ISSN: 2866 – 2441
Volume 13, Number 3, 2022
International Journal of Advancement in Physical Sciences

APPLICATION OF AEROMAGNETIC AND LANDSAT ETM-DATA IN THE INTERPRETATION OF STRUCTURES IN PARTS OF ANAMBRA BASIN, SOUTH-EASTERN NIGERIA

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ABSTRACT

Structural interpretation in parts of Anambra Basin in south-eastern Nigeria was conducted using aeromagnetic and Landsat-ETM data to identify the lineaments associated with the study area and to construe the effect of structures on the drainage system and its potential for hydrocarbon. The study area is geographically situated between longitude $7^0 00'E – 7^0 30'E$ and latitude $6^0 00'N – 6^0 30'N$. The study demonstrates the advantages of applying digitally processed Landsat-ETM data and Aeromagnetic data for geologic mapping. The data was processed and enhanced to give fractures /lineaments, geologic maps, drainage pattern, and colour composites. Trend analysis of the lineaments revealed on a rose diagram and from the regional plots displayed structural trends of the study area to be in NW-SE, NE-SW, N-S and E-W directions respectively but NW-SE was the most prevailing. When the Landsat data was compared with the aeromagnetic data, it was observed that the areas with high lineament density are also the areas with high basement relief where as low lineament density areas are characteristic of low basement relief. The spectral analysis of the study area revealed a depth to basement ranging from 1.9 km to 5.3 km with an average of 4.0 km which is unsuitable for the production of hydrocarbon. These shallower depths could be as a result of basement rocks that intruded into the sedimentary formations.

INTRODUCTION

The Anambra basin like every other sedimentary basins, has its peculiar characteristics, which can be attributed to its geographic location (Opara, 2011). The Benue trough in which the Anambra Basin is located is marked by a lot of igneous activities. Both magnetic and LANDSAT methods have a great deal in common and an interface for geological interpretation can be established between them (Opara *et al*., 2011). They are both extensively used as reconnaissance tools in oil exploration, mineral exploration as well as deep crustal studies. For the past twenty years, there have been new revolution in the use of aeromagnetic surveys from the interpretation of solely basement structures to detailed examination of structure and lithologic variations in the sedimentary sections. In many sedimentary basins, magnetic anomalies result from secondary mineralization along fault planes, which are often revealed on aeromagnetic maps as surface linear features (Opara, 2001). Some lineament patterns have been defined to be the most favourable structural conditions in control of various mineral deposits. Linear features are clearly discernible on aeromagnetic maps and often indicate the form and position of individual folds, faults, joints, veins, lithologic contacts, and other geologic features that may lead to the location of individual mineral deposits. They often indicate the general geometry of subsurface structures of an area thereby providing a regional structural pattern.

The inherent magnetism of rocks called magnetic susceptibility which depends on the amount of magnetite (Fe_3O_4) contained in the rock unit is caused by changes in the subsurface geologic

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structures (Dobrin *et al.*, 1988). The magnetic method is useful whenever the object of investigation has a contrast in the magnetic susceptibility or remanence that can be detected by the magnetometer and is measured in nanotesla (nT) or gamma (γ) units.

The traditional role of aeromagnetic studies over continental areas has been in establishing geologic and tectonic framework sand in exploring for mineral and other commodities. Magnetic anomalies can be defined by aeromagnetic surveys and interpreted in terms of the depth to the basement rock surface and consequently the thickness of overlying sedimentary rocks. The magnetic data can also be used to determine relief on the basement surface that may be directly related to structures favourable for accumulation of gas and oil in overlying sedimentary rocks. Thus, with magnetic data, it is possible to identify areas with potential for occurrence of petroleum and to provide information on thickness of sedimentary rocks plus some information on possible structures in sedimentary rocks.

The study is aimed at identifying and interpreting the structures associated with the area of study and to determine the potentials, economic or otherwise of the area using the aeromagnetic (depth to magnetic basement, which by implication is the sedimentary thickness of the area) and LANDSAT Enhancement Thematic mapper satellite imagery analysis. The objective of the study is to extract all possible information from the study area as far as the scope per

Location and Physiography of the Study Area

The study area is part of Anambra Basin, south Eastern Nigeria, which lies between longitude 7^0 00'E – 7^0 30'E and latitude 6^0 00'N – 6^0 30'N. The basin is 300 Km NE – SW trending syncline, located at the south western dip of the Benue trough in south eastern Nigeria. The trough is characteristically linear in slope and its sedimentary formations are continuous with the Nigerian Coastal Basin. It is characterized by hills and valleys. This hills and ridges were formed due to the resistance of sandstones to agent of denudation such as erosions etc. the plains and the valleys were formed as a result of the shales that were not resistant to agents of denudation. Therefore, the landform is as a result of the difference in the degree of resistance to agents of denudation and the bedrock varies from basement complex to shales, marls, and limestone, as well as sandstones and unconsolidated to semi-consolidated sands (Ukaegbu and Akpabio, 2009).

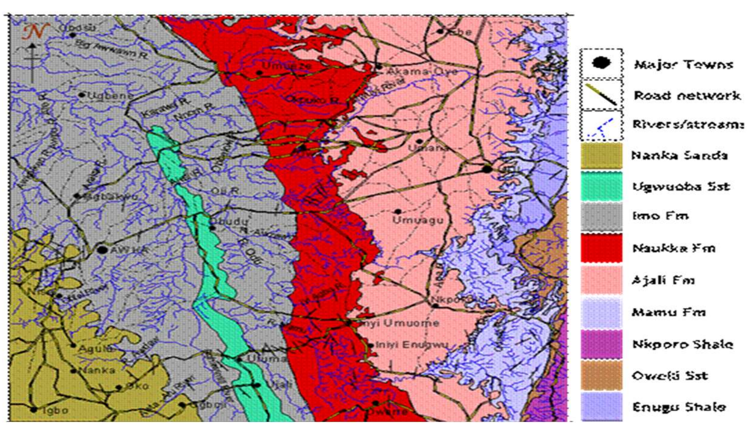

Figure 1: Geological map of the study area.
Source: Opara *et al.*, 2011

MATERIALS AND METHODS

The aeromagnetic maps exploited for the study were obtained from the Geological Survey of Nigeria. The nominal flying altitude above the terrain was 500 feet (approximately 152m) with flight line and tie-line spacing of 2km and 20km respectively. However, the flight and tie line direction is 150º/330º and 60º/240º respectively. The regional correction of the magnetic data was based on IGRI (Epoch data, 1 January, 1974).

The first phase of digital processing of the contoured aeromagnetic total intensity field map on 1:100,000 (Plate 1) was digitization. The map was digitized manually with a 2cm by 2cm (equivalent to 2km by 2km) grid spacing. The method of interpolation adopted is the Kriging method. This method determines the most probable value at each grid-node from the surrounding real data values. This was done by noting the coordinates (X and Y) and magnetic value (Z), forming a XYZ file. This is continuously done at every grid-node interval across the flight-lines. This produces XYZ as text files. These are run as 2XYZ program of the United States Geological Service (USGS) Potential Field method (Version 2.2 software) and Surfer Software to convert the binary numbers to post files called PST files. The Detour program, a Fortran 77 program is launched to view the data on screen to check errors. The Detour program produces the minimum and maximum values of X, Y, Z and shows the contour intervals. Geocon program, a screen viewing, shows the contouring interval. The contour program finally plots the Command (cmd) file to produce a total magnetic intensity map.

Various potential field softwares such as Oasis Montaj 8.3 HJ version, Surfer 10 and Matlab 8.1 with their respective analytical modules were used. Regional-residual separation was carried out using polynomial fitting, an analytical method in which matching of the regional by a polynomial surface of low order which exposes the residual features as random errors. The polynomial residual map was then subjected to the Fast Fourier Transformation software (FFTIL) to carry out further analysis.

Applying the complex form, the 2Dnal Fourier transform pair may be written in the forms as expressed in (1) and (2):

$$G(u,v) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} g(x,y)e^{-j(u_x+v_y)}dxdy \cdots\cdots\cdots \quad (1)$$

and

$$g(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} G(u,v)e^{j(u_x+v_y)}dudv \cdots\cdots\cdots \quad (2)$$

where u and v are respectively the angular frequencies in the x and y directions. This technique involves some practical problems such as aliasing, truncating effect or Gibb's phenomenon and those associated with even and odd symmetries of the real and imaginary parts of the Fourier transform (Opara *et al.*, 2014). These problems were taken care of by the software applied in the analysis.

The residual total intensity anomaly values of a given residual magnetic anomaly map of dimensions 1 x 1, can be expressed in terms of a double Fourier series expression as in (1):

$$T(x,y) = \sum_{n=1}^{N}\sum_{m=1}^{M} P_m^n \cos\left\{\left(\frac{2\pi}{l}\right)(nx+my)\right\} + Q_m^n \sin\left\{\left(\frac{2\pi}{l}\right)(nx+my)\right\} \cdots\cdots \quad (3)$$

where, 1= dimensions of the block, P_m^n and Q_m^n are the Fourier amplitudes, and N and M are the number of the grid points along the x and y directions respectively.

Reduction to the Pole (RTP) which eliminate the effects of geomagnetic latitude by applying a mathematical filter to the gridded data to produce an anomaly map that would have resulted had the area of interest been surveyed at the magnetic pole was performed (Reynolds, 2011). Likely, the first and second Vertical Derivatives which are similar to observing the vertical gradients directly with magnetic gradiometer and have the same advantages, namely enhancing shallow sources, suppressing deeper ones, and giving a better resolution of closely-spaced sources were also performed (Reeves, 2005). Upward and Downward Continuation filters transforming the data to what it should have been if the measurements had been made at different heights above the source were also carried out (Dentith *et al*., 2014).

Average depth values to buried magnetic rocks adopting the power spectrum of total intensity field were achieved using spectral analysis. These depths were established from the slope of the log-power spectrum at the lower end of the total wave number or spatial frequency band. The technique allows an estimate of the depth of an ensemble of magnetized blocks of changing depth, width, thickness and magnetization.

Landsat Thematic Mapper (Landsat 7 ETM) imagery acquired on April 2009 from NASRDA, Nigeria was used to map linear structures in the study area. The raw data was geo-referenced using the coordinates of the topographic sheets in the study area. The geo-reference projection was conducted using the Universal Transverse Mercator (UTM). Image processing, enhancement and analysis were conducted using ILWIS 3.1 Academic software. Image enhancement operations carried out on the imagery include contrast stretching, spatial filtering, edge enhancement and colour composite generation. The ArcView 6.3 software was used to extract the lineaments and carry out statistical analysis of the interpreted lineaments in the study area.

RESULTS AND DISCUSSION

Total field map and Total Magnetic Field Intensity map

The clustering of magnetic anomalies around the South Eastern part of the study area indicates a high basement relief. The basement in the area can be said to be close to the surface. Such areas have very low ability to produce hydrocarbons as there is not enough depth for deep burial and subsequently thermal maturation. However, because of the igneous and metamorphic nature of the basement, it has a high mineralisation potential.

The colour coded total magnetic field intensity map shown in Figure 2 has the areas with high magnetic intensity around the area colour coded light pink and pink (magnetic strengths of 7890 – 7970ngammas), followed by respectively in the order of decreasing intensity. The area colour coded yellow and green can be said to be of intermediate intensity of the study area with those coloured dark blue and subsequently light blue with the lowest intensity. This blue coded area is low basement relief.

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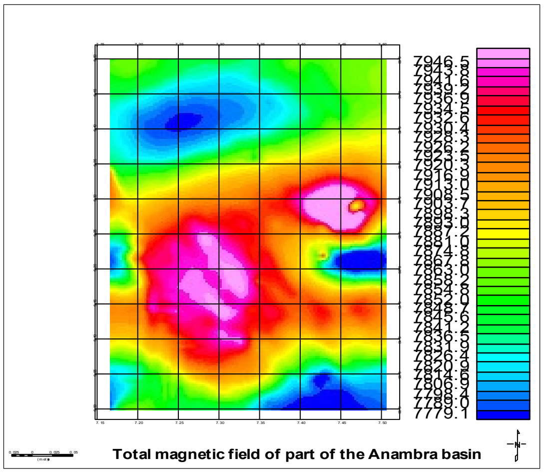

Figure 1: Total field map of study area

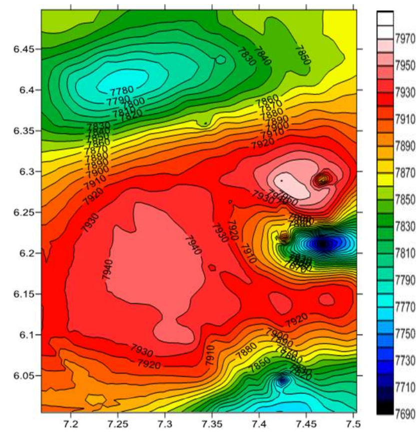

Figure 2: Colour coded Total Magnetic Field Intensity

3 D Surface and Wireframe maps of the total field of the aeromagnetic data

The 3D surface and wire maps in fig. 3 and fig. 4 helped to provide information on basement topography and relief. Three dimensional surface map generated clearly indicates areas of high magnetic intensity. The areas with high magnetic intensity is indicated as an uplifted area with the highest point being the blue shaded area, this blue coloured area has the highest basement relief of the study area. The 3D surface map of the area effectively shows the shape and features of the basement underlying the deposited sediments. It is the basement that produces the magnetic field recorded by the magnetometer for this study. The areas coloured green has the lowest basement relief and these areas would definitely contain more sedimentary deposits than the areas with high basement relief.

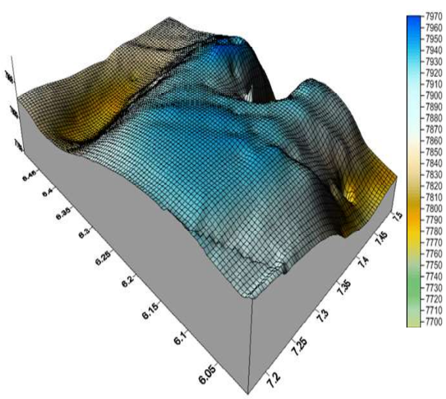

Figure 3: 3D Surface map of the total field of the aeromagnetic data of the study area

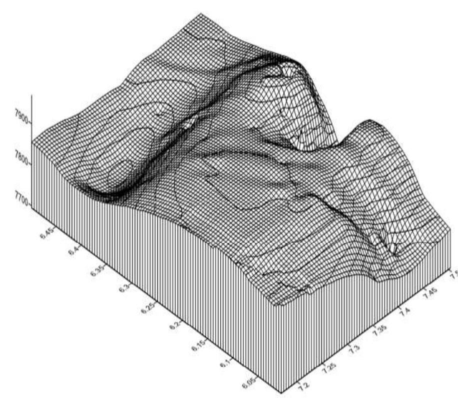

Figure 4: 3D Wireframe map of the total field of the aeromagnetic data of the study area

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First and Second Derivative and Reduction to Pole

Figures 5, 6 and 7 represent the first vertical derivative, second vertical derivative, and the Reduction to Pole (RTP) aeromagnetic maps respectively. The three are in conformity with the distribution of magnetic highs and lows in the study area. It could be concluded that the far Northern region is magnetically low while the central portion is very high.

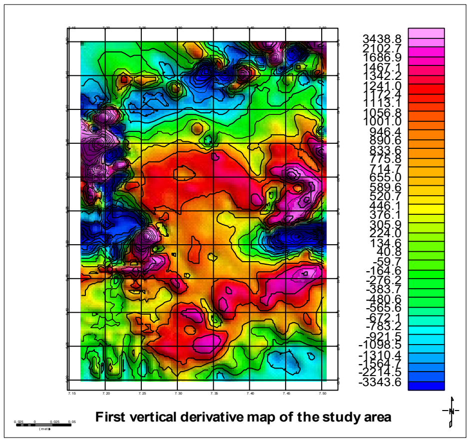

Figure 5: First Vertical Derivative Map

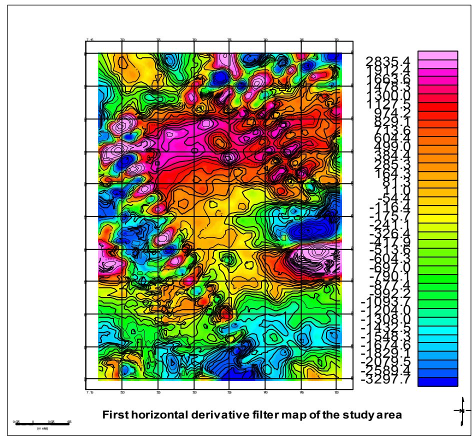

Figure 6: Second Vertical Derivative

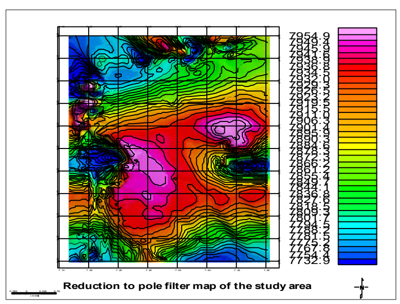

Figure 7: Reduction to Pole Map

Spectral Depth to Magnetic Basement

Table 1: The spectral computed (depths in km) of the study area.

Town	X_1	X_2	Y_1	Y_2	Estimated Depths (Km)	
					D_1	D_2
Udi	7.00	7.25	6.00	6.25	3.285	4.941
	7.00	7.25	6.25	6.50	2.285	5.342
	7.25	7.50	6.00	6.25	0.785	1.858
	7.25	7.50	6.25	6.25	1.348	3.667
Average					***1.925***	***3.952***

The Spectral determination of depth to magnetization at different points within the study area was perfumed using Udi as reference, highlighted in table 1. The estimated depths to magnetic basements are shown as D_1 and D_2. The first layer depth (D_1) is from the shallower sources and varies from 0.8 km to 3.3 km with an average of 1.9 km while the second layer depth (D_2) varies from 1.9 km to 5.3

km with an average of 4.0 km.The sedimentary thickness (basement depth) contour map - D_2 of part of the study area (Udi reference) is shown in figure 8. This revealed thick deposits in the range of 3km to 5km in the NW – SW flanks.

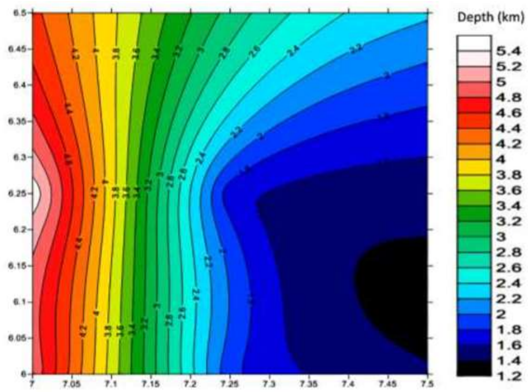

Figure 8: Sedimentary Thickness Contour Map

Structural Interpretation

Structural interpretation of the study area using figure 9 indicates that the areas marked "S" (which are low to high magnetic regions) represents near surface magnetic features, suggesting intrusive rocks. The areas marked "E" (which depict stretched to high magnetic region) represents near surface magnetic features likely made of elongated intrusion with strike in the NE – SW direction, the areas marked "M" (which are large to high magnetic regions) represents deep seethed magnetic features suggesting intrusive rocks, while "J" bears shape suggestive of joints though requiring further examination with the Landsat ETM data. F_1, F_2, and F_3 are interpreted as faults based on the pattern of magnetic contours around them.

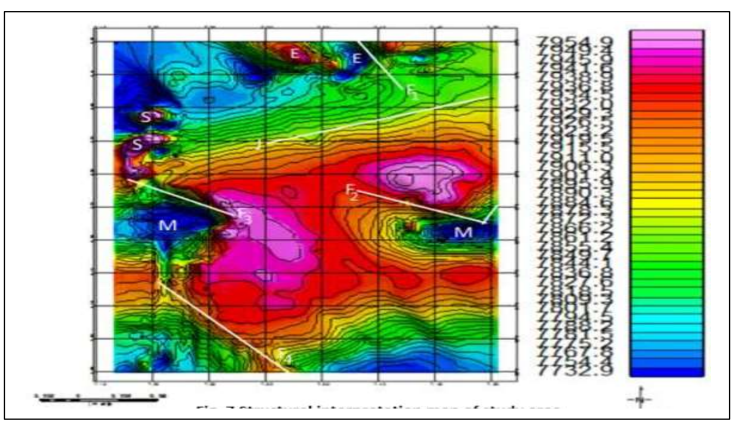

Figure 9: Structural Interpretation Map of the Study Area

Digital Elevation

The digital elevation map is utilized for tectonic, geologic and structural interpretations designate plate location, geomorphology, slope, lineaments, faults, drainage pattern, and the boundary between geologic units. The elevation of the area is on the increase as you move from the north-eastern part to the south-western part of the area. The highest peaks represented by the dark green colour are seen as small patches following a topographically high feature with a maximum topographic height of 540m running N-W. Light green, yellow and red colours are closely packed together representing an abrupt change in topography from 442m to 148m. The map revealed a high elevation ranging from 344 m – 540 m which is the highest peak in the area; the central part in red has an average elevation ranging from 148m – 343m above sea level. The northern part has a low elevation of 17m – 146 m above sea level.

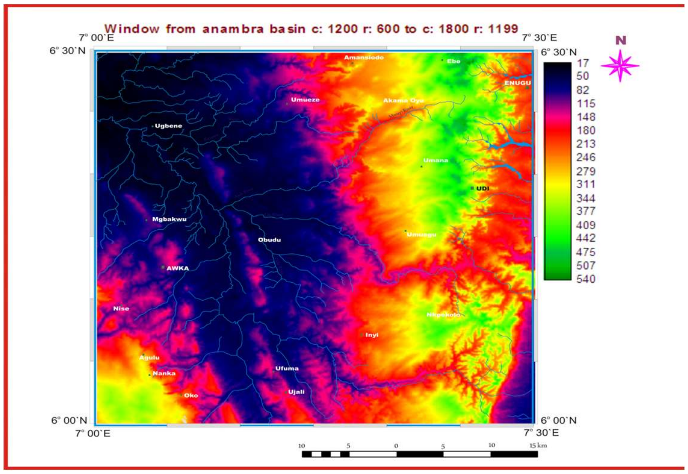

Figure 10: Digital Elevation Model (DEM)

Lineament Density

The interpretation of lineament density map portrayed in figure 11 revealed a number of lineaments and very large lineaments over 15 km in size inclining in the NE – SW, NW – SE N – S and E – W directions. The trend surface analysis of the tectonic and structural features of the area in relation to the interpreted lineaments from the rose diagram (figure 13) revealed surface trend of NE – SW, N-S, NW – SE, and E – W directions with the dominant structural trends being in the N – S and in the NE – SW which corresponds to the major lineament trend of the study area. This shows that the area has a rocky topography and it is partly deformed by tectonic activities. The lineament trends are in line with the results of previous works which suggested that the south-eastern part of Nigeria has a complex network of fractures.

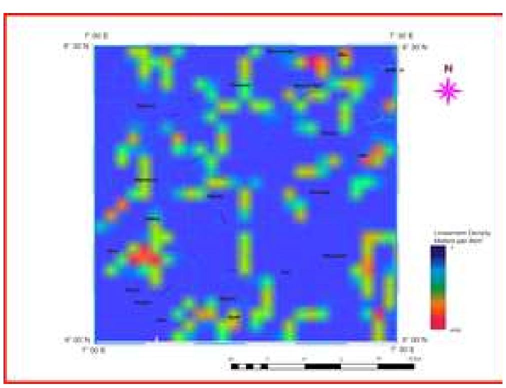

Figure 11: Lineament Density map

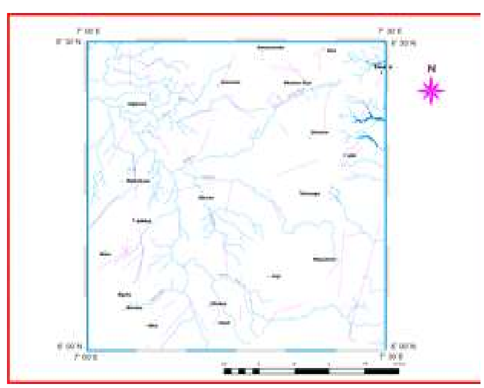

Figure 12: Lineament on Drainage Map

Figure 12 shows the lineament on density map used to correlate the trends of structural and drainage orientation in the whole area. From statistical analysis and visual observation, it reveals that the drainage pattern in the study area is structurally influenced since both the lineaments and drainage system correspond with each other. The composite images revealed a dendritic pattern which trends in the NE-SW, NW-SE and N-S directions. This pattern reveals a topographical, structural and lithological homogeneity of the study area. This occurs on gentle, homogeneous, uniformly sloping sedimentary surface which may indicate a fault or fracture.

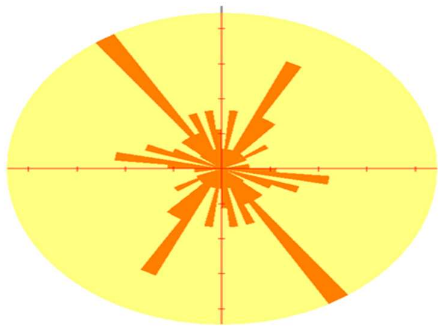

Figure 13: Rose Diagram of the Linear Structures of the Study Area.
Number of data plotted = 60; Sector interval angle = 6°; Scale spacing = 3% [2 data]; Maximum = 13.3% [8 data]; Mean resultant dir'n = 169; Circular mean Dev. = 79°

The rose diagram which is a plot of the lineaments showing their trends in different directions, and displays the lineaments in their subtle trends and their dominant trends is shown in figure 13. The dominant trend is always recognized as the longest plotted lineament. In the figure 13, the NE-SW trend controlled the deposition of sediments in the Trough, the cretaceous formation of igneous rock by the solidification of magma and orientation of folds belts, drainage and mineralization in the area (Burke, 1972; Agagu *et al*., 1985). In contrast NW-SE trend influenced distribution of facies and discontinuities along which occurred synsedeimentary faults. The course of major rivers and their tributaries appears to be determined and influenced by these structural features.

Normalised difference Vegetation index (NDVI)

The normalized difference vegetation index is an idex of plant "greenness" or photosythetic activity, and is one of the most commonly used vegetation indices. The above map is indicative of the kind of vegetation cover noticed around UDI and the northeastern part of the map. The brown patches could be indicative of one or more of three things; residential areas, highlands or erosion areas. The yellow coloured area is of sparse vegetation. Areas with -0.28 to -0.14 could be said to be areas with evidence of erosion.

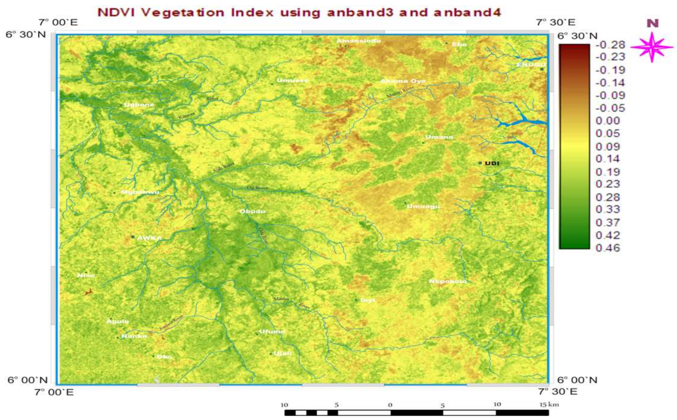

Figure 14: Normalised difference Vegetation index (NDVI) Composite

CONCLUUSION

Identification and classification of structures expressed as lineaments according to their spatial and directional attributes was carried out. The aeromagnetic and Landsat-ETM data were processed in a way that would both enhance trends and to make easy the computation of locations and depths to magnetic sources. Drainage pattern, termination of potential field (gravity or magnetic) map anomalies on a linear trend, termination of drainage line on linear trends and straight stream segments were the basic hypothetical models adopted to map fractures. Ajayi, *et al.* (1991) believes that lineaments can also be revealed on aeromagnetic maps by breaks in anomaly trends (lengthwise) and prominently narrow magnetic lows (breadthwise) and sharp gradients of anomaly. The aeromagnetic analysis and interpretation as well as digitally processed satellite remotely sensed data have revealed that the prominent structural patterns in the study area are trending in the NW-SE, NE-SW, N-S and E-W directions respectively. Also, the rock type distribution within the vicinity in terms of igneous/metamorphic or sedimentary rocks has been revealed. The lineament patterns observed on the Landsat-ETM image have been summarized using rose diagram and further analyzed using geo-statistical techniques. The lineament density in the study area varies from 0 – 4000 m per 25 km^2 in the area.

From the economic point of view, it can be drawn that the average sediment thickness of 4.0 km obtained in this study is not significant for accumulation and entrapment of hydrocarbons. This average basement depth is not in agreement with past works done in and around the area. As such one cannot postulate any existence of petroleum accumulation at such depth in this part of the Lower Benue Trough. Though, it is possible to observe the existence of other mineral traps such as lead, and anhydrides etc. Furthermore, the structures found in the study area are more magnetic which agrees to the cretaceous geology of the lower Benue trough. This study has therefore shown beyond doubt that both Landsat-ETM and aeromagnetic has a lot of research potentials for geologic application.

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