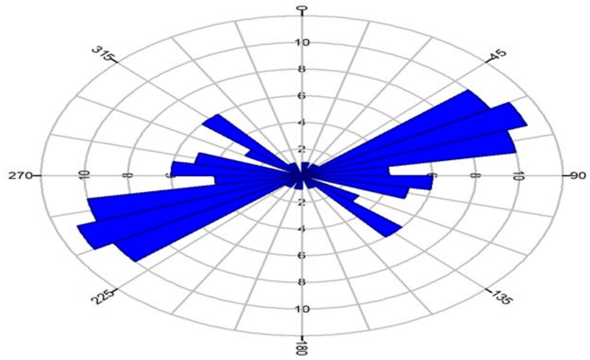

Figure 7. Magnetic rose diagram of the study area

The magnetic lineament density map varies from low to high density and correlates with the distribution of lineaments in the study (Figure 8). High lineament densities were delineated in Udi, and W and NE of Igumale and Eha-Amufu areas, respectively, while lows were mapped in Adani, Enugu-Ezike, Awka, Awgu, Enugu, Nsukka, Okposi, Nkalagu and Ukehe areas. These lineament density distributions are reflections of varying degrees of basement tectonics and faulting in the study area. The high lineament density indicates more deformed than the less deformed in low lineament density areas in the study [24].

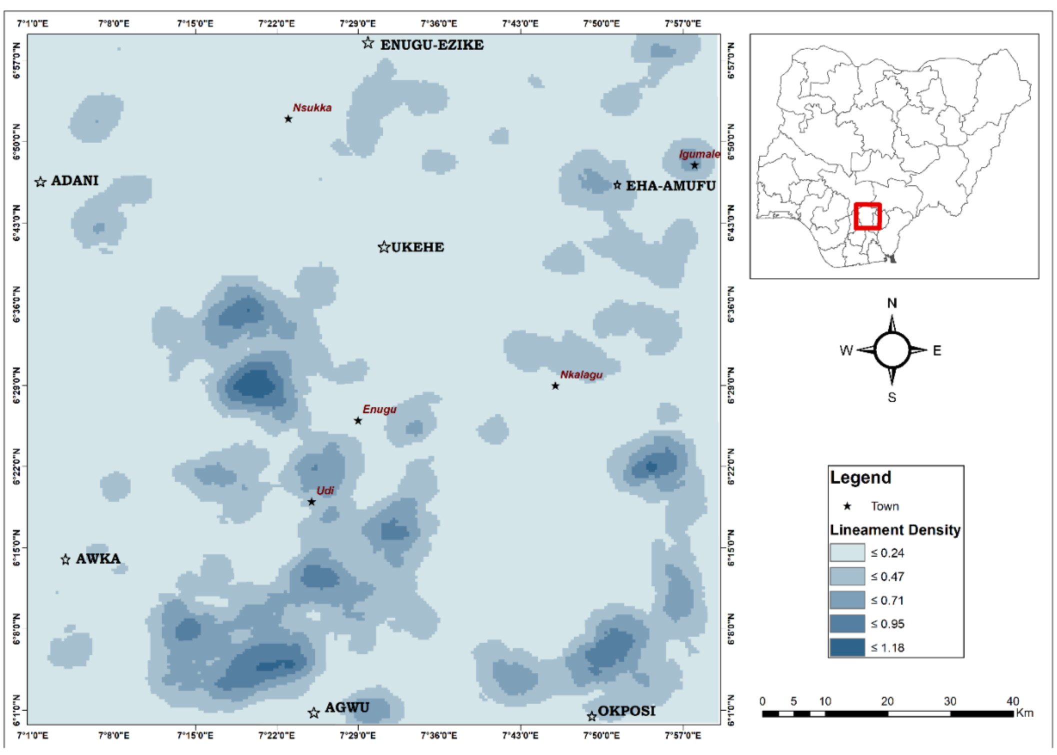

Figure 7. Magnetic lineament density map of the study area

5. Discussion of results

The maps of magnetic parameters (TMI, RMI, SPI) and Lineaments, exhibit characteristics colour gradations and magnetic anomalous distributions caused by subtle contrasts in magnetic susceptibilities of the underlying rocks, reflecting magnetic heterogeneity, structural, lithological and depths to anomalous source variations in the study area. These maps were visually analyzed and evaluated in terms of structure, lithology and contacts for possible indications of hydrocarbon prospect in the lower Benue trough.

The Total Magnetic Intensity (TMI) map is characterized by elliptical magnetic lows and ridge-like magnetic highs trending in the E-W direction. These magnetic signatures suggest anomalous magnetic features mostly of regional origin in the study. However, residual magnetic intensity (RMI) map exhibits distinct elliptical to isolated hemispherical magnetic lows bounded by ridge-like magnetic highs and both trends mostly in the NE-SW with minor E-W trend in contrast to the E-W trend delineated in the TMI map. This apparent discrepancy in structural orientation is attributed to magnetic susceptibility variations of local magnetic sources at shallow depths.

Low magnetic anomalies were delineated in Adani, Enugu-Ezike, Nsukka, Awka, Awgu, Enugu and Nkalagu areas while magnetic highs were delineated in Eha Amufu, Okposi, Igumale, Udi and Ukehe. Analysis of the SPI data revealed that sediment thickness vary from 95.5m in the shallow basement depths to 3318.8m in the large basement depths. This result is in agreement with the estimate of 3300m of sedimentary thickness by [25] and the works of [26-27] in the lower trough. Results show that the magnetic highs are characterized by shallow basement depths in contrast to the large basement depths in the magnetic low areas. The boundaries of these magnetic lows and highs are suspected to be linear belts of fracture zones or lithologic contacts running parallel to the NE-SW trend in line with the predominant tectonic trends of the trough [28-29].

Magnetic lineaments are widespread but densely distributed in the magnetic highs than low areas in the study area. The lineaments occur predominantly in the NE-SW and NNE-SSW lineament orientations, with minor occurrences in the NW-SE, E-W and N-S lineament orientations. Magnetic lineaments density analysis reveals variable lineament density across the study area. Lineament density varies from low to high densities and correlate with the spatial distribution of lineaments in the study. According to [24], high lineament density corresponds to the most deformed areas and low lineament density for less deformed areas. Therefore, high lineament densities in Enugu, Udi, Ukehe, Eha-Emufu and Igumale suggests that these areas are more deformed than the low lineament density areas of thick sediment cover in Adani, Enugu-Ezike, Awka, Agwu, Nkalagu and Okposi areas.

According to [17,30-31], sediment thickness greater than 2000m is favorable for the thermal maturation of potential source rocks and hydrocarbon formation. Shallow basements depths (-95.5m to -561.7m) with high magnetic intensities and high lineament densities were mapped in Enugu, Udi, Ukehe, Eha-Emufu and Igumale and suggests structurally deformed areas with less thick sediment cover unfavourable for hydrocarbon formation but with good prosspect for mineral deposits and groundwater resource. Large basement depths (-1661.2m to -3318.9m) with low magnetic intensities and low lineament densities were mapped in Adani, Enugu-Ezike, to the SW of the study between Awka and Awgu as well as to the NE of Okposi towards Nkalagu. This suggests structurally less deformed areas with thick sedimentary cover and comprised of rocks poor in magnetic content that are associated with potential source rocks and reservoirs favourable for hydrocarbon formation and accumulation in the lower trough.

Correlation of residual magnetic map with the geologic map revealed that areas of low magnetic anomalies with thick sedimentary cover correspond to parts of the Mamu and Nkporo shale formations and Ajali Sandstones. According to [16,21-22], Nkporo and Mamu shale Formations exhibit characteristics of potential hydrocarbon source rocks for a series of oil/gas and condensate shows found within the Ajali reservoir sandstones. The interbedded marine sandstone facies in the Nkporo and Mamu shales could provide additional reservoirs in the formations. The shales and claystones of the Nsukka and Imo Formations may provide regional seals to these petroleum systems in the trough.

6. Conclusion

Aeromagnetic data were analyzed to characterize magnetic features, in other to delineate prospective indications of hydrocarbon in parts of lower Benue trough. Residual magnetic intensity (RMI) map exhibits distinct elliptical to isolated hemispherical magnetic lows bounded by ridge-like magnetic highs and both trends mostly in the NE-SW with minor E-W trend. This apparent discrepancy in structural orientation is attributed to magnetic susceptibility variations of local magnetic sources at shallow depths. Low magnetic anomalies were delineated in Adani, Enugu-Ezike, Nsukka, Awka, Awgu, Enugu and Nkalagu areas while magnetic highs were delineated in Eha Amufu, Okposi, Igumale, Udi and Ukehe.

Magnetic lineaments are widespread but densely distributed in the magnetic highs than low areas. The lineaments trend predominantly in the NE-SW and NNE-SSW lineament orientations, with minor occurrences in the NW-SE, E-W and N-S lineament orientations. Lineament density varies from low to high densities and correlate with the spatial distribution of lineaments in the study. Therefore, high lineament densities in Enugu, Udi, Ukehe, Eha-Emufu and Igumale suggests that these areas are more deformed than the low lineament density areas of thick sediment cover in Adani, Enugu-Ezike, Awka, Agwu, Nkalagu and Okposi areas.

Areas of shallow basements depths (< 2000 m), with high magnetic intensities and high lineament densities were mapped in Enugu, Udi, Ukehe, Eha-Emufu and Igumale, suggesting structurally deformed areas with thin sediment cover unfavourable for hydrocarbon formation but with good prospect for mineral deposits and groundwater resource. While large basement depths (> 2000 m) with low magnetic intensities and low lineament densities were mapped in Adani, Enugu-Ezike, Awka Awgu, Okposi and Nkalagu suggesting structurally less deformed areas with thick sedimentary cover favourable for hydrocarbon formation and accumulation in the lower trough. Correlation of residual magnetic map with the geologic map revealed that areas of low magnetic anomalies with thick sedimentary cover (Adani, Enugu-Ezike, Awka, Agwu and Nkalagu) correspond to parts of the Mamu and Nkporo shale formations and Ajali Sandstones, reported to exhibit characteristics of potential hydrocarbon source rocks for a series of oil/gas and condensate shows found within the Ajali reservoir sandstones and were thus recommended for detailed seismic surveys.

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