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Evaluation of Hydrocarbon Prospect in Parts of Lower Benue Trough Magnetic and Remote Sensing Data

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Abstract

The study was meant to investigate for indications of hydrocarbon prospect using remote sensing and aeromagnetic data in parts of Lower Benue Trough. With the objective of evaluating structures and lithology that could have direct bearing to hydrocarbon formation. Oasis Montaj, Surfer 13, Arc GIS and Rockworld softwares were used for qualitative and quantitative interpretations. Results from remote sensing data revealed that lineament distributions, density and orientations vary across the study area. The escarpment (Agwu, Awka, Enugu, Nsukka, Udi and Ukehe) areas, have high prevalence of lineaments than the lowlands/valleys, suggesting a structurally deformed area. The magnetic data revealed low magnetic anomalies were delineated in Adani, Enugu-Ezike, Nsukka, Awka, Awgu, Enugu and Nkalagu while magnetic highs were delineated in Eha Amufu, Okposi, Igumale, Udi and Ukehe, indicating sedimentary and uplifted basement areas, respectively. Sediment thickness varies from < 2000m in Enugu, Udi, Ukehe, Eha-Emufu and Igumale and > 2000m in Adani, Enugu-Ezike, Awka Awgu, Okposi and Nkalagu areas. Remote sensing and magnetic lineament analysis show that NE-SW and NNE-SSW were the predominant lineament orientations, with minor occurrences in the NW-SE, E-W and N-S lineament orientations. Surface and subsurface lineaments correlate mostly within the escarpment zones (Enugu, Udi, Agwu and Awka), indicating the connectivity of these lineament structures and act as conduits for the upward propagation of hydrocarbon in the overlying sedimentary cover. While Adani, Nsukka, Ukehe, Enugu-Ezike and Nkalagu areas, with poor surface and subsurface lineament correlation suggests that the surface lineaments were not structurally connected to the subsurface structures and therefore, unfavourable for hydrocarbon formation but could be good prospect for mineral deposits and groundwater. Comparison of areas of high lineaments connectivity with areas of large sedimentary thickness (> 2000m), low magnetic intensities and geologic map, indicates that Awka and Awgu areas were the most probable hydrocarbon prospect areas.

Keywords: *Remote sensing; Aero magnetic; Escarpment; Hydrocarbon; Lineament; Benue trough.*

1. Introduction

As the hydrocarbon potential of the prolific Niger delta becomes depleted or in the near future may be exhausted due to continuous exploitation, attention needs to be shifted to other sedimentary basins [1]. The area under study is underlain by Cretaceous sediments of the lower Benue Trough, mainly comprising shales, sandstones and limestones considered to be non-magnetic. This basin possesses the requisite structural elements and stratigraphy similar to the contiguous basins of Chad and Niger Republics and Sudan, where commercial hydrocarbon discoveries have been made [2-5]. Aeromagnetic method and Remote sensing offers an attractive, robust and innovative reconnaissance technique that compliments the geophysical methods in the evaluation of hydrocarbon prospect.

Remote sensing and aeromagnetic survey prospecting techniques are suitable for field geological survey of area under difficult conditions and the both methods complement one another, mostly to improve the reliability of interpretation. Really the principles of the two methods are related in their ease of operation, coverage, accuracy, low cost and speed, but they both describe the characteristics and properties of observed geological body, by ascertaining

field information. There is a natural complementarity between remote sensing and aeromagnetic methods. Integrating remote-sensing and aeromagnetic data has the potential to define the qualitative details of hitherto unknown areas and reduce the ambiguity of geological interpretation [6-9]. Each of this methods have the application of identifying subsurface topographic and lineament structures favorable for exploration, hydrocarbon seepages and assessment of in-place hydrocarbon potentials [10-11]. The word "lineament" was first used by [12], who describe it as a significant linear landscape that exposes the architecture of different rock basement.

Aeromagnetic method of measurement tries to compare the magnetic differences between minerals (rocks) under the ground, through the measurement of magnetic signatures of geological body, distribution of mineral resources and also study the geological structure. It has the advantages of detecting great depth [13]. Because magnetic minerals may directly indicate the presence of oil and gas deposits, magnetic methods are applied to hydrocarbon exploration in oil bearing sedimentary basins. Isolation of weak magnetic anomalies sourced by low concentrations of the magnetic minerals present, is the ambiguity of magnetic method. These weak anomalies are often covered by much stronger magnetic anomalies caused by underlying basement rocks and/or by rocks in the basin sediments.

The remote sensing technology involve detecting physical, surface geometrical properties and surface radiation. On the other hand, satellite imagery has been proved as an important tool for mapping regional structures and geologic unit of an area. The availability of high resolution and multi-spectral data as well as the advanced potentialities of digital image processing techniques, in generating enhanced and interpretable image has further enlarged the potential of Remote Sensing in delineating the geological structure and lithological contacts in great details and with better accuracy. Paramount applications of Remote Sensing in geology involve the delineation of structures, discrimination of different rock and soil types and resource exploration. The application of remote sensing faces setbacks when it comes to interpretation of geological and structural data because different surface conditions such as vegetation, agricultural activities, weathering, urbanization and industrialization may act as hindrances to geological and structural signals.

Lineament indicate the form and position of individual lithologic contacts, folds, joints, faults, veins, and other geologic features that may have direction to the location of hydrocarbon deposits and these linear features are clearly recognizable on Landsat images and aeromagnetic maps. They constantly show the general geometry of surface and subsurface structures of an area thereby providing a regional structural pattern. The need for studying and comparing geologic structures such as lineaments (which include faults, joints and fractures) cannot be overemphasized. This is because, they do not only act as zones for ores and minerals deposits, but also act as reservoirs for oil, gas and water storage.

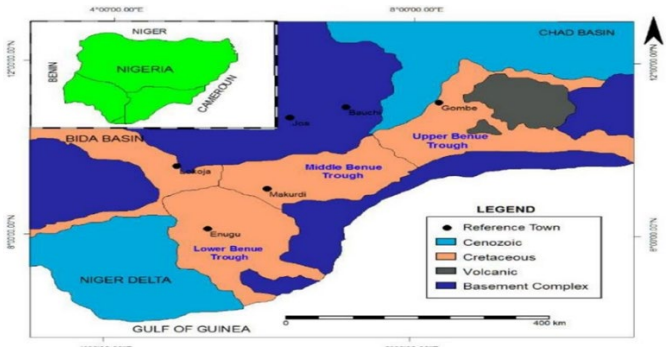

Figure 1. Location map of the study area (after [15]).

This present study, delineate and map the surface lineaments and compared them with subsurface lineaments for evaluation of hydrocarbon prospect zones in parts of the lower Benue Trough. The study area lies in the lower Benue basin and delineated by latitude 6°00'N–7°00'N and longitude 7°00'E–8°00'E (Fig. 1), covering most parts of Anambra, Benue, Ebonyi and Enugu States. The area is characterized by mixed biomes and rainfall is at its peak in June and low in November with average daily temperature of 32°C [14].

2. Geology of the study area

The study area falls within the Abakaliki, Anambra and Afikpo geological belts in the lower Benue basin. The basin is underlain by thick pile of sedimentary rocks from early Cretacous - Tertiary, with intra-sedimentary igneous intrusions from the Precambrian basement. The Basement Complex consist of essentially granitic and magmatic rocks which outcrop mostly in the eastern portion of the study area [16].

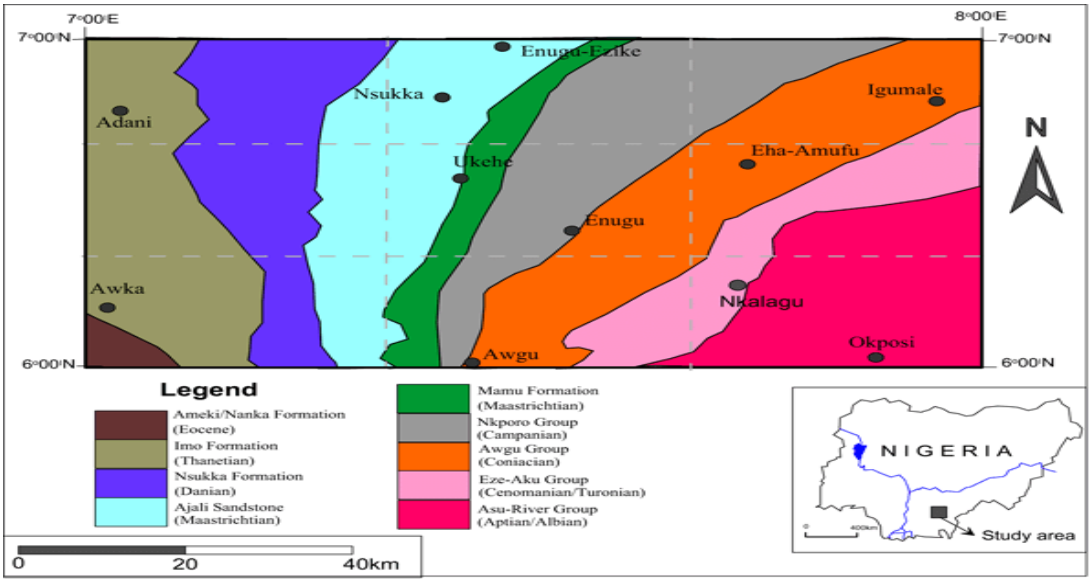

Figure 2. Geologic map of the study area [17].

The stratigraphic sequence of the lower Benue basin range in age from the Aptian to mid Eocene. It is comprised of the Asu River Group, Eze-Aku, Awgu, Nkporo Group, Mamu, Ajali, Nsukka, Imo and Bende-Ameki Formations (Figure 2).

At least two potential petroleum systems exist in the basin: The Lower Cretaceous petroleum system likely capable of both oil and gas generation and the Upper Cretaceous petroleum system that could be mainly gas-generating [4,18-19]. The trough is characterized by structural lineaments which controls both tectonic and magmatic activities as well as sedimentary depositions in the basin [20-21].

2.1. Method of the study

In this study, the aeromagnetic data and remote sensing imagery were the preferred option for lineament mapping and extraction. Four sheets of high-resolution aeromagnetic data over Nsukka, Igumale, Udi and Nkalagu areas were obtained from the Nigeria Geological Survey Agency [22]. 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 and processed by removal of regional magnetic effects through the application of filtering (regional-residual separation) to generate a residual magnetic map of the study, 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 15 software program.

Lineaments were also interpreted using Landsat-8 OLI/TIRS and Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM) data on 1:50,000 scale. The lineaments were identified and interpreted on the basis of tonal lineaments, straightness of river course, soil tonal lineaments and topographic and vegetation alignments. Data enhancement techniques such as filtering operations, were applied to data

to enhance lineament extraction. Structural lineament features were delineated using PCI Geomatica 14.0, and subsequently, an orientation analysis via rose diagram were carried out using Rockworks 15 software to detect the basic structural trend of the study area.

Furthermore, composite map of the area was generated using Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM) data. These were to guide in the delineation of favorable areas for exploration.

Finally, these maps (from aeromagnetic and remote sensing data) were analyzed visually on the basis of amplitude and shape as well as identification of anomalous boundaries, volcanic zones, surface and subsurface lineaments and other regional structures that could be akin to those that is associated with probable petroleum accumulations.

3. Presentation of result

The results obtained from the integration of aeromagnetic and remote sensing data were transferred into information through variety of maps. These maps include surface and subsurface lineament density, composite, residual magnetic intensity (RMI) and rose diagram. The maps were visually inspected, analyzed and interpreted for indications of hydrocarbon prospects in parts of the lower Benue Basin.

3.1. Composite analysis

RGB Composite analysis (Figure 3), of the elevation map was carried out for the recognition of subtle features that were ab initio not apparent in the elevation map. The map shows that the escarpment thickens towards the NE and thins in the SW. Evidence of faulting along the escarpment to the East is also visible on the map. Result also reveal that the western part of the escarpment is steeper than the eastern part with high drainage density and vegetation index, which suggests deformation by faulting.

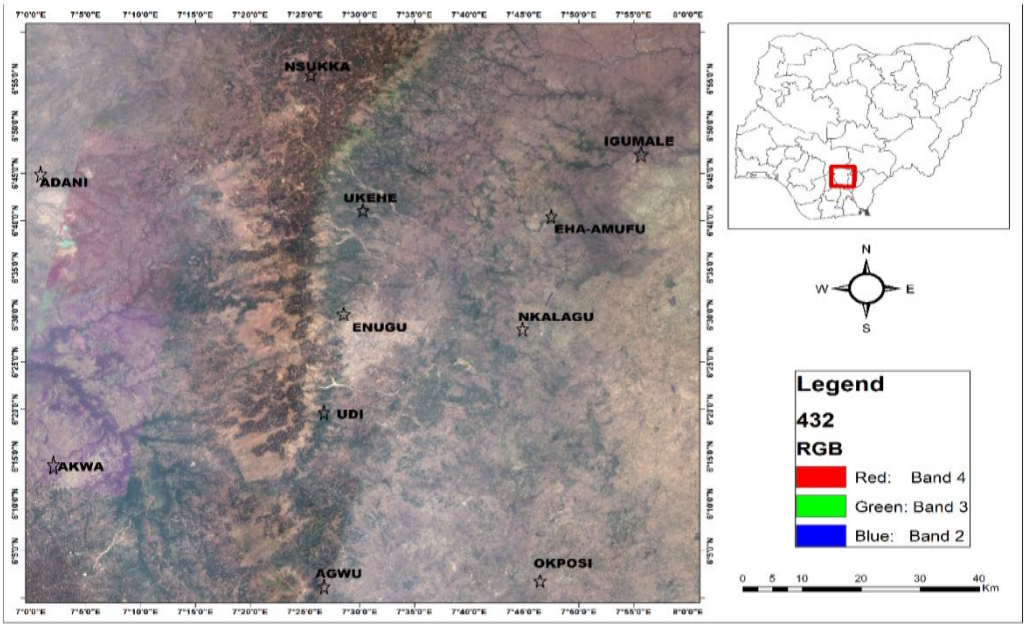

Figure 3. Composite Map of the study area [14].

3.2. Lineament and drainage overlay map

The drainage is sourced from the flanks of the escarpment in the study area. The NE-SW flowing streams dominate the western and southwestern parts and exhibit characteristic dendritic drainage pattern, while The NW-SE flowing streams occur mainly in the eastern and southeastern parts with parallel drainage pattern (Figure 4). These drainage patterns have

tectonic and lithological connotations and could be related to hydrocarbon prospect zones in the basin.

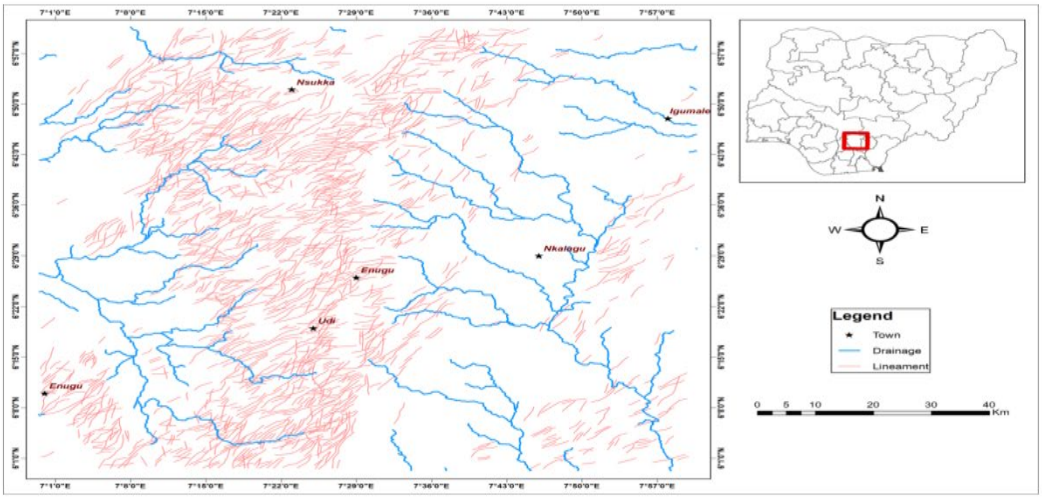

Figure 4. Lineament and drainage map overlay [14].

3.3. Landsat lineament density analysis

The lineament density map varies from low, medium and high density (Figure 5). Agwu, Awka, Enugu, Nsukka, Udi, Ukehe areas lie in medium to high lineament density zones, while Adanu, Nkalagu and Igumale areas lie in low lineament density zones. According to [22], areas with high lineament density are likely to be the most deformed than areas with lower degree of deformation. Therefore, the observed high lineament density on the escarpment indicates that the escarpment was more deformed than surrounding lowland/valley areas in the study area.

Lineament orientation analysis using geostatical rose diagram (Figure 6), suggests a monodirectional structural control in the basin. The study area is dominated mostly by NE-SW lineament orientation, with minor occurrences of NW-SE, N-S and E-W lineament orientations.

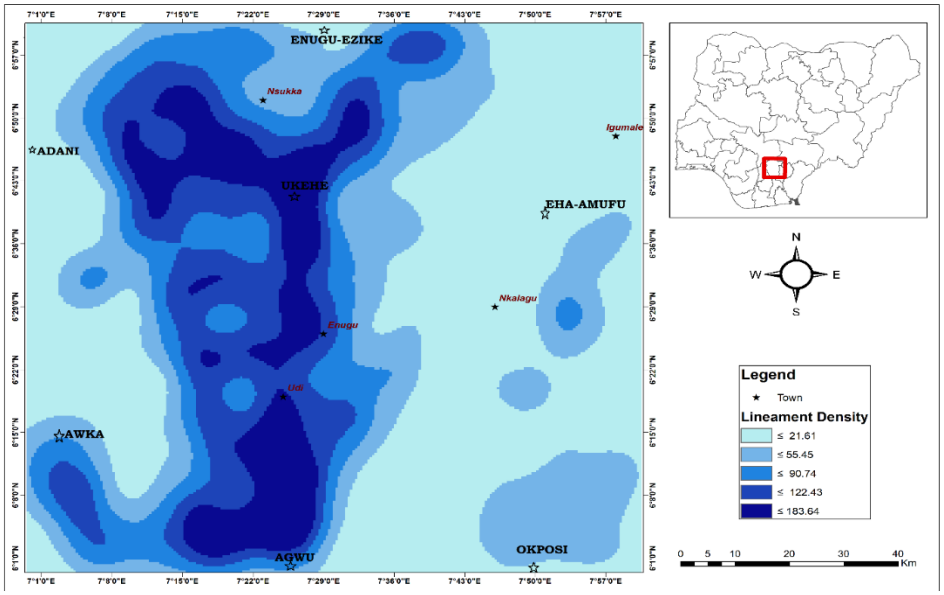

Figure 5. Landsat Lineament Density Map of the study area [14].

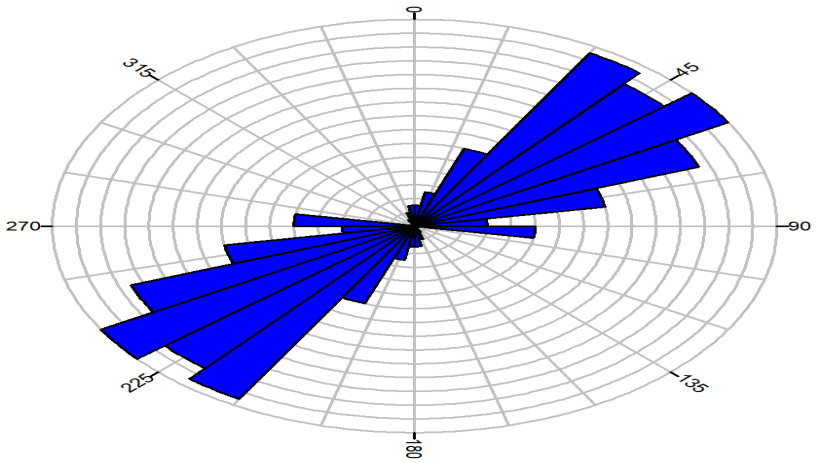

Figure 6. Landsat Rose Diagram of the study area [14].

3.4. Residual magnetic intensity (RMI) analysis

The residual magnetic intensity (RMI) map (Figure 7), is dominated by local anomalous features within the sedimentary thickness. It exhibits characteristics low, medium and high magnetic anomalous signatures with intensities varying from -52.80nT to 54.11nT. The elongated to rounded low, medium and ridge-like high magnetic anomalies have intensities varying from -52nT to 1.12nT, 2.73nT to10.31nT and 11.79nT to 54.11nT, respectively.

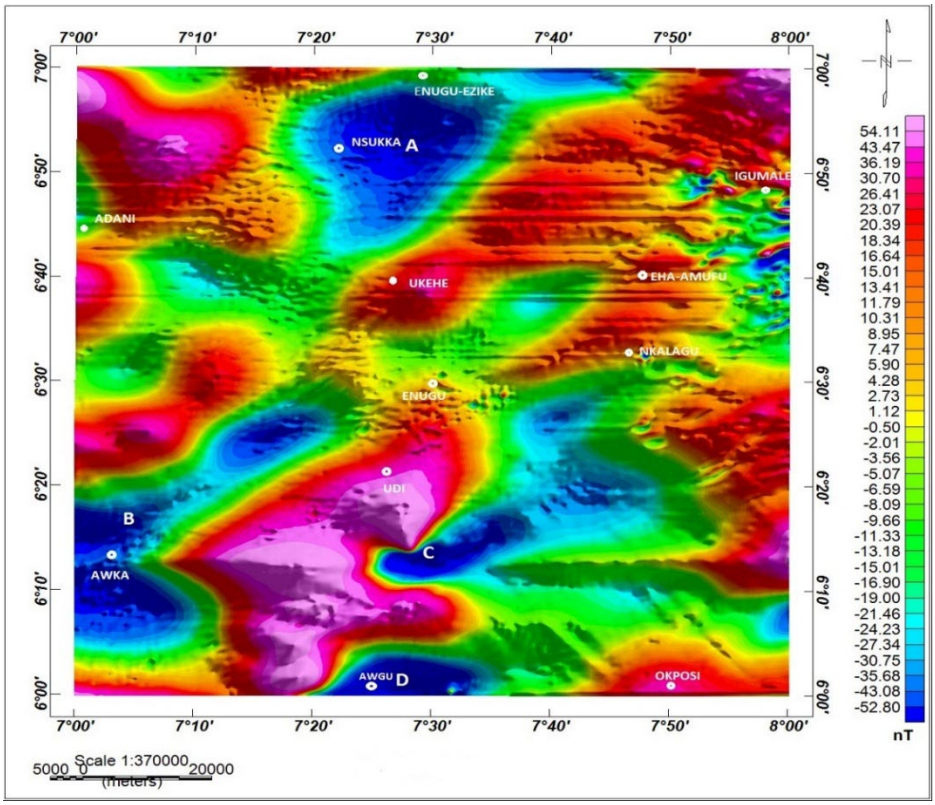

Figure 7 Residual magnetic intensity (RMI) map of the study area [23].

Low magnetic intensities were delineated at locations A, B, C and D (Nsukka. Akwa, and Agwu) alternating with the medium to high magnetic intensities (at Udi, Ukehe and Nkalagu).

These broad areas of low intensities correspond to thick sedimentary cover over a deeply buried magnetic basement. The medium to high magnetic intensities correspond to thin sedimentary cover over shallow and uplifted magnetic basements. The alternation between low and high anomalies with steep gradients and elongated anomalous features indicate the presence of faults or contacts that divided the studied area into several blocks with different magnetization contrasts. The magnetic anomalies trend dominantly in the NE-SW, in line with the tectonic trend of the basin.

3.5. Source parameter imaging

Source Parameter Imaging (SPI) map displays the depth to magnetic sources in the study area (Figure 8). 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.

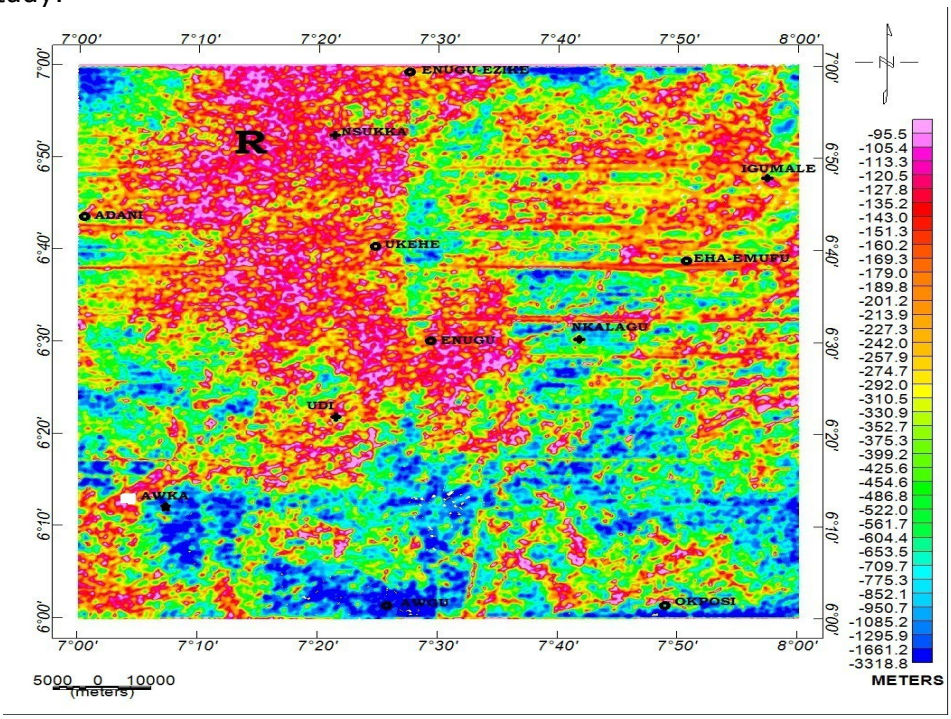

Figure 8. Source Parameter Imaging (SPI) map of the study area [23].

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.

3.6. Magnetic lineament density analysis

The magnetic lineament density (Figure 9) correlates with the distribution of faults/contacts in the area. High lineament densities were delineated around Enugu, Udi, Akwa and Okwosi areas and low densities in Nsukka, Igumale, Adani, Ukehe, Eha Amufu and Nkalagu areas. These variations in lineament densities are reflections of varying basement tectonics and faulting of the overlying sedimentary cover. The lineament rose diagram (Figure 10), quantitatively show a dominant NNE-SSW trend with minor NW-SE and E-W trends in the study area.

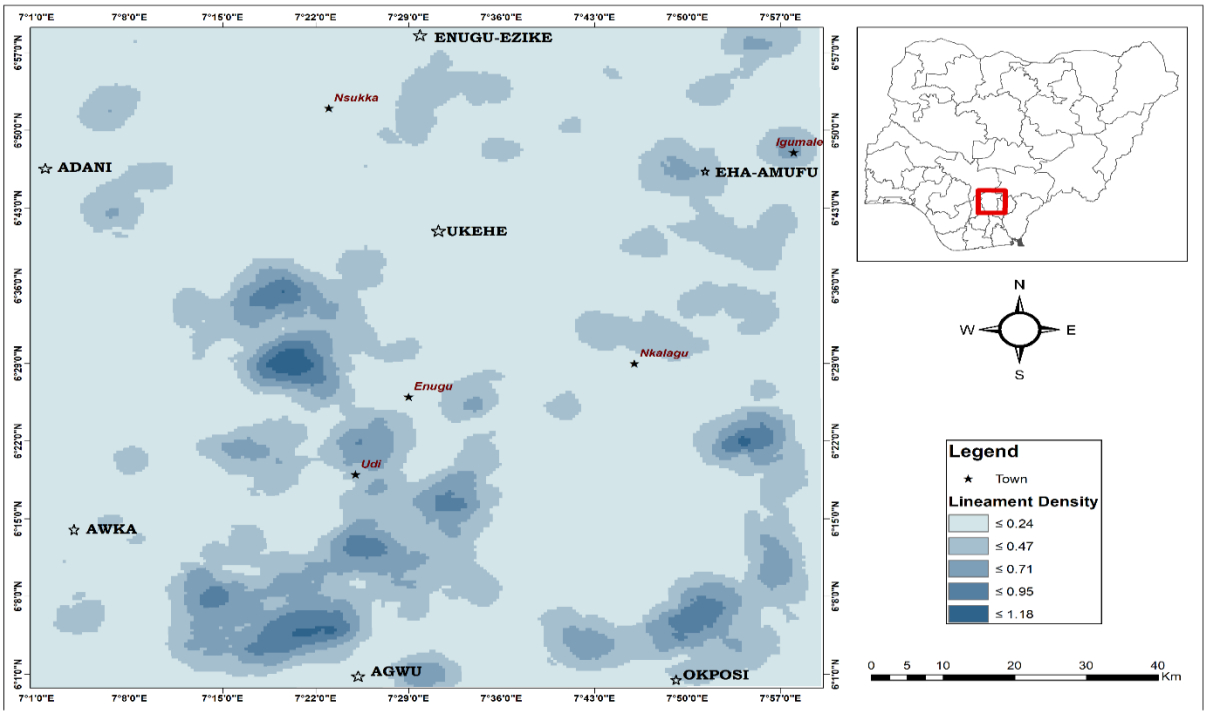

Figure 9. Magnetic lineament density map of the study area [23].

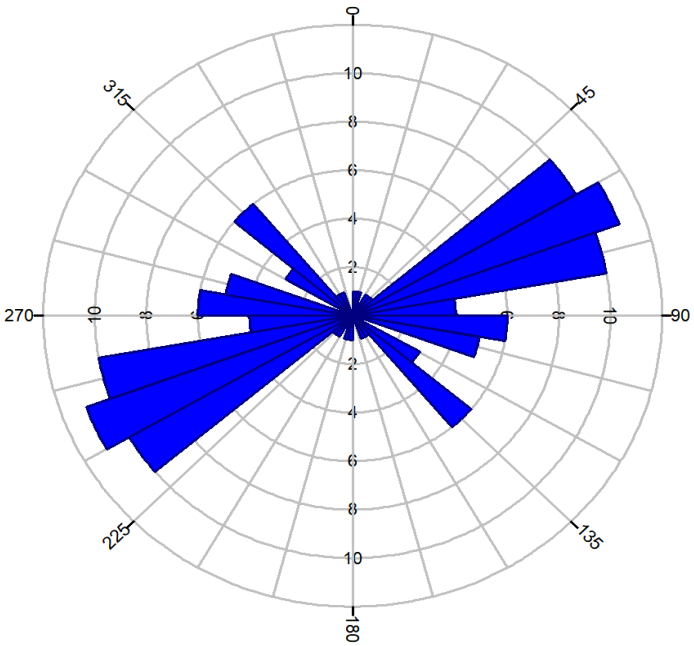

Figure 10. Magnetic rose diagram of the study area [23].

3.7. Aeromagnetic lineament and landsat lineament overlay analysis

Aeromagnetic and Landsat lineament overlay map (Figure 11), compares the distribution of the surface lineaments and subsurface lineament of the study area.

Dense surface and subsurface lineaments correlate mostly within the escarpment zones (Enugu, Udi, Agwu and Awka area) showing that the surface lineaments were structurally controlled by the subsurface lineaments. The structural lineament orientation of these areas

are dominated mostly by NE-SW. This result indicates the connectivity of these surface lineaments with deep seated structures and suggests that the highlands are structurally deformed.

There is low correlation of surface lineaments and subsurface lineaments mostly around Adani, Nsukka, Ukehe, Enugu-Ezike and Nkalagu areas and lineament orientation around these areas are dissimilar, with surface lineament trending mostly NE-SW while the subsurface lineament trend NW-SE. This is in confirmation of the fact that the lowlands are structurally less deformed.

Areas that did not show strong correlation in distribution of the magnitude of the subsurface lineament and surface lineament (Igumale, Okposi, and Eha-Amufu), suggest that the area varies in lineament intensity due to different stress regimes that affected the area at different geological time.

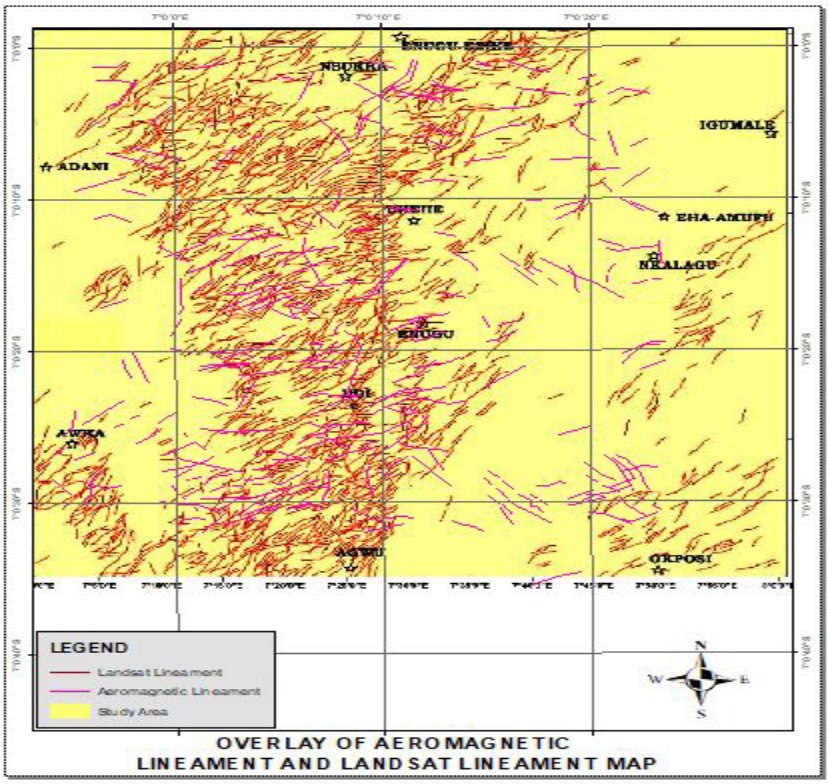

Figure 11. Aeromagnetic and Landsat Lineament overlay map of the study area.

4. Discussion of remote sensing result

Drainage channels are similar in orientation with the lineaments and elevation in the study, which revealed that high drainage network corresponds to high lineament density especially, to the west and southwest of the study. The drainage channels and the escarpment are characterized by high NDVI values, indicating the importance of moisture on plant growth. Agwu, Awka, Enugu, Nsukka, Udi and Ukehe located on the escarpment lie in medium to high lineament density, suggesting a structurally deformed zone capable of developing petroleum entrapment structures with probable hydrocarbon prospect. while Adanu, Nkalagu and Igumale in the lowlands/valleys lie in low lineament density, suggesting less deformed zone [24].

The NE-SW dominant lineament orientation and the NW-SE, N-S and E-W less dominant lineament orientations, is in line with the trend of the basin and agrees with the works of [25-27]. The NE-SW dominant lineament orientation and minor occurrences of NW-SE, N-S and E-W lineaments are imprints of the continental extensions of the underlying basement faults and associations, propagated into the weak overlying sedimentary strata by tectonic forces in the basin [26-28]. The connectivity and spatial relationships between these surface lineaments and

their supposed basement counterparts, could provide mechanism for probable hydrocarbon migration and entrapment in the overlying sedimentary rocks.
The result of this present study was validated by correlating lineament density and location of known hydrocarbon seepage in the study. Result revealed that high lineament density correlates with known location of hydrocarbon seepage around Egwueme in Agwu escarpment, indicating the connectivity of these lineaments with deep seated structures.

5. Discussion of aeromagnetic result

Areas with high magnetic intensities and high lineament densitie mapped in Enugu, Udi, Ukehe, Eha-Emufu and Igumale are characterized with less thick sediment cover (-95.5m to -1661.2m) and suggests structurally deformed areas unfavourable for hydrocarbon formation but with good prosspect for mineral deposits and groundwater resource.

Areas with low magnetic intensities and low lineament densities mapped in the SW of the study between Awka and Awgu as well as in the NE of Okposi towards Nkalagu are characterized with thick sediment cover (-1661.2m to -3318.9m). 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. According to [29-31], sediment thickness greater than 2000m is favorable for the thermal maturation of potential source rocks and hydrocarbon formation.

Correlation of residual magnetic map with the geologic map revealed that areas of low magnetic anomalies with thick sedimentary cover are underlain by the Mamu and Nkporo shale formations and Ajali Sandstones. According to [32-34], 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.

Adani, Enugu-Ezike, Awka Awgu, Okposi and Nkalagu were thus recommended for detailed seismic surveys. 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.

6. Correlation of surface and subsurface lineament structures

In the overlay analysis, surface lineaments and subsurface lineaments are densely spread and parallel to each other within the escarpment zones. The result obtained from the correlation of these lineaments structures, shows that surface lineament and subsurface lineament correlate mostly within the escarpment zones (Enugu, Udi, Agwu and Awka areas). This suggests that the surface lineaments are structurally controlled by their subsurface counterparts, trending majorly in Northeast– Southwest direction [35-36].

The result revealed that these surface lineaments are structurally connected with their subsurface counterparts in the study. The connectivity of these lineament structures act as conduits for the upward propagation of hydrocarbon in the overlying sedimentary cover, for hydrocarbon formation and accumulation in the lower trough.

Adani, Nsukka, Ukehe, Enugu-Ezike and Nkalagu areas, with poor surface and subsurface lineament correlations and distributions suggests that these surface lineaments were not structurally connected to the deep-seated structures, which is unfavourable for hydrocarbon formation but could be good prospect for mineral deposits and groundwater. The surface and subsurface lineament orientation are antiparallel with each other, while the surface and subsurface lineament orientations trends NE-SW and NW-SE, respectively. According to [37] when basement surface has been affected by different stress regime in different geological times, it results in the reactivation of various ancient faults along different directions. During the process of reactivation and propagation in the lower trough, additional sets of faults and fractures could have been developed which may account for the poor correlations in lineament orientations in the study.

Surface and subsurface lineaments around Igumale, Okposi, and Eha-Amufu areas, did not correlate in distribution and orientation. Which is attributed to the variation in tensional and

compressional forces within the surface and the subsurface of the areas or the stress field intensity prevalent in the basement, that affected the area at different geological time.

Comparison of areas of high lineaments connectivity (Enugu, Udi, Agwu and Awka) with areas of large sedimentary thickness (> 2000 m), low magnetic intensities (Adani, Enugu-Ezike, Awka Awgu, Okposi and Nkalagu) and geologic map, indicate that Awka and Awgu areas were the most probable hydrocarbon prospect areas and are underlain by the Mamu and Nkporo shale formations and Ajali Sandstones. Awka and Awgu were delineated as the most probable hydrocarbon prospect areas (were surface and subsurface structures correlate perfectly), for further geophysical studies.

Implying that the basement in the area is structurally deformed with high fracture connectivity and could have direct bearings to geological structures, where oil containment structures or hydrocarbon plays may develop in the trough. The result of this present study was validated with the work of [38], around Egwueme in Agwu escarpment, were there is evidence of surface hydrocarbon seepage and connectivity of these lineaments in the trough.

7. Conclusion

In the present study, remote sensing and aeromagnetic analysis was conducted for extracting lineaments, sedimentary thickness and terrain attributes for hydrocarbon prospect evaluation in parts of the lower Benue basin.

The result obtained from the correlation of lineaments structures, shows that surface and subsurface lineaments correlate mostly within the escarpment zones (Enugu, Udi, Agwu and Awka areas), were the connectivity of these lineament structures act as conduits for the upward propagation of hydrocarbon in the overlying sedimentary cover in the lower trough. While Adani, Nsukka, Ukehe, Enugu-Ezike and Nkalagu areas, with poor surface and subsurface lineament correlations and distributions suggests that the surface lineaments were not structurally connected to the deep-seated structures, which is unfavourable for hydrocarbon formation but could be good prospect for mineral deposits and groundwater.

Comparison of areas of high lineaments connectivity (Enugu, Udi, Agwu and Awka) with areas of large sedimentary thickness (> 2000 m), low magnetic intensities (Adani, Enugu-Ezike, Awka Awgu, Okposi and Nkalagu) and geologic map, indicate that Awka and Awgu areas were the most probable hydrocarbon prospect areas and are underlain by the Mamu and Nkporo shale formations and Ajali Sandstones. This result agrees with the work of [38], around Awgu were there is evidence of surface hydrocarbon seepage.

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