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Tectono-structural analysis of part of the Anambra basin, Nigeria.

Onyewuchi, R.A.* and Ugwu, S.A

Department of Geology, University of Port Harcourt, Rivers State, Nigeria.

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ABSTRACT

This paper presents structural and tectonic analysis of Udi and Okigwe part of the Anambra basin using aeromagnetic data and Landsat imagery. The study targets to achieve the following objectives: to delineate major surface and subsurface structural lineaments and their trends, to determine the influence of structure on the sedimentation in the area as well the delineation of the basement topography. The aeromagnetic data processing was carried out by subjecting it to low pass filtering and the use of some analytical methods such as reduction to pole, upward continuation, trend surface analysis and first vertical derivative. Similarly, the Landsat imagery processing involves enhancement and transformation routines. Result of the study revealed that the dominant structural trend directionof the study area is in the NE-SW direction. The NE-SW trend is suspected as a continental extension of the Chain and Charcot Oceanic fracture system. Other structural trends are in the NW-SE, NNE-SSW and N-S directions. Lineament density map revealed a suspected megafracture zone around Lokpaukwu and environs. The 3-D basement map revealed a folded topography which reflects the level of tectonism within the study area. The residual polynomial surfaces revealed deep seated anomalies around Lokpaukwu. Finally, the abundance of pyroclastics within part of the study area makes the area viable for ore mineral and quarrying explorations.

Introduction

Tectonism in the southern Nigeria dates back to the separation of African plate from the South American plate and consequently the opening of the Atlantic during the early Cretaceous time. Two major episodes of tectonism are recognized in the Benue trough: the Cenomanian and the Santonian tectonic episodes. The Cenomanian time saw a minor tectonic event which resulted in the movement along the NE-SW trending fault. This earlier Cenomanian episode affected only the Albian sediments. According to Olade (1975), the cause of this episode is the temporary ceasing of the mantle contraction which resulted in the formation of the rift-like Abakaliki-Benue trough. The second episode occurred in the Santonian time. It was characterized by compressional movement along the NE-SW trend, (Burke et al., 1972). This resulted in the upliftment of the Abakaliki – Benue fold belt. At the same time when the Abakaliki uplift occurred, the Anambra platform subsided and the axis gave rise to the Anambra basin in which the study area belongs to. However, the axis of this basin was displaced to a position SW of the Benue folded belt and NW of the Abakaliki uplift (Murat, 1972).

The geologic history of the southeastern Nigeria is controlled by the major tectonic events and their resultant depositional cycles as posited by Short and Stauble (1967). The Anambra basin was properly formed after the Santonian tectonic pulse, which dates back to 84 M.a.Nwajide and Reijers (1996) reported that the Benue trough with the Abakaliki and Benue basins were essentially an intracratonic mobile sediment during the Albian to Santoniansubstage.

The study area and its environs have been studied using various surface geological mapping techniques.

However, subsurface geological mapping in the study area by integrating airborne magnetic method and remote sensing techniques has less been performed. Thus, determination of subsurface geology is fundamentally dependent on the use of regional geophysical survey such as airborne geophysical survey. Airborne geophysical survey has been a very useful tool available to earth scientists in interpreting geology of difficult terrain (Gunn, 1997). Aeromagnetic survey has proved useful in displaying the depth to anomalous basement, spatial distribution and relative abundance of magnetic minerals and nonmagnetic minerals in the upper levels of the crust which can help in the visualization of the geology and geological structures of the upper crust of the earth (Gunn, 1997). 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. Remote sensing interpretation on the other hand has been used in delineating structural features, designing of new maps and updating the existing ones.

This study will incorporate aeromagnetic and Landsat data in the structural interpretation of the area under review.

Tele:
E-mail address: regonye28@yahoo.co.uk

The objectives of this study are: to delineate major surface and subsurface structural lineaments and their trends, to determine the influence of structure on the sedimentation in the area and to delineate the basement topography.

Geological Setting

The study area which lies within part of the Anambra basin, is delimited by latitudes $5^0 30^1$ - 6^0 30^1N and longitudes 7^0 00^1 - 7^0 30^1E (figure 1).

The flexural inversion of the Abakaliki "trough" led to the development of the Anambra Basin from the Anambra Platform and the Afikpo Basin from the Ikpe Platform (Popoff, 1988; Zarboski, 1998; Benkhelil, 1989).

Sedimentation in the Anambra basin and the adjoining basins have been characterized by phases of regression and transgression (Murat, 1972; Nwachukwu, 1972). This has been interrupted by two major tectonic episodes: the Cenomanian and Santonian tectonic pulses (Maluski et al., 1995; Olade, 1979). The Cenomanian tectonic pulse affected the only Albian sediments whereas the Santonian was characterized by compressional movement along a NE-SW trend and consequently the upliftment and subsidence of the Abakaliki fold belt and Anambra platform respectively (Burke et al., 1972; Murat, 1972). These pulses were interrupted by phases of magmatism which are represented by alkaline rocks that injected the sediments (Coulon et al.,1996; Mascles et al.,1986; Nurnberg and Muller, 1991). The sediments that underlie the study area are: the Asu River Group, Ezeaku Group, Awgu Group, Nkporo Shale/Awgu Sandstone, Mamu Formation, Ajali Sandstone, Nsukka Formation, Imo Shale/ Ebenebe Sandstone, Bende-Ameki Formation and Coastal Plain Sands. The Santonian tectonism was preceded by the deposition of Awgu Shale in the Coniacian substage. The folding phase of the Santoniantectonism was trailed by a prolonged period of erosion of the uplifted sediments before the subsidence which initiated a minor transgression in the upper Cenomanian (Campanian to Early Maestrichtian), hence the Nkporo Shale was deposited unconformably on the Awgu Shale. The abundance of Pyroclastics within Lokpaukwu explains the fact that this part of the study area witnessed prolonged phase of tectonic activity. Anambra basin is filled with over 2000m thick sediments of Campano-Maestrichian sediments (Murat, 1972; Zarboski, 1998).

Theory and Method

The dataset used for this study: aeromagnetic and Landsat data, were remotely obtained. They serve as one of the cheapest and fastest means of carrying out reconnaissance surveys for oil and mineral exploration. Both have surficial discontinuities recognized by the common correspondence of linear anomalies to surficial evidence of faulting across the area.

The aeromagnetic data used in this work was part of the nationwide geophysical survey carried out in 2008 by Fugro Nigeria Ltd. for the Nigerian Geological Service Agency (NGSA).Flight line direction was NNW-SSE at station spacing of 0.5km with flight line spacing of 0.5km at an altitude of about 80m terrain clearance. Tie lines were flown in an ENE-WSW direction. Regional correction of the magnetic data was based on the IGRF (epoch date of 1st January, 2000). For this study, aeromagnetic sheets 301 and 312 were used which covered the areas within latitudes $5^0 30$ - 6^0 30^1N and longitudes 7^0 00^1 - 7^0 30^1E. The aeromagnetic data came in digital format and of higher quality due to improvement in technology and powerful error correcting software that was used in the processing.

The aeromagnetic data used were subjected to a low pass filtering operation. 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 software with different analytical modules were used in the interpretations of the aeromagnetic map; among which are: Geosoft Oasis Montaj 6HJ version, U.S. Geological Survey Potential-Field geophysical software Version 2.2, Surfer 12 and Matlab 7.5. Regional - residual separation was carried out using polynomial fitting. These maps are published on a scale of 1:100,000. The regional gradients were removed by fitting a plane surface to the data by multi- regression least squares analysis. The expression obtained for the regional field T(R) is given as:

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

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 is of low degree.

The nature of filtering applied to the aeromagnetic data in this study was chosen to eliminate certain wavelengths and to pass longer wavelengths. Analytical methods used include 2-D spectral inversion, trend surface analyses, upward continuation and 3-D Euler deconvolution. Mathematical transformation such as reduction to the pole (RTP) and analytic signal, was applied to superimpose the magnetic anomaly over the magnetic source. Reduction-to-pole (RTP) transformation was applied to the aeromagnetic data to reduce polarity effects (Blakely, 1995). 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. Most linear anomalies of the study area were not revealed by total field intensity magnetic data.

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. Mathematically, a vertical derivative is shown as 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, which means 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. Upward continuation filtering aided in the determination of the depth range of deeper magnetic sources.

Finally, the seven-band Landsat 5 Thematic Mapper (TM) image acquired on the 11th of October 2015, belong to a scene with Path number 188 and Row number 56. This imagery was acquired from NARSDA, Nigeria and used in mapping linear features. 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 on the imagery among others are: contrast stretching, spatial filtering and edge detection.

Also, ArcView 9.3 software was used to extract the lineaments and carry out statistical analysis of the interpreted lineaments in the area.

Results

Aeromagnetic Data Interpretation

The aeromagnetic data used in this study which came in digital format was acquired during the nationwide aeromagnetic survey which was sponsored by the Nigerian Geological Survey Agency (NGSA) and completed in 2008 by FUGRO Nigeria Ltd.

The aeromagnetic data used for this study area belong to sheets 301 and 312 of Udi and Okigwe maps respectively. The regional gradients were removed by fitting a plane surface to the data by multi- regression least squares analysis. Figure 2 is the total field aeromagnetic data of the study area presented as a contour map, while figures 3 is the 3-D surface map of the total magnetic field intensity. The total field of the aeromagnetic data is dominated by different magnetic zones characterized by anomalies of long and short wavelengths which correlates to magnetic highs and lows. Four prominent magnetic zones are observed which have NE-SW trending direction. Whereas two of the magnetic zones have high intensity values, the other two have low.

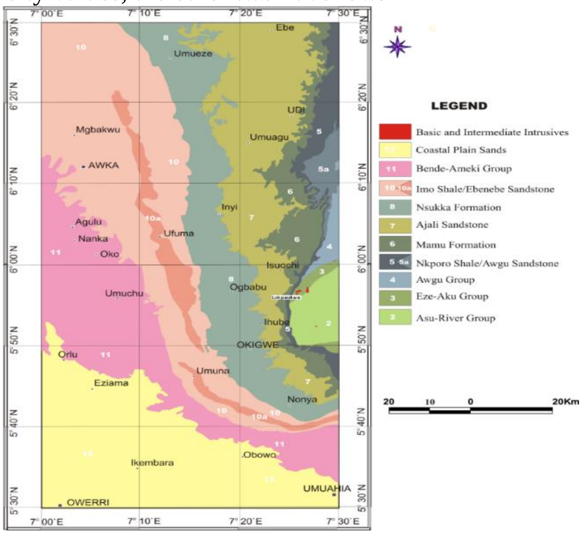

Figure 1. Updated GIS-based Geology map of the study area.

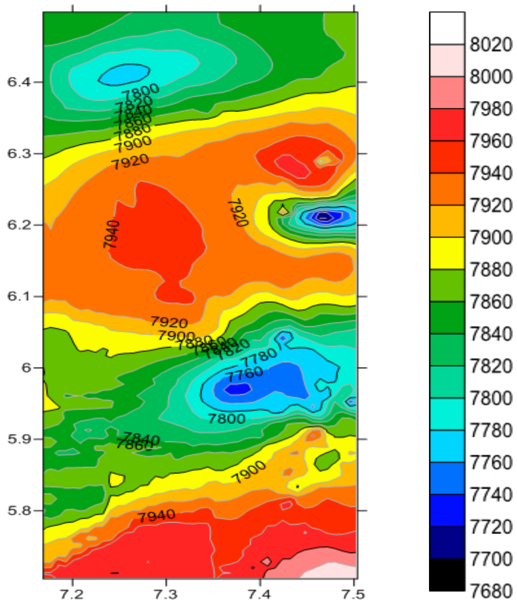

Figure 2. Total field intensity map of the study area (Raster Map).

The magnetic intensity values range from 7740 to 8020 gammas, with a mean value of 7850 gammas. Areas with high magnetic intensity values include the upper central and both flanks of the lower southern portions of the study area. The values are in the range of 7960 to 8020 gammas. These high intensity values are interpreted for areas with lineament of deep-seated origin and suspected of having magnetic materials close to the surface. The areas with high intensity are more tectonically active than the areas with magnetic lows. This is observed around Udi, Uturu, 1km south of Orlu and Umuahia. Similarly, magnetic lows are observed around Awgu, the central portion of the study area, Lekwesi and Lokpaukwu. This is interpreted for areas underlain by sedimentary rocks: loose sediments, shale and limestone. On the geology map (figure 1), these areas are underlain by Mamu Formation, Nkporo Shale, Asu River and the Ezeaku Shale groups known for coal seam, mudstone and Limestone respectively. Closed magnetic lows are observed around Lokpaukwu, parts of the central and northern sections. Major faults may be recognized as a series of closed lows exhibiting a linear trend on the aeromagnetic field map (Alligham, 1966). Therefore, it is logical to interpret the presence of faulted zones around those areas with closed lows. These linear, sub-parallel, closely spaced features with steep gradient are interpretative of faults. The lineaments trend in the NE-SW direction which is in conformity with that of the Benue trough. On the other hand, the areas with broad circular or elliptical high intensity could be interpretative of folded basement which is suspected to be the termination of the Abakaliki fold belt in the Anambra basin. Its NE-SW trend tends to align with the Abakaliki fold belt. High magnetic intensity is observed in places such as: Udi, Ufuma, Inyi, Uturu, 1km south of Orlu and Umuahia. The alternation of magnetic highs and lows suggests folding of the basement in the study area. Result from the 3-D surface map (figure 3) confirms intrusive and folded basement underneath the study area. The spiky intrusive basement surfaces (figure 3) correlates to the basic and intermediate intrusive igneous rocks seen around Lokpaukwu on the geology map (figure 1). Both the intrusion and folding seen on the 3-D surface map confirms that magmatism and compressional stress regimes were operational within the study area.

Results of both regional and residual total magnetic intensity polynomial surfaces (figures 4 and 5) were used in the determination of structural trend and existence of magnetized bodies. The regional polynomial surface revealed that, tectonic structure of deeper and regional extent affected the study area. The dominant structural trend as shown by 1^{st} to 4^{th} degree regional polynomial surfaces (figure 4) is in the NE-SW, NW-SE and E-W, but the NE-SW is the dominant trend as revealed by the first degree surface. The NW-SE reflects the old and deeper tectonic trends.

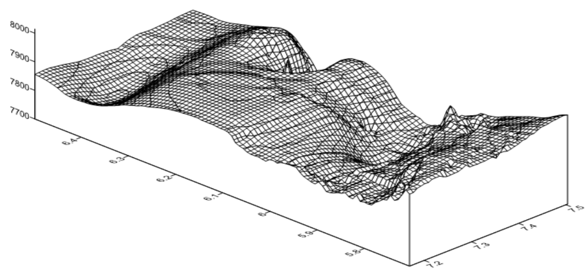

Figure 3.Total field of the aeromagnetic data presented as 3-D map showing the basement topography.

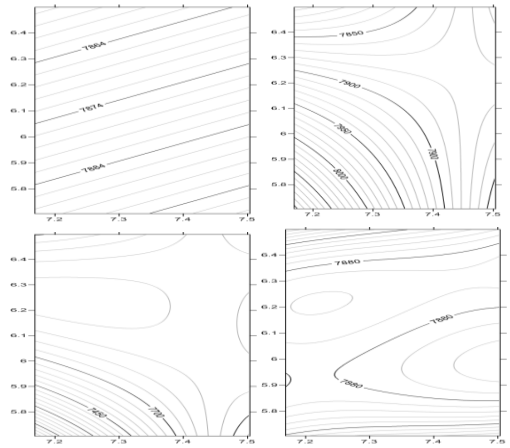

Fig 4. First to fourth degree (polynomial) surfaces of the Regional fields of the Aeromagnetic data.

However, the NE-SW trend reflects the younger tectonic events, because the younger events are more pronounced and tends to obliterate the older events. The Santonian deformation was characterized by compressive folding, generally along a NE-SW direction, parallel to the Trough margin. The NE-SW trend is suggested as continental extension of the oceanic fracture zones: the Chain and Charcot Fracture system.

It was discovered from the residual polynomial surface (figure 5) that the residual magnetic intensity of the study area ranges between -100 to 100 gammas. These residual magnetic intensity values portray the study area as having both positive and negative residuals. The positive residuals are attributed to areas underlain by shallow to near-surface magnetized bodies, while the negative residuals are linked to deep-seated magnetized bodies. The areas with negative residual values have low magnetization while the positive residual anomalies infer areas with high magnetization. The areas with positive residual anomalies include: Udi, Ufuma, Inyi, Uturu, and 1km south of Orlu. This implies that there is an existence of shallow to near-surface magnetized bodies in those areas. Lokpaukwu, Awgu and Lekwesi are underlain by negative residuals which imply that the intrusives seen in the area are deep-seated in origin. Onwualu-John and Ukaegbu, (2009) using petrographic and major element geochemistry of pyroclastics from Lokpaukwu suggest that they represent high-K_2O alkaline basalts, which resulted from the fractionation of the ferromagnesian mineral and plagioclase from a common magma source. Similarly, it was observed that the positive residuals are flanked by the negative anomalies. The flanking negative residuals are related to sedimentary sub-basins within the area.

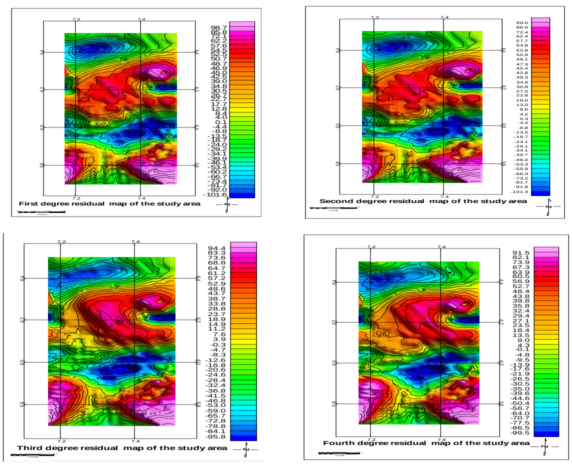

Fig. 5. First to fourth degree residual surfaces of the Residual fields of the Aeromagnetic data.

The first vertical derivative (1VD) (figure 6) highlighted the lineation trending in the NE-SW direction which border the magnetic highs and lows as being of deep-seated nature. The high amplitude closures seen around the southern portion of the zero contour of the second vertical derivative (figure 7) are similar to those on the residual anomalies. They reflect areas with similar lithology and shallow to near surface magnetized source bodies. It can be inferred that four broad lithological boundaries exist within the study area. These are classified based on the colours separating the patterns: green, blue, pink and reddish yellow. The green patterned contours are seen in the extreme northern section with isolated reddish yellow contours, high amplitude pink contours are isolated in the upper and lower western flank, the reddish yellow contours are observed on the central portion of the study area and the blue pattern are prominent on the southern portion of the study area. The green with small closure of yellow pattern on the upper left extreme correlates to areas underlain by the Imo shale whereas the blue and pink areas are underlain by sandstone.

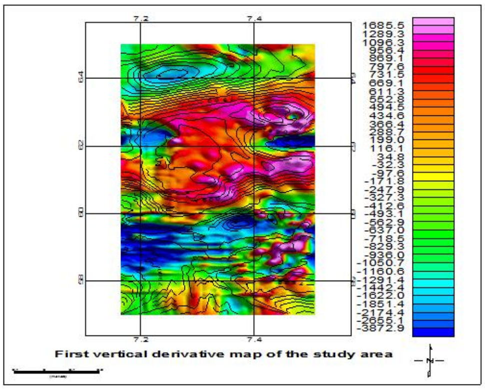

Figure 6. First Vertical Derivative Map of the study area.

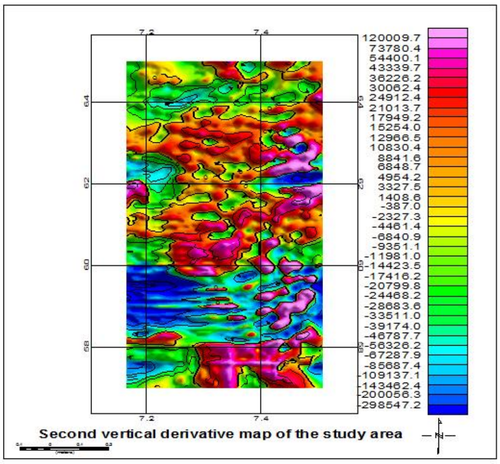

Fig 7. Second Vertical Derivative of Zero Contour Map of the Study area.

The aeromagnetic data of the study area were upward continued at altitudes; 1km, 2km, 3km and 4km respectively above the flight-lines; with Fast Fourier Transform (FFT). The analytic continuation to any altitude of above the flight-line reflects the geologic structures at such depths down which suppress the magnetic effects from shallow structures. The essence of producing upward continuation maps is to determine the trend and nature of any observable deep-seated anomalous bodies at deeper depths. The upward continued maps (figure 8) show that most of the observed deep anomalies at1km to 4km above flight elevation revealed trend directions of NE-SW around Lokpaukwu, E-W and NW-SE elsewhere.

The observed anomalies on the total field maps were visible on the upward continued maps. This implies that those anomalies are deep seated in the earth crust at depth in excess of 4km.

Landsat Imagery Interpretation

Results from the digital elevation model (DEM) (figure 9) of the study area revealed that dendritic and trellis drainage patterns are effective in the study area. The dendritic pattern is seen in most part of the study area, such as: Ebe, Udi, Awka, Oko, Orlu, Owerri, Lokpanta and Okigwe. This pattern is interpreted for areas with horizontally layered sediments or uniformly crystalline rocks. Also, it could be inferred that there was a regional gentle slope at the inception of drainage of sediments from their provenance. The dendritic pattern suggests that the underlying sediment is a homogenous unit. Also dendritic pattern reveals that the lithology has least resistance to erosive action of the river and streams. On the other hand, trellis pattern which is interpreted for a dipping or folded sedimentary terrain is isolated around Umuahia area. It could be inferred for an area that has parallel fracture system.It will be right to interpret the lithology of the topographic high areas as characterized by sandstone and the low areas as characterized by shale and mudrock. Similarly, the permeability of the underlying lithology could be inferred from the DEM of the study area. Low drainage density correlates to permeable soil or lithology; conversely, high drainage density correlates to impermeable lithology. The study area can be divided into two: the permeable areas covering Owerri, Ikembara, Umuchu, Oko, Nanka, Udi and Ebe; and the impermeable areas covering Awka, Nonya, Ufuma and Umuna. Most of the surface water in the permeable areas ends up underground thereby enhancing reduced overland flow. The lowly elevated areas are more prone to flooding as a result of the impermeable nature of their lithology.

Lineaments can be identified through topographic features such as straight valleys and continuous scarps, abrupt change in direction of drainage, straight rock boundaries and sudden tonal variations. In this study, lineaments of both shorter and longer lengths have been observed. The lineaments of longer lengths have deep penetrating power than those of shorter ones. Linear features equal to or greater than 1km were considered. The lineament on edge enhanced and lineament density maps (figures 10 and 11), reveal high concentration of lineament around Lokpaukwu and environs; which are areas where magnetic rock outcrops.

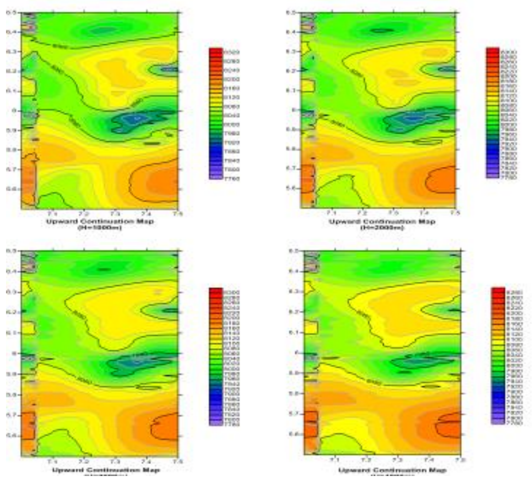

Fig 8. Upward Continued Map of the Study area.

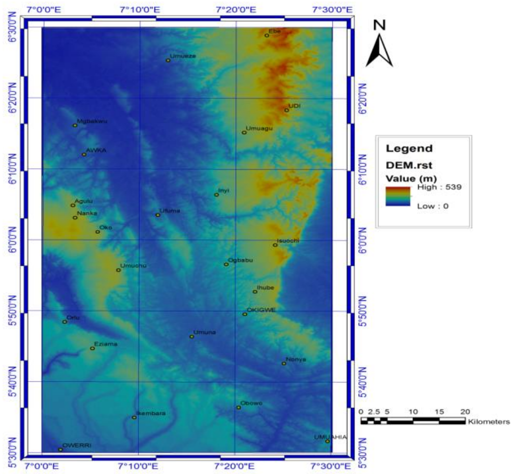

Fig. 9. Digital Elevation Model (DEM) of the Study area.

This appears as heavy cluster of lineaments on the edge-enhanced map (figure 10) and red pattern on the density map (figure 11). Lineaments on these areas cross-cut each other, and some run parallel to each other. The implication is that these areas have gone through several tectonic events. This area may be regarded as a megafracture zone owing to the concentration of lineaments within the area. The lineaments reveal four groups of linear features. The maxima having NE-SW direction, others trend in NW-SE, NNE-SSW and N-S directions. Umeji (1988) and Zarboski (1998) recognized the Pan African Shield as characterized by NNW-SSE to NNE-SSW trending structures, varied intrusives and the lower Cretaceous characterized by NE-SW oriented shear zones and fractures controlled by volcanism.Lineament quantification and statistical analysis were done regarding the orientation frequency of these lineaments to construct a rose diagram (figure 12). Similarly, the rose diagram (figure12) shows a predominant peak direction of NE-SW trend and other directions as observed on the edge-enhanced lineament map. The area was dominated by a NE-SW trending structures and are interpreted as higher degree of shearing and faulting which may have been formed during Pan African thermo-tectonic activity. The NE-SW trend is the dominant azimuth direction which reflects that of the basin. The NE-SW trend represents the younger tectonic events, because the younger events are more pronounced and tends to obliterate the older events.The NE-SW trend is suggested as continental extension of the oceanic fracture zones: the Chain and Charcot Fracture system (Ananaba, 1991).

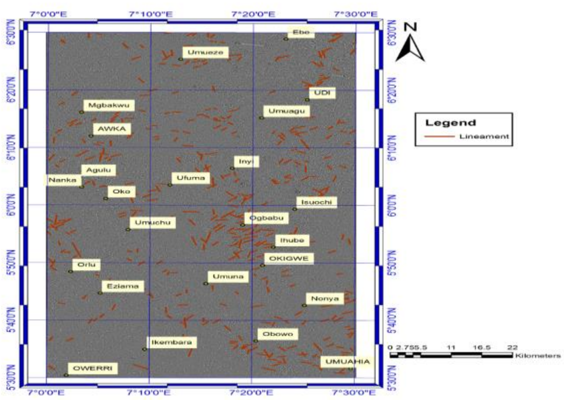

Fig 10. Lineament draped on the edge-enhanced Map of the study area.

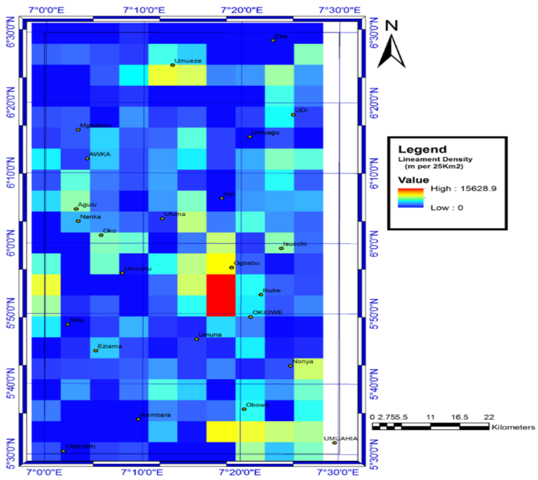

Fig 11. Lineament Density Map of the Study area.

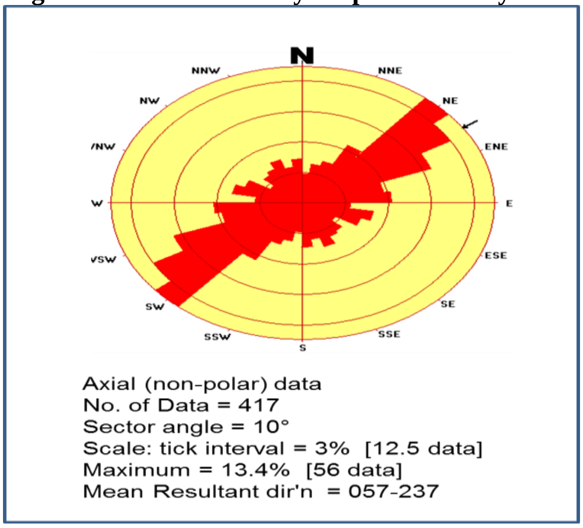

Fig 12. Rose diagram of the Study area.

Discussion and Conclusion

In order to map the structure and tectonism of the study area, the aeromagnetic and Landsat dataset were processed in a manner that enhance the determination of linear features and their trends. The filters applied to the datasets helped in the delineation of structures and the various lithological boundaries.

The study area is interpreted as a tectonic active zone owing to the presence of observed faults and intrusives. The presence of faulting and intrusion signify that the deep seated anomalies are prevalent within the study area. The interpreted aeromagnetic data and Landsat imagery revealed dominant NE-SW trend which reflects the basinal trend. This trend direction would have played an essential role in the control of the geodynamic evolution of the region. The regional fields establish the major tectonic elements of deeper and regional extent which affected the structural framework of the study area. The pyroclastics observed in the study area form domal to lenticular reliefs in the sedimentary terrain in Lokpaukwu and are concordant to the axis of Abakiliki-Okigwe Anticlinorium in southern Benue Trough. Field relations in Lokpaukwu consist of low-lying sedimentary sequences made up of shale of the Asu River Group (Albian), Nkporo Shale (Late Turonian), and Mamu Shale (Middle Maastritchian), with associated topographic highs of pyroclastics, basalts, and dolerites (Onwualu-John and Ukaegbu, 2009).The intrusives in the study area include: dolerites, micro-gabbros and micro diorites which are dated radiometrically as Coniacian - Santonian for dolerites and micro-gabbros, and Santonian for micro - diorites. The sediments appear to be falsely bedded and lineated mostly, in NE-SW and NW-SE directions. They are fractured, fissured, slightly folded and faulted in localized zones (Ajibade et al. 1998). The pre-Santonian sediments which have been deformed by the Santonian thermal regime are further exposed to erosion and subsequent non-deposition within the study area.

Some of the linear features interpreted from regional polynomial surfaces show dominant trend of NE-SW which correspond to the strike and direction of some paleo-structures, faults and tectonically related joints. Lineament observed on the lineament density indicate that high density occurs around Ogbabu, Lokpanta and Lokpaukwu areas. This high density lineament area corresponds to regions underlain by the spiky surfaces observed on the 3-D magnetic basement map. The area may therefore be termed as a megafracture zone. The residual polynomial surfaces revealed that the surface lineaments seen around Lopkaukwu are deep seated in nature.

Economically, the study area may hold less prospect for hydrocarbon accumulation owing to the high level of tectonic activities, but viable for ore minerals sequel to presence of numerous structures.

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