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Geological Interpretations Inferred From Airborne Magnetic and Landsat Data: Case Study of Nkalagu Area, Southeastern Nigeria

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ABSTRACT

Structural interpretation of Nkalagu area using aeromagnetic and Landsat imagery was carried out to determine the depth to the magnetic basement, delineate the basement morphology and relief, delineate the structural features associated with the basin and to infer the effects of such structures on the general tectonic history of the study area. Similarly, this study is aimed at determining whether the Okposi Brine Lake in the study area is structurally controlled. The aeromagnetic and Landsat data were subjected to various image and data enhancement and transformation routines. Results of the study revealed lineaments with trend directions in the N-S, NE-SW, NW-SE and E-W directions, with the NE-SW trends been dominant. The presence of a lineament zone around Okposi is believed to be responsible for the formation of the Okposi brine lake. It is believed that this linear feature must have cut through the basinal brine of the Asu River group. Results of the 2-D spectral analysis revealed a two layer depth model. The shallower magnetic source (d_1) has an average depth of 1.041km while the deeper magnetic source bodies (d_2) have an average depth of 3.574km.The shallower magnetic anomalies is as a result basement rocks which intruded into the sedimentary rocks while the deeper magnetic anomalies is associated with intra-basement discontinuities like faults. Finally, the average sedimentary thickness of 3.574km estimated in the study area is favourable for hydrocarbon generation.

Keywords: *Structural Interpretation, Aeromagnetic, Landsat, Nigeria, Lineaments, Basement depths.*

1. INTRODUCTION

The interpretation of aeromagnetic maps in the past decade has moved from the interpretation of basement structures to detailed examination of structures and lithologic variations in the sedimentary section. Magnetic basement is an assemblage of rocks that underlies sedimentary basins and may also outcrop in places. If the magnetic units in the basement occur at the basement surface, then depth determinations for these will map the basin floor morphology and its structure [1]. In many sedimentary basins, magnetic anomalies arise from secondary mineralization along fault planes, which are often revealed on aeromagnetic maps as surface linear features. Most mineral deposits are related to some type of deformation of the lithosphere, and most theories of ore formation and concentration embody tectonic or deformational concepts[2,3].Some lineament patterns have been defined to be the most favourable structural conditions in control of various mineral deposits. They include the traces of major regional lineaments, the intersection of major lineaments or both major (regional) and local lineaments, lineaments of tensional nature, local highest concentration (or density) of lineament, between echelon lineaments, and lineaments associated with circular features. 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. Similarly, during the past two decades, the interpretation of Landsat imagery using manual or digital processing [4,5], finds application in designing new maps and or revising and improving the pioneer maps on poorly outcropping areas[6]. Regional structural analysis by this process is effective and more with radar interpretation [7,8].

Several studies have been carried out on the structure, stratigraphy, petroleum geology and economic geology of the Benue trough [9-18]. The Benue Trough is a linear NE-SW trending trough with a length of approximately 800km and opens into the Gulf of Guinea where the Cenozoic Niger Delta has built out upon oceanic crust. The Benue Trough is conventionally subdivided into lower Benue trough, middle Benue trough and upper Benue trough [9,10]. The study area which covers Nkalagu area is located within longitudes $7^o 44'$ to $7^o 54'$E and latitudes $6^o 00'$ to $6^o 08'$N.

This research work presents an aeromagnetic and Landsat based structural interpretation of Nkalagu area. The objectives of this study are to produce a digitized aeromagnetic map of sheet 302 (Nkalagu), determine magnetic basement depth, delineate basement topography, determine trends of deformation and determine whether Okposi brine Lake is structurally controlled.

1.1. Background Geology

The study area occupies the lower part of the Benue trough. It is located within latitudes $6^o\ 00^1$ to $6^o\ 30^1$N and longitudes $7^o\ 30^1$ to $8^o\ 00^1$E (Fig.1).

The depositional history of the Benue trough is characterized by phases of marine regression and transgression [9,19-20]. These sedimentary sequences were interrupted by large scale tectonism which occurred in two phases: the Cenomanian and the Santonian deformations [21-22].

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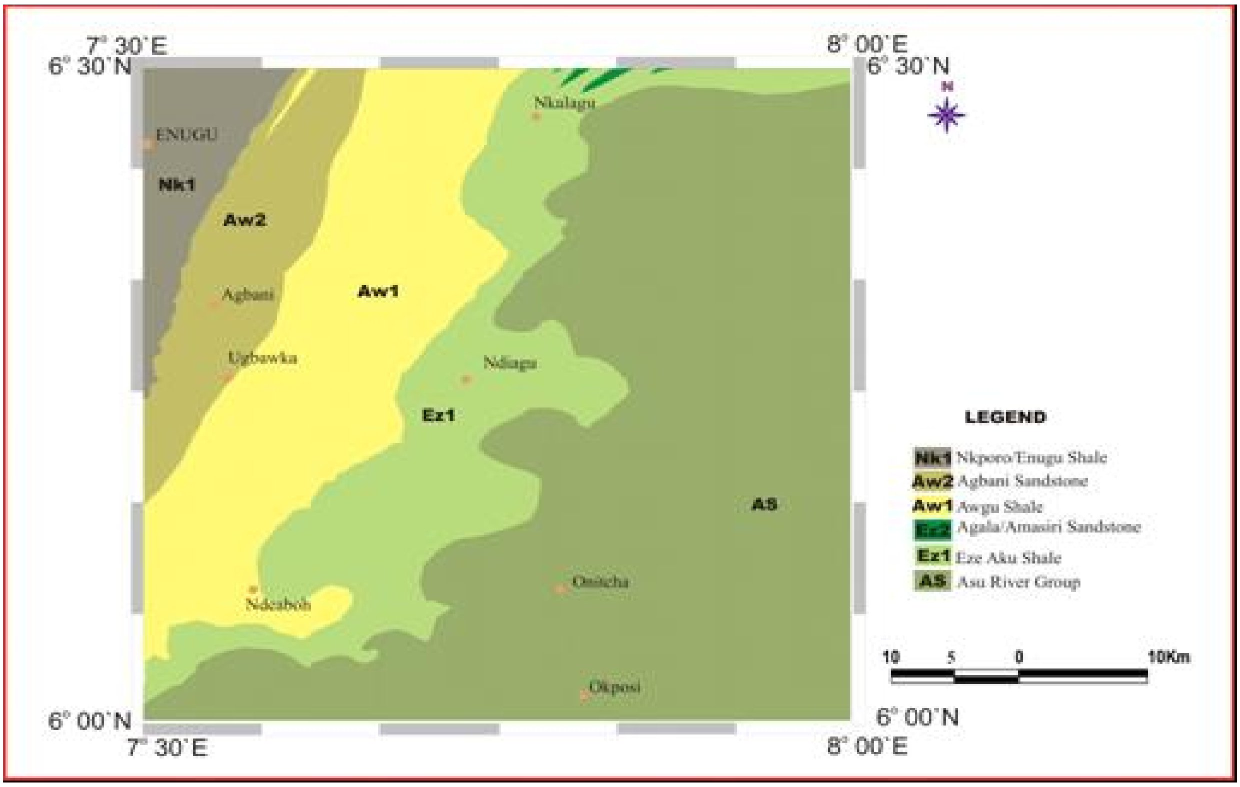

Fig.1: Geology Map of the Nkalagu area(adapted from Nigerian Geological Survey map, sheet 302)

The Santonian deformation was characterized by compressive folding, generally along a NE-SW direction, parallel to the trough margin.The folding episode that took place during the Santonian strongly affected the development of the Abakaliki Anticlinorium. The predominantly compressional nature of the folds that developed during this period is revealed by their asymmetry and the reversed faults associated with them. Benkhelil [11], in a detailed report of the geology of Abakaliki suggests that the compression responsible for the large scale folding and cleavage was directed N155^{o} E. The magmatism that occurred resulted in the injection of numerous intrusive bodies into the shale of the Eze Aku and Asu River Group. The sediments that occur in Nkalagu area belong to the following geological formations: Asu River Group (Albian), Eze Aku Shale (Turonian), Agala/Amasiri sandstone (Turonian), Awgu Shale (Coniancian), Agbani (Coniancian) and Nkporo Shale (Campanian).

The geological map of the study area (Fig.1) clearly shows that Okposi is entirely underlain by sedimentary rocks which belong to the Asu river group of Albian age [23]. Okposi is underlain by sedimentary rocks which belong to the Albian, Asu River Group. This group comprises of bluish black shale with minor sandstone units.The shales are fissile and highly fractured. Akande and Mucke [24] reported the presence basinal brine in the Asu River Group. Around Abakaliki, the shales are associated with pyroclastic rocks. This group overlies the basement complex.

2. THEORY AND METHODS

Both magnetic and landsat data have a great deal in common, and an interface for geological interpretation can be established between them. They are both extensively used as reconnaissance tools in oil and mineral exploration. Similarly, both have surficial discontinuities recognized by the common correspondence of linear anomalies to surficial evidence of faulting across the area.

The aeromagnetic data used were filtered using a low pass filter. The nature of filtering applied to the aeromagnetic data in this study in the Fourier domain was chosen to eliminate certain wavelengths and to pass longer wavelengths. Several potential field softwares with different analytical modules were used in the interpretations of the aeromagnetic map. These include Geosoft Oasis Montaj 6.4.2.HJ version, U.S. Geological Survey Potential-Field geophysical software Version 2.0, Surfer 10 and Matlab 7.5. Regional - residual separation was carried out using polynomial fitting. This is a purely analytical method in which matching of the regionals by a polynomial surface of low order exposes the residual features as random errors. For the magnetic data, the regional gradients were removed by fitting a plane surface to the data by using multi- regression least squares analysis. The expression obtained for the regional field T(R) is given as:

$$T(R) = 7612.158 + 0.371x - 0.248y ....(1)$$

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The regional trend is represented by a straight line, or more generally by a smooth polynomial curve. The fitting of polynomials to observed geophysical data is used to compute the mathematical surface giving the closest fit to the data that can be obtained within a specified degree of details. This surface is considered to approximate the effect of deep seated or regional structures if it of low degree.

Other analytical methods used include Reduction-to-pole, Second vertical derivatives and trend surface analysis 2-D spectral analysis,. Reduction-to-pole (RTP) transformation was applied to the aeromagnetic data to minimize polarity effects [25]. These effects are manifested as a shift of the main anomaly from the center of the magnetic source and are due to the vector nature of the measured magnetic field. The RTP transformation usually involves an assumption that the total magnetizations of most rocks align parallel or anti-parallel to the Earth's main field. Similarly, second vertical derivative filters were used to enhance subtle anomalies while reducing regional trends. These filters are considered most useful for defining the edges of bodies and for amplifying fault trends. In mathematical terms, a vertical derivative can be shown to be a measure of the curvature of the potential field, while zero second vertical derivative contours defines the edge of the causative body. Thus, the second vertical derivative is in effect a measure of the curvature, i.e., the rate of change of non-linear magnetic gradients. The zero magnetic contours of the second vertical derivative often coincide with the lithologic boundaries while positive and negative anomalies often match surface exposures of the mafic and felsic rocks respectively.

Average depth values to buried magnetic rocks using 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 application of spectral analysis to the interpretation of potential field data is therefore sufficiently well established [26]. The method allows an estimate of the depth of an ensemble of magnetized blocks of varying depth, width, thickness and magnetization. Most of the approaches used involve fourier transformation of the digitized aeromagnetic data to compute the energy (or amplitude) spectrum. This is plotted on a logarithmic scale against frequency. The slopes of the segments yield estimates of average depths to magnetic sources of anomalies.

Finally, Landsat Thematic Mapper (Landsat-TM) imagery acquired on 17/02/2011 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 carried out using the Universal Tranverse Marcator (UTM). Image processing, enhancement and analysis were carried out using ILWIS 3.1 Academic software. Image enhancement operations carried out include contrast stretching, spatial filtering and edge detection, which were done to enhance sharpness of the satellite image for better visual interpretation, reduce noise in the image and to aid structural interpretation. Similarly, ArcView 9.3 software was used to extract the lineaments and carry out statistical analysis of the interpreted lineaments in the area.

3. RESULT PRESENTATION AND INTERPRETATION

The data used in this study are the aeromagnetic map obtained from the Geological Survey of Nigeria and Landsat 5 TM image acquired on the 17th of December 2011. The magnetic data used were obtained as part of the nationwide aeromagnetic survey which was sponsored by the Geological Survey of Nigeria (GSN) and completed in 1976. Flight line direction was NNW-SSE at station spacing of 2km with flight line spacing of 20km at an altitude of about 150m. Tie lines were flown in an ENE-WSN direction. Regional correction of the magnetic data was based on the IGRF (epoch date1 of January, 1974). For this study, aeromagnetic sheet 302 was used. The aeromagnetic map was digitized along flight lines at 2km intervals. The regional gradients were removed by fitting a plane surface to the data by multi- regression least squares analysis. Fig.2 is the total field aeromagnetic data of the study area as a contour map, while figures 3 and 4 are the shaded relief and 3-D surface maps of the total magnetic field intensity. The total field of the aeromagnetic data revealed that the underlying basement around Okposi has magnetic intensity estimated at 7920 gammas. The wire-frame revealed high basement relief in places indicating folded topography, which may be interpreted as part of the Abakaliki folded belt. Magnetic anomalies both short and long wavelengths were interpreted within the study area. These are represented by magnetic highs and lows. Areas with high magnetic intensity anomalies are seen on the western flank and around Okposi on the study area. At Okposi, the intensity ranges from 7900γ to 7930γ.

Similarly, the first to fourth degree regional and residual fields are presented in figures 5 and 6 respectively. The Reduction-to-Pole aeromagnetic data, computed from the grid of total-field magnetic data is shown in Fig.7. The zero contours of the second vertical derivatives indicated the lithologic boundaries between the different formations, while, the distribution of mafic and felsic rock forming minerals were correlated to the positive and negative second vertical derivative anomalies around Nkalagu area (Fig.8).

For the spectral determination of depths to layers of magnetization, the study area was divided into four (4) blocks containing 14×14 km. In doing this, adequate care was taken so that essential parts of each anomaly were not cut by the blocks. In order to achieve this, the blocks were made to overlap each other. Graphs of the logarithms of the spectral energies against frequencies obtained for various blocks are shown in fig. 9. The estimated depths to magnetic basement are shown as D_1 and D_2 (table 1). The first layer depth (D_1), is the depth to the shallower source represented by the second segment of the spectrum (Fig.8). This layer (D_1) varies from 0.817km to 1.15km, with an average of 1.041km. The second layer depth (D_2) varies from 2.863km to 4.672km, with an average of 3.574 km.The basement depth (sedimentary thickness) contour map of the study area is shown in fig. 10

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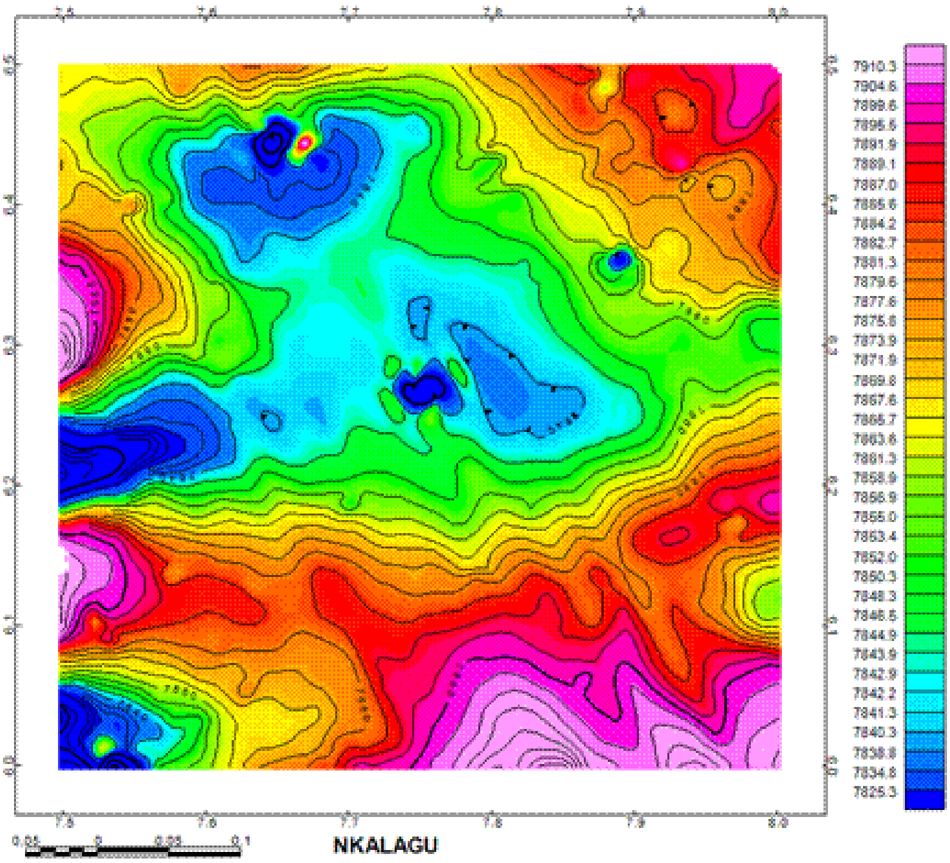

Fig.2: Total Magnetic Field Intensity Contour Map of the Study area (contoured at 5 gammas interval)

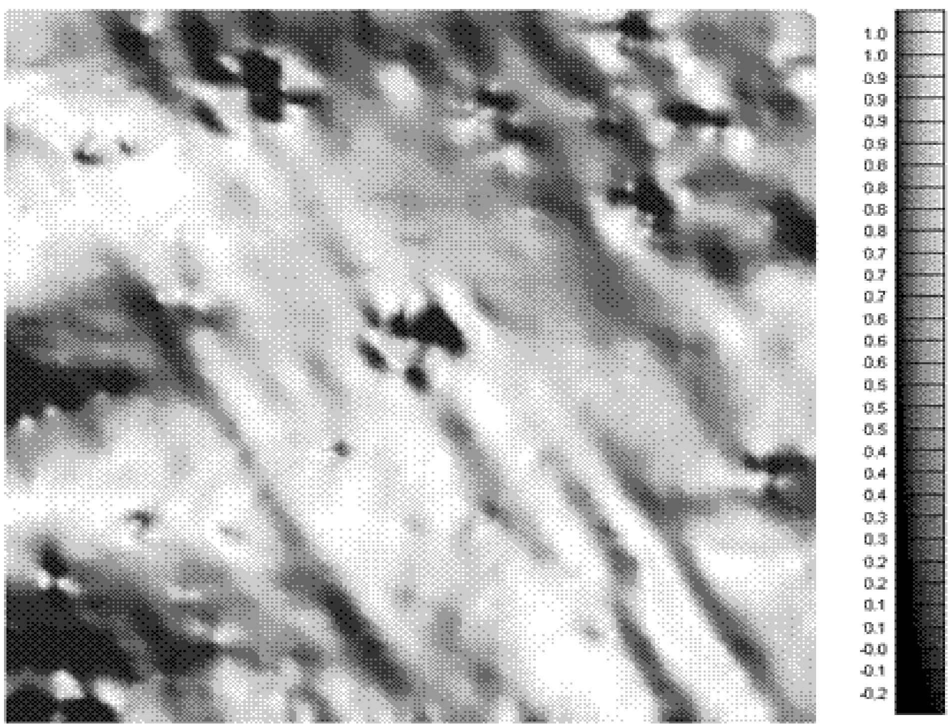

Fig.3: Shaded Relief Map of the Total Magnetic Field of the Study Area showing Magnetic Basement Relief

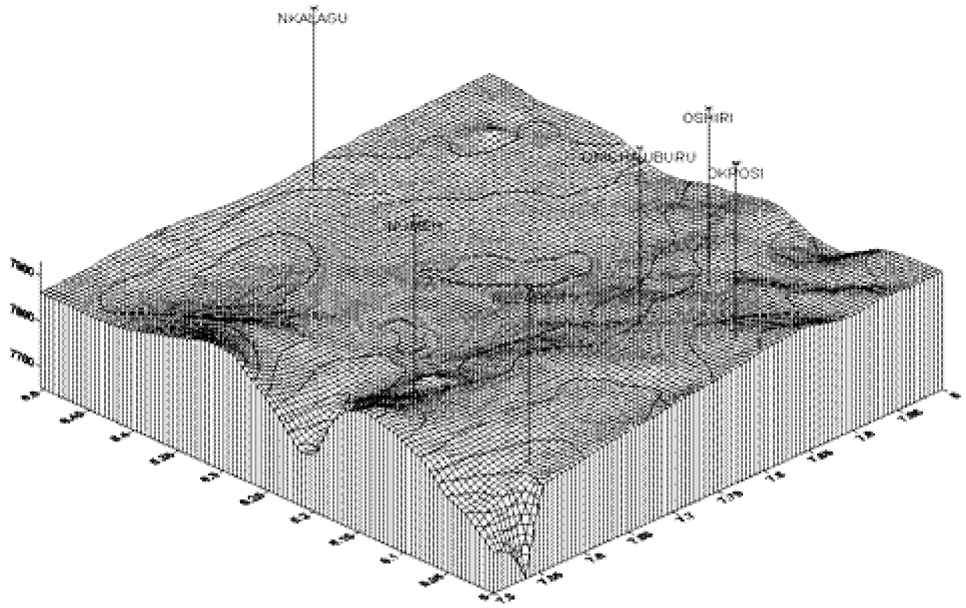

Fig.4: Total Field of the Aeromagnetic Data Presented As 3-D Map Showing the Basement Topography

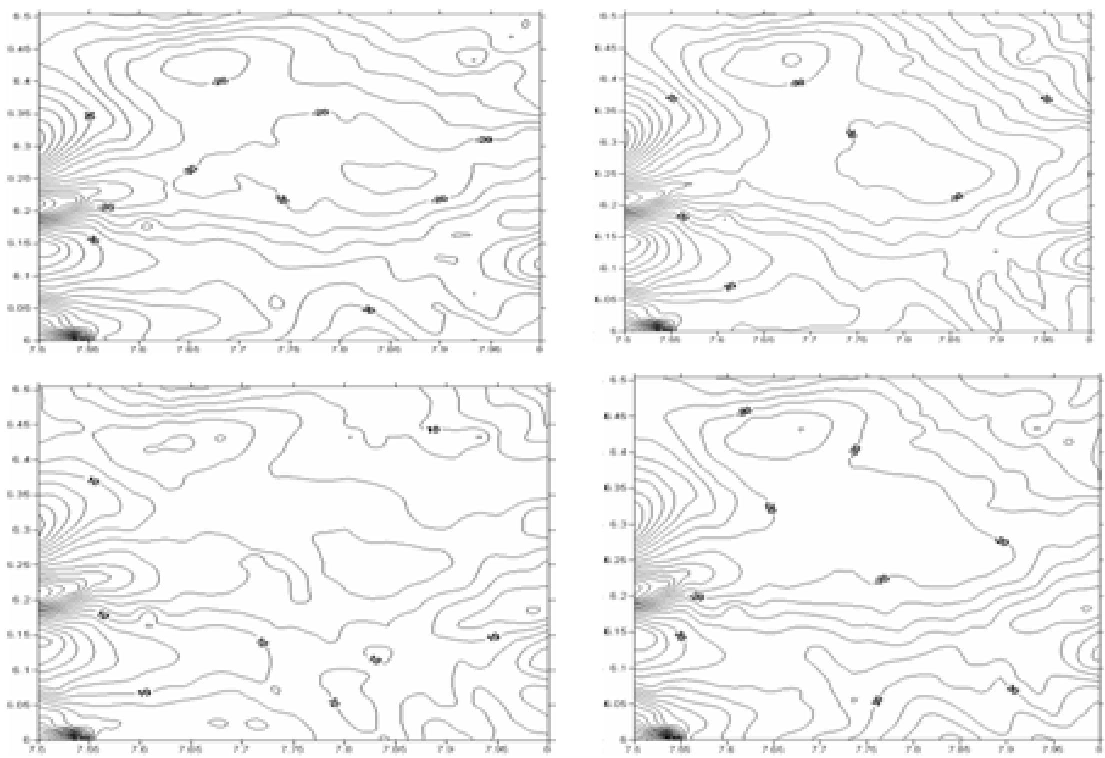

Fig.6: First to Fourth Degree Residual Fields of the Aeromagnetic Data

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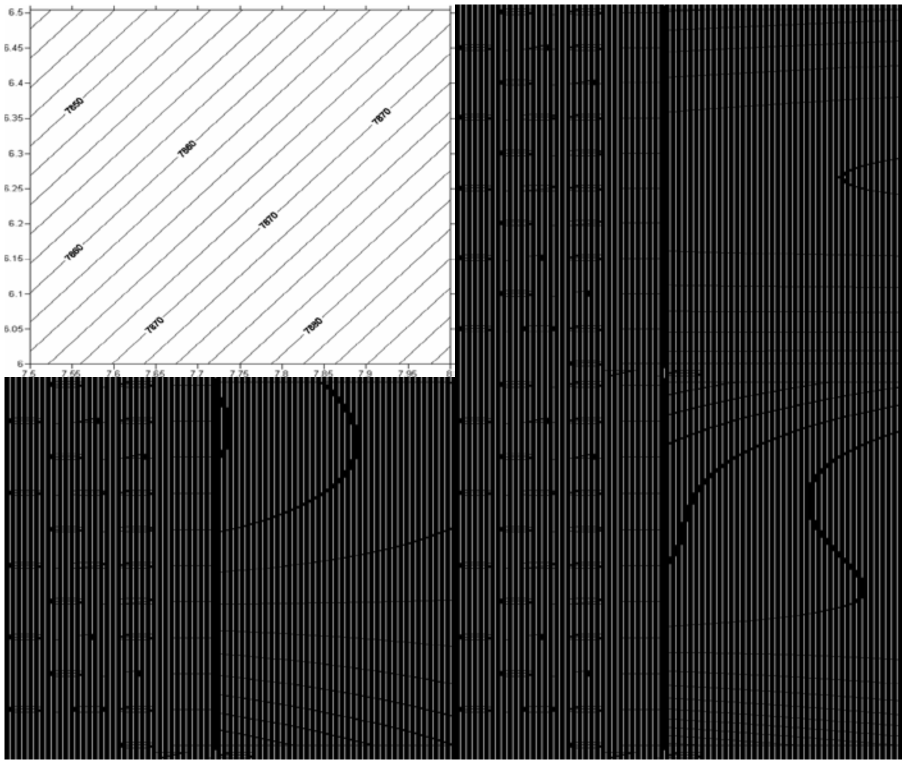

Fig.6: First to Fourth Degree (Polynomial) Surfaces of the Regional Fields of the Aeromagnetic Data

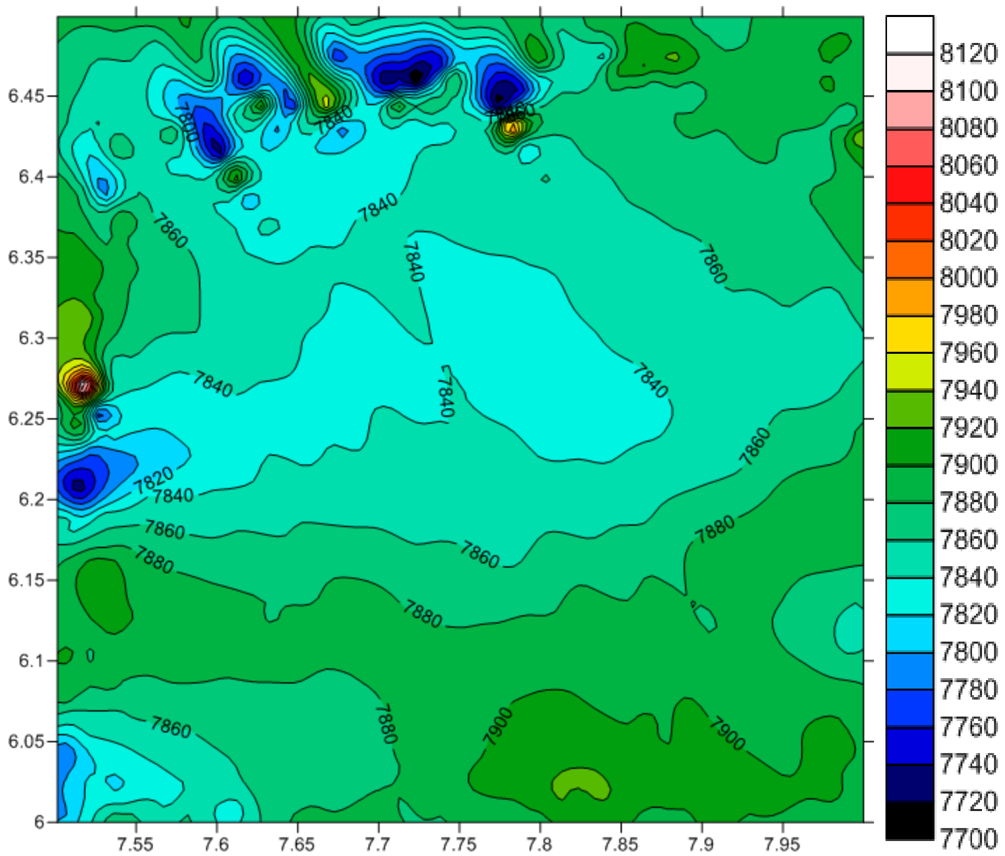

Fig.7: Reduction to Pole Contour Map of the Aeromagnetic Data of the Study Area

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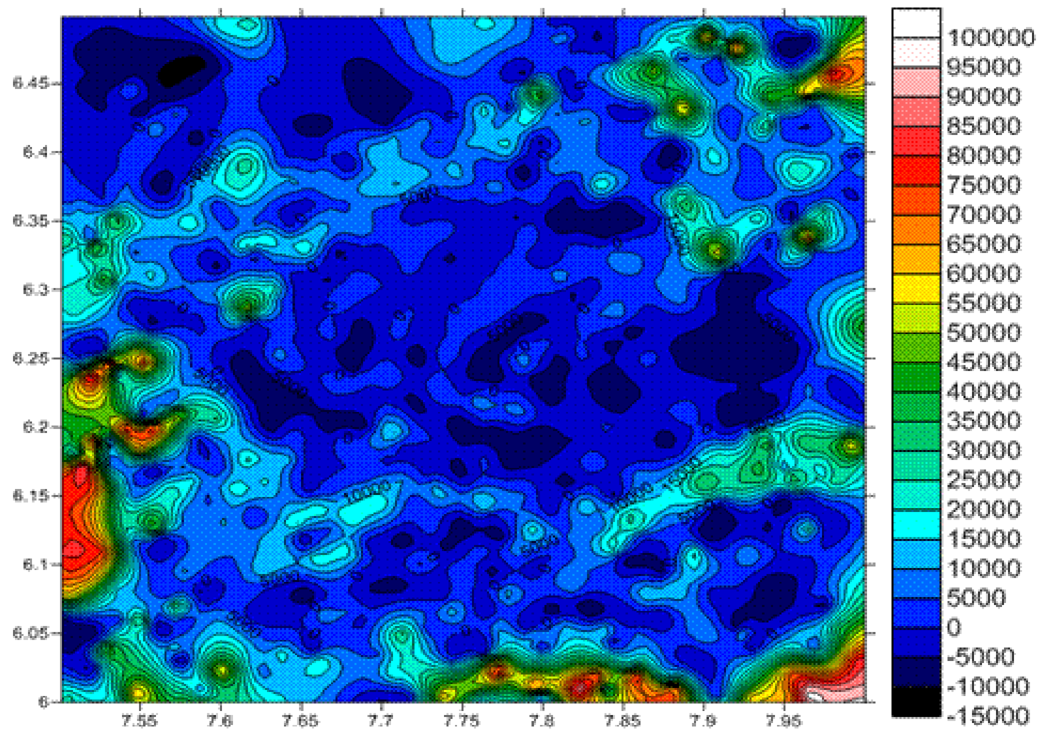

Fig.8. Second Vertical Derivative Contour Map of the Aeromagnetic Data of Study Area

Fig.9: Energy Spectra for Blocks A, B, C, And D for The Determination of Basement Depths

The local anomalies in the original aeromagnetic field map were modeled in terms of intrusions using non linear optimization techniques. The method seek to minimize a non linear objective function which represents the difference between the observed and calculated fields through an iterative change of the non linear parameters (location, thickness and depth) by non-linear optimization while at the same time obtaining optimum values for the linear parameters (magnetization components, quadratic regional and composite magnetization angle) by least-square analysis. Graphical methods (Peter's, slope method, Hannel and Tiburg methods) were also used in calculating depth estimates to the anomalous bodies (Fig.11). The estimated depths and linear parameters are presented in table 2.

The Landsat 5 TM was digitally processed so as to help the image analyst have the ability to carry out the following functions: correct the data for geometric and radiometric imperfections, improve the visual quality of the image data, carry out appropriate user customer manipulations to enhance or suppress certain details necessary for information extraction and conduct computer assisted thematic mapping from digital imageries. These functions are conveniently referred to as image rectification, enhancement, transformation and classification respectively. For this study, IDRISI 32 software and other appropriate modules in ILWIS 3.1 academic were image enhancement. Two major filters were applied to the imagery using ILWIS 3.0 filter module: Laplace filter and edge enhancement filter. This was done to increase the spatial frequency of the imagery so as to enhance high frequency features, which would include fractures (lineaments). The edge enhancement filter image was observed to be more appropriate for this work. The interpreted lineaments were superimposed on the edge enhanced map to show the relationship between geological formations and structural features (fig.12).Similarly, the lineament density map of the study area is shown in fig. 13. The lineaments density map and enhanced filtered map reveal a high density fracture zone 5km east of Okposi, along the Ebonyi River. This zone is interpreted thus, because of the high density of lineaments seen in this area. This implies that there was intense tectonic activity along the river channel Around Okposi existence of lineament is interpreted. Finally, the lineament trend directions were summarized by using a Rose diagram as shown in fig. 14.

The Digital Elevation Model (DEM) (fig.15) was created by performing a colour shaded operation on Shuttle Radar Topographic Mission (SRTM) data. On the DEM, highest elevations of the study area are represented as light green patches. This feature is seen on the top left corner of the map. This feature is interpreted as sandstone ridge, running NE-SW direction. The ridge is suspected to be part of Enugu cuesta. The slope of the ridge is identified where light green, yellow and red colours are closely packed together; representing a sudden change in topography from 232 to 109 metres. The slope is characterized by numerous streams, gullies and a river. It will be correct to interpret the topographic high areas as characterized by sandstone and the low areas as characterized by shale and mud rock. This is justified by the dendritic drainage pattern expressed in the low lying area, which points to an underlying clayey lithology. Geologically the area with dendritic pattern correlates to the Ezeaku Formation. The sandstone ridge represents the watershed for the study area.

Since the primary objective of this study is to identify structures and geomorphic features expressed as lineaments and classify them according to their spatial and directional attributes, it was necessary to process the aeromagnetic and Landsat -TM data in a manner that would both enhance trends and facilitate 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 used to map fractures. Ajayi, et al [27], believes that lineaments can also be revealed on aeromagnetic maps by breaks in anomaly trends (lengthwise) and prominently narrow magnetic lows (broad wise) and sharp gradients of anomaly. Lineaments quantification and statistical analysis were done regarding the orientation frequency of these lineaments to construct a rose diagram. The rose diagram revealed four peaks of preferential direction: NE-SW, E-W and N-S with the NE-SW trend been the dominant orientation. However, the NE-SW trend reflects the younger tectonic events, because the younger events are more pronounced and tends to obliterate the older events. Similarly, subsurface linear structures identified in the study area (from first - fourth degree regional and residual maps) revealed tectonic features with principal trend directions in the N-S, NE-SW, NW-SE, and to a lesser extent E-W directions, with the N-S fractures. Lithologic control was deduced from the observed variation in both the number and frequencies of the system of linear structures.

4. DISCUSSION AND CONCLUSION

It can be deduced that the D_2 values obtained from the spectral plots represent the average depths to the basement complex in the blocks considered. This layer may be attributed to magnetic rocks intruded onto the basement surface. Another probable origin of the magnetic anomalies contributing to this layer is the lateral variations in basement susceptibilities, and intra-basement features like faults and fractures [28-29]. Depth to source interpretation of aeromagnetic field data provides important information on basin architecture for petroleum exploration and for mapping areas where basement is shallow enough for mineral exploration. Magnetic basement is an assemblage of rocks that underlines sedimentary basins and may also outcrop in places. Onyedim et al [30] believes that if the magnetic units in the basement occur at the basement surface, then depth determinations for these will map the basin floor morphology and its structure appropriately. The interpretation of Landsat imagery and aeromagnetic data of study reveal that Nkalagu map (sheet302) has a dominant NE-SW trend which reflects that of the basin. The high magnetic intensity and intrusives around Okposi suggest the existence of deeply penetrating fractures within the area. With the presence of the deep seated struc- ctures which cut across the basement, the existence of fractures around Okposi has been established. Okposi brine Lake could then be suggested as emanating along a deep fracture trace (fault trace) that must have cut through the basinal brine of the Asu River group. It is possible that the fault trace have provided a migration pathway for the brine.This suggests that the Brine Lake is structurally controlled. Elsewhere, lakes with similar features include: the Loch Ness in Scotland and Baikal in Asia.

This present research is therefore in agreement with previous studies which suggested that Nigeria has a complex network of fractures and lineaments with dominant trends of NW-SE, NE-SW, N-S and E-W directions. These linear structures running NE-SW observed from the study are suggested as the continental extension of the known pre-Cretaceous oceanic fracture zones viz. Charcot and Chain fracture zones which run along the trough axis beneath the sedimentary cover [31]. Furthermore, it is geologically plausible that the landward intersections of the transform fracture zones may have influenced the formation of the river patterns and basin formation. Finally, the correlation of these lineaments with mineralization in the area has been ascertained by previous authors [3, 32-35].

Table 1: Depth to Magnetic Basement Estimated from Spectral Analysis

LONGITUDE		LATITUDE		DEPTH (KM)	
X_1	X_2	Y_1	Y_2	D_1	D_2
7.50	7.75	6.00	6.25	1.15	4.672
7.50	7.75	6.25	6.50	1.223	3.3
7.75	8.00	6.00	6.25	0.817	2.863
7.75	8.00	6.25	6.50	0.973	3.461

Table 2: Calculated Depth to the Magnetic Source of the aeromagnetic map of Nkalagu Area

TOWN	COORDINATE		DEPTH ESTIMATION IN KM			WIDTH (KM)	AMPLITUDE (GAMMA)	MAGNETIZATION (A/M)	1% RADIANCE	TYPE OF ANOMALY
NKALAGU	LAT	LONG	PETER'S SLOPE	TIBURG	HALF WIDTH					
A	6.4287	7.4615	3.910	4.672	3.448	8.5	7828	0.10	-1.10	LOW
B	6.2761	7.6041	3.223	3.3	2.448	7.4	7832	0.20	1.28	LOW
C	6.1651	7.7305	0.8167	2.863	2.098	7.2	7892	1.00	1.59	HIGH
D	6.1850	7.9024	0.973	2.461	1.798	9.0	7897	1.05	1.42	HIGH
E	6.2157	7.3288	1.53	1.848	1.348	8.2	7780	0.09	1.50	LOW

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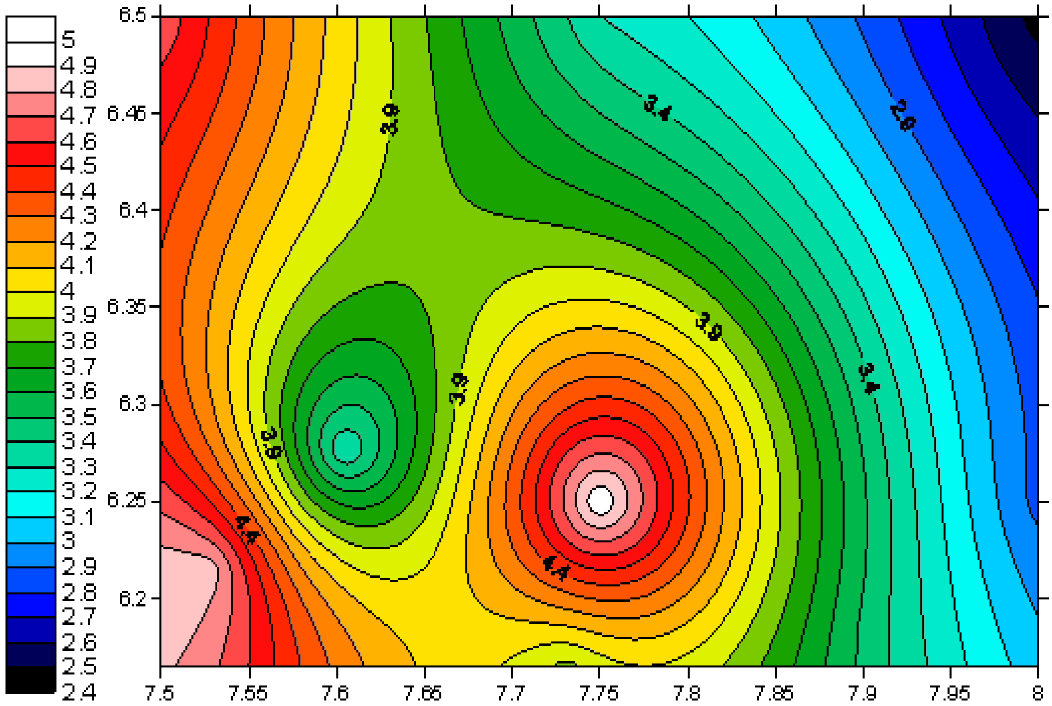

Fig.10: Depth to Basement (Sedimentary Thickness) Map Estimated from Spectral Inversion Contoured in Metres

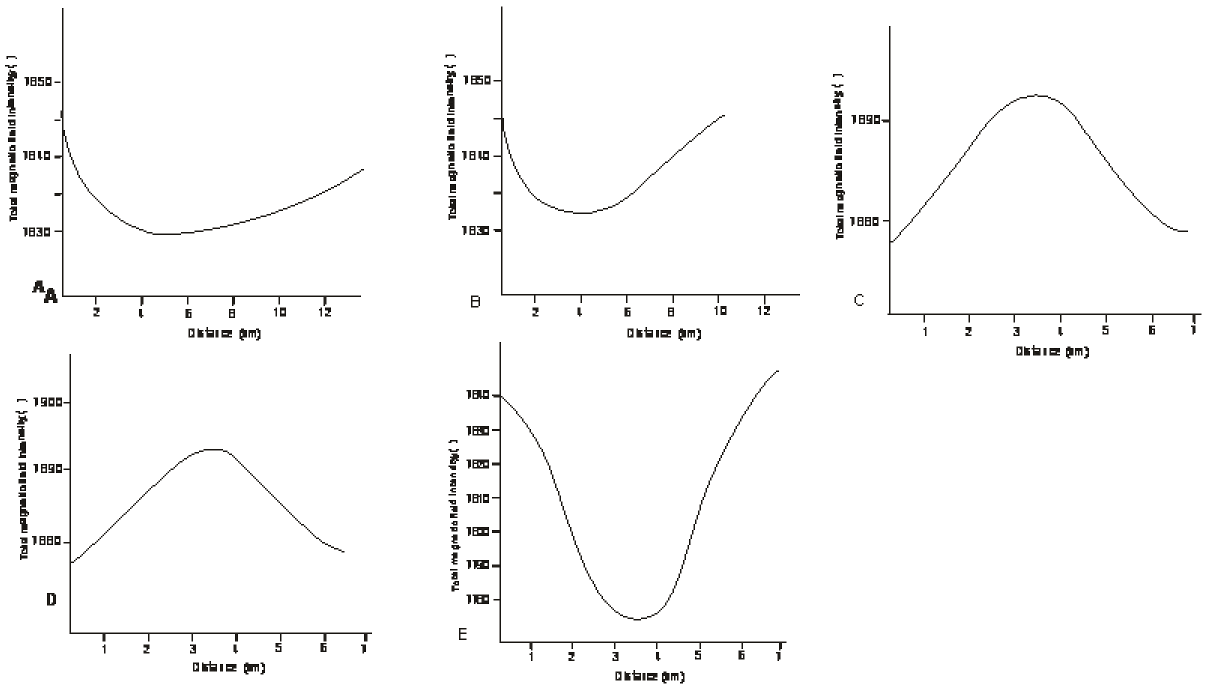

Fig.11: Interpretation of some linear magnetic anomalies from Nkalagu Sheet. Profiles A→E were taken as follows: Profile[A], 17Km East of Enugu; Profile[B], 20Km South of Nkalagu; Profile[C], 5Km North-East of Oshiri. Profile [D], 12Km North-Oshiri. Profile [E], 13Km South-East of Mberubu

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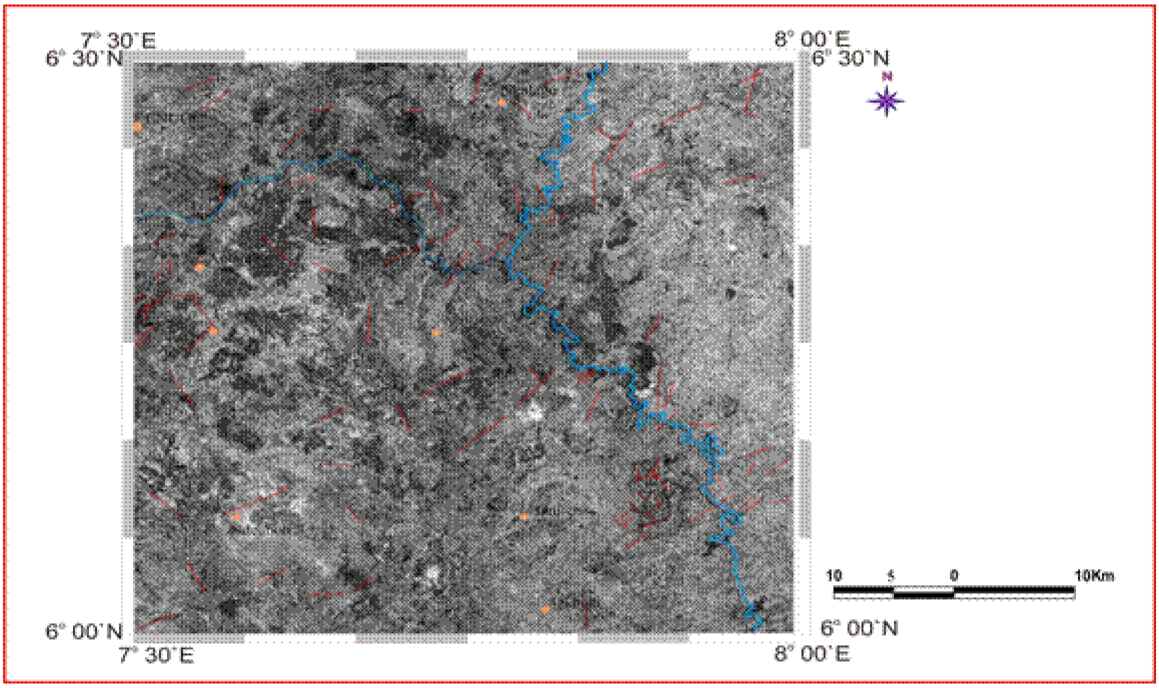

Fig.12: Lineaments superimposed on Edge Enhanced Filtered Landsat Image

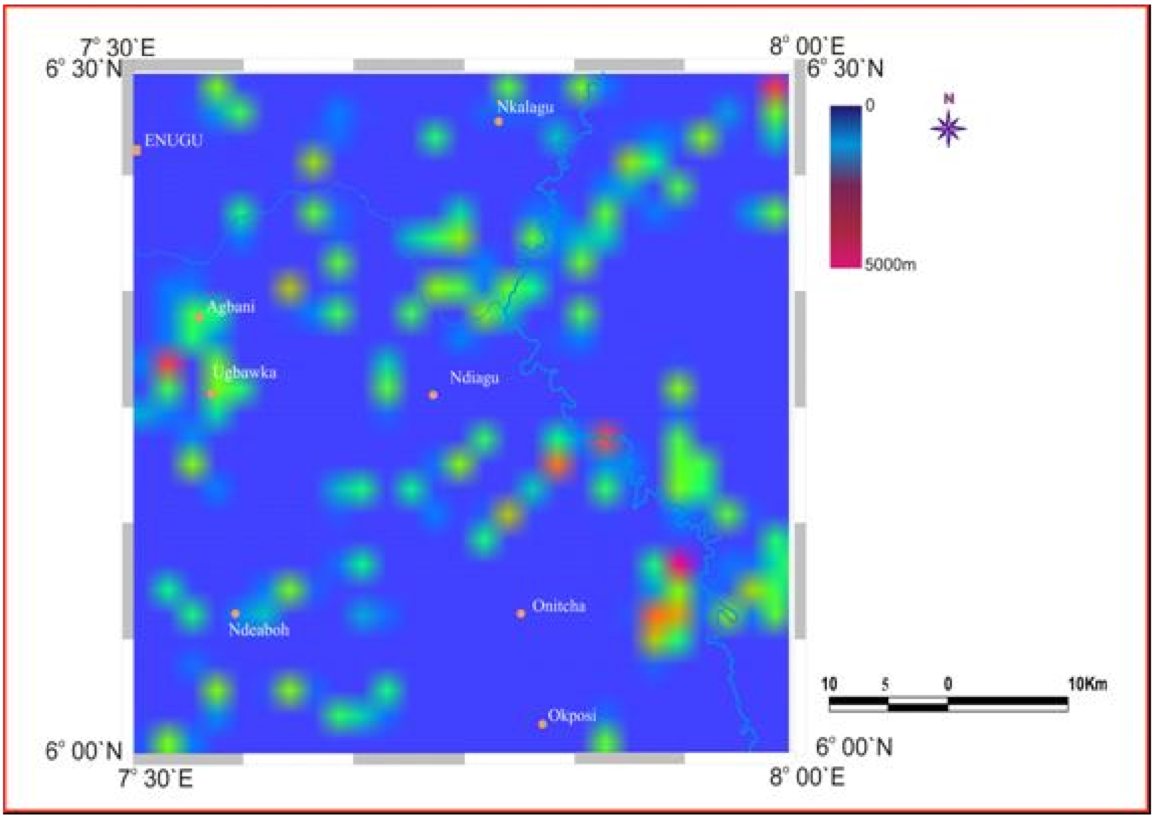

Fig.13: Lineament Density Map of the Study Area

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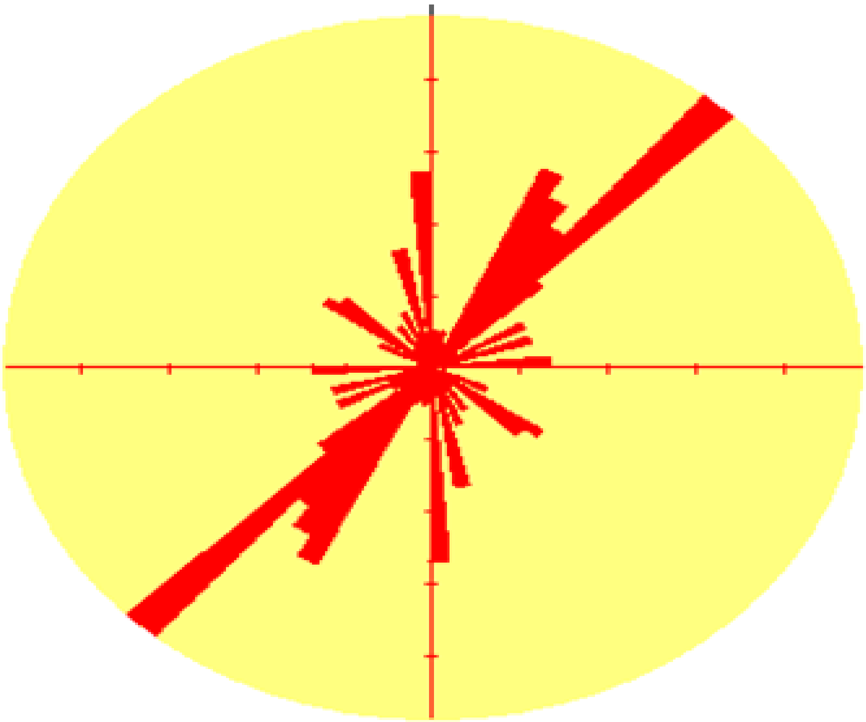

Fig.14: Azimuth Frequency (Rose) diagram of the study area generated from the Landsat Data[Number of data plotted = 99; Sector Interval Angle = 5°;Scale spacing = 3% (3 data) Maximum = 14.6% (14 data);Mean Resultant direction = 032 ;Circular Mean Dev. = 44°]

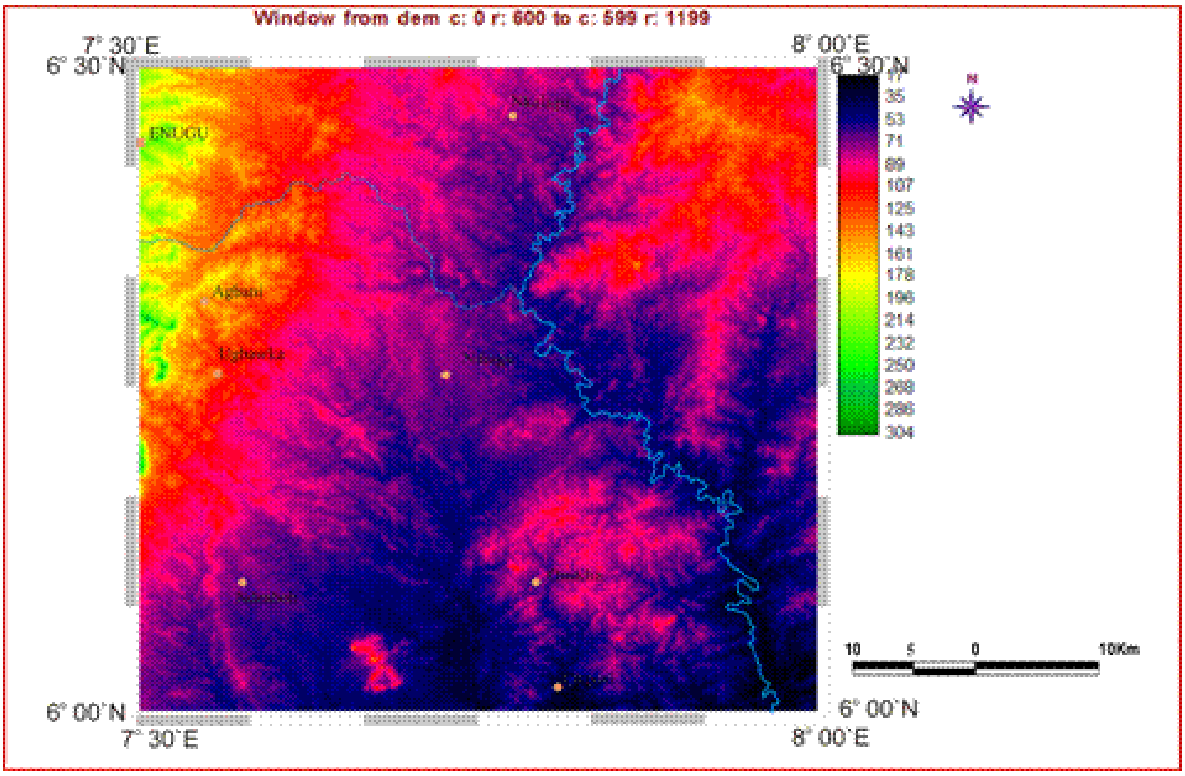

Fig.15: Digital Elevation Model (DEM) of the Study Area

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