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Lineament Mapping of Structural-trend Analysis over the Niger-Benue River-confluence and its Environs, A Case Study of North-Central Nigeria

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Abstract

Evaluation, analysis and interpretation of aeromagnetic and satellite imagery data acquired over the Nigeria confluence and environs; Northcentral Nigeria were carried out in order to characterise the structural framework of the study area. Fourier domain of digital filtering tools and reduction to magnetic equator (RTE) operations were achieved to enhance the available data's results. The geomagnetic field of the earth was removed from the aeromagnetic data using the IGRF- 12 model. Results from the 2D radially average power spectrum of the enhanced magnetic data estimate the depth of the magnetic sources as 20m. Several digital image enhancement techniques such as edge enhancement and general contrast stretching were applied to the satellite imagery after which the lineaments extracted from the magnetic data and images were mapped out on-screen using ArcMap 10.8. The RTE map showed a high magnetic intensity values ranging from 33051. 93 nT to 33165.3 nT and trend approximately E -W direction at the eastern and northwestern parts. The digital elevation model (DEM) of the confluence and environs was used to enhance geomorphic features. The structural lineaments orientation obtained from the analysis showed that the primary structural lineaments bearing is NE – SW, ENE -WSW and NNW – SSE and the structural directions derived from the 2D maps are aligned along NE – SW and NW – SE. This conforms to the general trend of structures produced by the Pan African events.

Keywords: Lineament extraction, Structure-trend analysis, Aeromagnetic, Satellite imagery, North-central Nigeria.

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INTRODUCTION

Geophysical techniques investigate a unique physical property of the earth crust, which tends to solve a peculiar problem within the earth's subsurface. Magnetic method is the oldest geophysical exploration method used in prospecting. Magnetic method measures variation in the Earth's magnetic field caused by changes in the subsurface geological structure or the differences in near-surface rocks' magnetic properties (Telford *et al.,* 1998). The aim of a magnetic survey is to investigate subsurface geology on the basis of anomalies in the Earth's magnetic field resulting from the magnetic properties of the underlying rocks. Although most rock-forming minerals are effectively non-magnetic, certain rock types contain sufficient magnetic minerals to produce significant magnetic anomalies. Aeromagnetic survey data is collected along oriented and differentially spaced flight lines with the aim of maximizing signal and suppressing noise. Accordingly, flight lines are commonly flown orthogonal to the dominant geologic and structural trend to capture the greatest amount of signal. Levelling procedures in an aeromagnetic survey are carried out to minimize the effects of line-to-line variations caused by diurnal or instrument drift and navigational errors. Signal amplitude artefacts associated with flight line variations will manifest as either a herringbone effect or corrugation bands parallel to the flight direction (Flis and Cowan, 2000). The principal behind levelling potential field data is identifying and then minimizing the presence of any erroneous signal to ensure the resulting signal image best reflects geology-related physical property variations (Mauring *et al.,* 2002).

Lineament analysis is often applied to various geoscientific data including aerial photography, topography, remotely-sensed images and, to a lesser degree, geophysics. The purpose of lineament analysis is to identify linear features commonly representing lithological contacts, faults, fractures and dyke swarms. Geological terranes will often have a dominant structural pattern defined by the orientation and density of lineaments reflecting a terrane's unique geologic and tectonic history (O'Driscoll, 1980; O'Driscoll, 1986; Woodall, 1994; Twidale, 2007; Woodall, 2007). This dominant structural pattern is often revealed through lineament analysis. However, linear artefacts associated with data acquisition (navigational and diurnal) will also be identified through lineament analysis. Lineament analysis can be carried out either on a visual (Harris, 2008) or quantitative basis (Masuda *et al.,* 1991; Raghavan *et al.,* 1993; Karnieli *et al.,* 1996). Often, quantitative methods are chosen over visual-based methods to save time and ensure consistency (Mauring *et al.,* 2002).

This work is devoted to outline the tectonic framework and the structural setup of the study area, as well as delineating prolific zones of interest. The subsurface study is mainly based on interpretation essentially the total intensity aeromagnetic maps of the same latitudes and longitudes, with available subsurface geologic information acquired and obtained from Nigerian Geological Survey Agency, NGSA. To fulfill this objective, several geophysical methods and different transformation techniques were applied on the available data (aeromagnetic and satellite maps) which had been subjected to the same qualitative and quantitative techniques of interpretation. Correlation between the results obtained from various analytical techniques applied and all available geologic information led to establish the tectonic trends map of the study area. The map shows the main lineament trends and depth estimate from power spectrum all over the area and exhibits also the main trends affecting the area. It is necessary to compare structures or magnetics anomalies delineated from the derivatives with the surface features as can be seen from aerial photographs or satellite images (Ogunmola *et al* 2016). Satellite imagery can give us surface picture of outcrops and features such as dyke.

Also, rock units and geological structures show a strong correlation with relief and can be mapped with detailed topographic analysis. The digital elevation model (DEM) is used to derived topographic attributed such as elevation, drainage network, etc. with the aid of Geographic information system (GIS). Magnetic data analysis can be used to establish the relationship between basement tectonics and overlaying structures within the sediments. The total intensity magnetic map was reduced to equator and subjected to regional-residual separation using the Fast Fourier Transform (FFT) while analytic signal method and first vertical derivative were employed for defining the edges of the magnetic bodies and amplifying the orientation of the structures. This work attempts to interpret aeromagnetic data alongside ancillary data such as SPOT 5 Image and digital elevation model (DEM) to map out lineaments and to understand the structural framework and geometry of the Nigeria confluence and environs which can further aid detailed exploratory effort in the area.

LOCATION, GEOLOGY AND PHYSIOGRAPHY OF THE STUDY AREA

The study area is located within latitudes 7° 00' N and 8° 30' N and longitudes 6° 00' and 7° 30' E (Fig. 1) and has an area extend of 27, 875 km^2. It comprising the confluence and environs which is part of the Bida Basin, Middle Benue Trough, Anambra Basin and the Basement Complex (Fig. 2). The basin consists of the basal Lokoja Formation, overlain by the Patti Formation and capped by the Agbaja Formation. The basal Lokoja Formation is a sequence of matrix supported conglomerates and sandstones overlying the Pre–Cambrian to lower Paleozoic basement. A prominent positive anomaly on this surface is interpreted as the product of a mantle plume centered near the Niger/Benue confluence at minimum depth of 30km. This inferred plume is thought to have been a major factor controlling the structural setting and formation of the basin (Likkason., 1993). The depositional environments are predominantly within fluvial systems of a continental setting. (Megwara and Udensi, 2014). The area of study falls under the banded iron Formation of Nigeria, generally they occur in metamorphosed folded bands, associated with Precambrian basement complex rocks which included low meta-sediments, high grade schist, gneisses and migmatites. Included in this group are well known Lokoja-Okene occurrences notably at Itakpe, Ajabanoko, Chokochoko, Toto Muro and Taijimi. In the northwestern parts of Nigeria, the banded iron Formation occurs sporadically in narrow band and lenses inter-bedded with massive green phyllites, feebly developed slaty rock and amphibolites. The dominated lithologic units in the area are gneisses of migma-tite, biotite and granite. Olade, (1975) pointed that the ferruginous quartzite is the source of the iron ore mineralization. The Benue Trough was formed as a result of series of tectonics and repetitive sedimentation in the Cretaceous time when South American continent separated from Africa and the opening of the South Atlantic Ocean. The Pre–Cambrian (4600–570 Ma) to lower Paleozoic (570–500 Ma) basement gneisses and schist is overlain by alternating shales, siltstones, claystones and sandstones (Obaje, 2009; Obaje *et al.*, 2011).

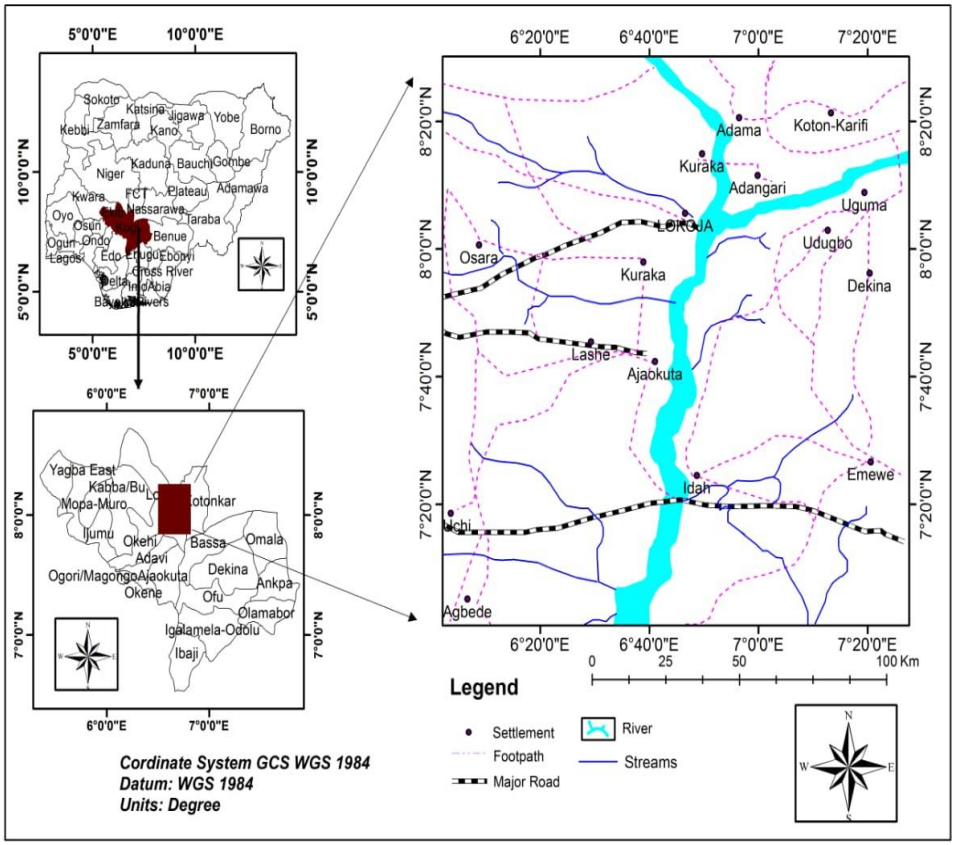


Figure 1: Location map of Nigeria showing the Study Area (Modified from Obaje, 2009)

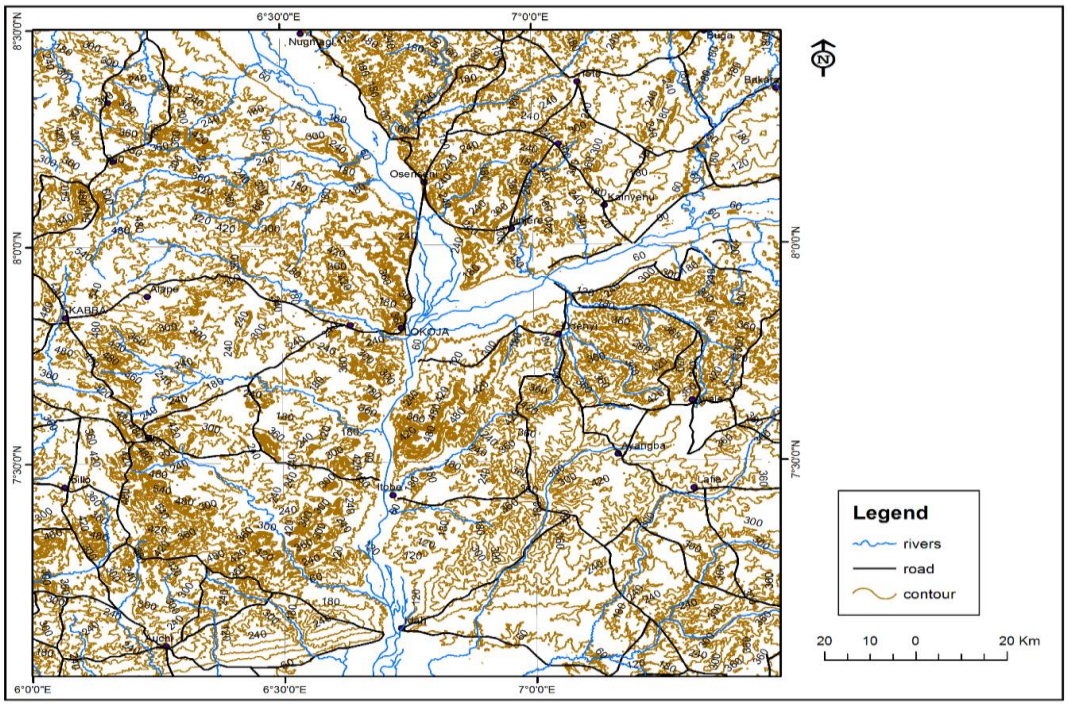


Figure 2: Topographic map of the Study Area (from DEM)

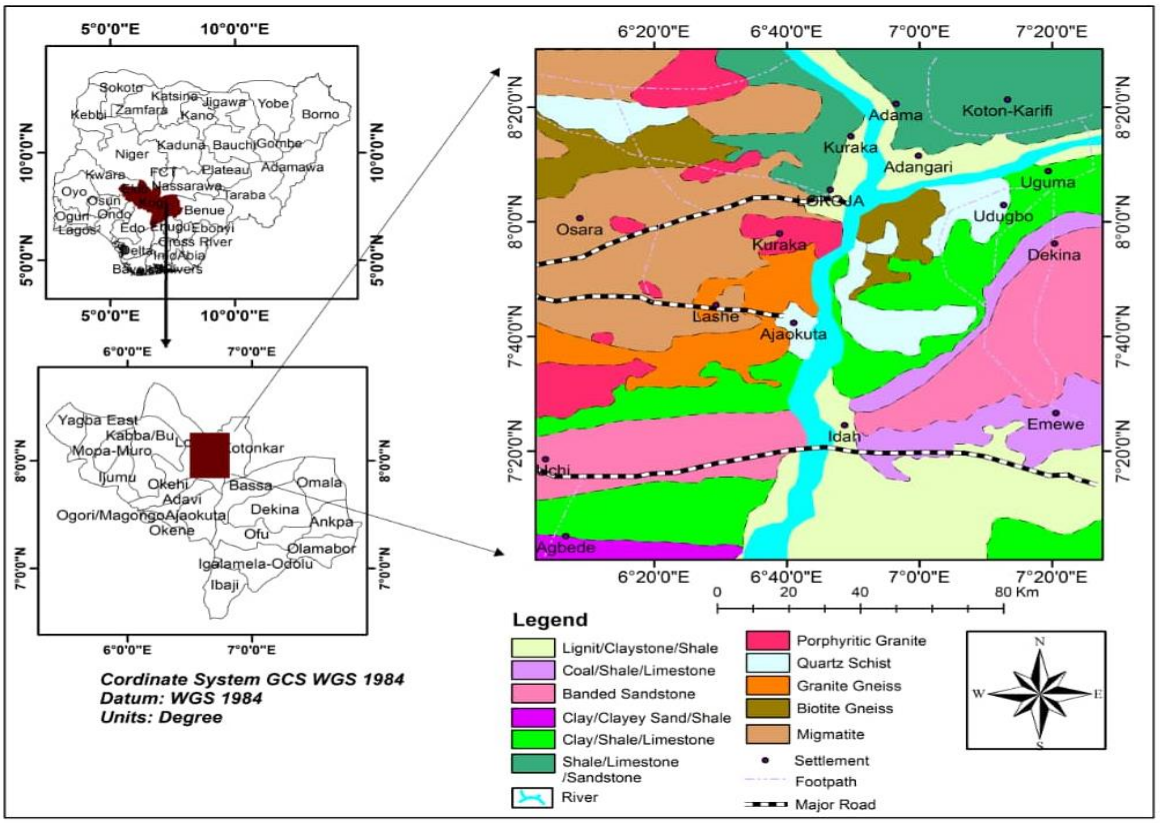


Figure 3: Geological map of the Study Area (Adopted from NGSA, 2018)

MATERIALS AND METHODS

Data available

The data set used for this research and the software package are:

- Grid and line aeromagnetic data covering Lokoja and its Environs (Nine (9) aeromagnetic data sheets; 226, 227, 228, 246, 247, 248, 266, 267 and 268).
- Satellite Imagery (Spot 5 and Digital Elevation Model (DEM)).
- Geosoft Oasis montaj Version 8.4. (2015)
- ArcGis Version 10.8 (2019)
- ILWIS 3.3 (2005), Sufer 13 (2015), Grapher5 (2004) and Microsoft excel (2016).*3.*

Magnetic data

The high-resolution aeromagnetic data used in this study was acquired by Fugro airborne survey on behalf of Federal Government of Nigeria through Nigerian Geological Survey Agency, (NGSA). The aircrafts were flown at 500m line spacing with 80m terrain clearance and nominal tie line spacing of 2km. The survey data, recorded at constant flight line altitude, predominantly in the NW-SE and at a constant terrain clearance, were incorporated into the Magnetic Anomaly Map of Nigeria. The International Geomagnetic Reference Field (IGRF) for the time of acquisition was removed from the data. The Nigerian Geological Survey Agency (NGSA) provided the research area's total magnetic intensity map, which included a total of nine aeromagnetic grids (data sheets) with a scale of 1:5,70,000 and a 5 nT contour. To obtain the corrected magnetic intensity data, 33,000 nT was added to the Z column (TMI).

SPOT 5

SPOT 5 data with ground resolution of 5 m was used in this study. The data provided have successfully met all the quality standard required. Its unrivalled acquisition capability with its two High Resolution Geometric (HRG) instruments. It holds the ideal balance between high resolution and wide-area coverage. SPOT 5 coverage is a key asset for applications such as medium-scale mapping at (1:25 000 and 1: 10 000).

Digital Elevation Model (DEM)

The DEM data set used for this study is from the Shuttle Rader Topography Mission (SRTM) flown by National Aeronautics and Space Administration (NASA) that acquired digital elevation model of the earth's surface with a spatial resolution of 20 m. The SRTM of Lokoja and its environs was downloaded from the Global Land Cover Facility (GLCF).

Total intensity magnetic map reduced to the equator (RTE)

Since the study area is positioned within a low latitude region in the northern hemisphere; the original aeromagnetic data are subjected to a reduction to the northern equator (RTE). The RTE transformation usually involves an assumption that the total magnetizations of most rocks align parallel or anti-parallel to the Earth's main field. According to Leu (1982), magnetic data can also be reduced to the equator (RTE) such that the magnetic bodies will appear horizontal at the equator. At low latitudes RTE shows little changes in data as observed in the Nigeria confluence and its environs with a declination of -2.64, and inclination of -9.29 and total intensity value ranging from 3288,40 to 33165.31 nT (from the IGRF 12 Model) which showed a resultant grid similar to the total magnetic intensity (TMI) grid. There is a specific program made by Raid *et al., (*1990) at the USGS (United States Geological Survey) called GX's (Geosoft eXecutables), which is compatible with the Geosoft and contains the RTE operation in low latitudes (the study area is between 7° 00' N and 8° 30' N (Fig. 1).

Methodology

Regional–residual separation using the fast Fourier transform (FFT)

The fast Fourier transformation (FFT) was applied on the RTE aeromagnetic survey data to calculate the energy spectrum. As a result, a two-dimensional power spectrum curve was obtained (Fig. 4). Based on the appearance of the spectrum, (change in the slope of the spectrum curve), the slopes of the segments yield estimates of the average depths to magnetic sources. The depth of each source ensemble responsible for each segment was calculated by introducing the slope of this segment in the formula:

$$\text{H (depth)} = \frac{-Slope}{4\pi} \quad \ldots\ldots\ldots\ldots (1)$$

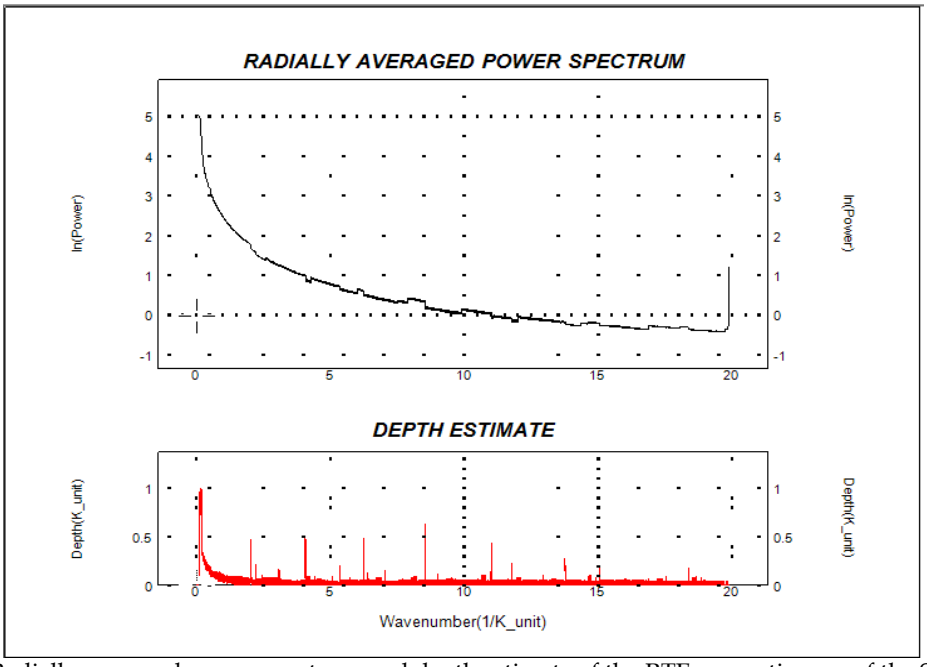


Figure 4: Radially averaged power spectrum and depth estimate of the RTE magnetic map of the Study area.

Regional (Low-Pass) magnetic map

The regional magnetic map (Fig. 5) shows deep seated high amplitude positive and low magnetic anomalies. Careful examination of the map indicates that, some of the magnetic anomalies continue to appear from original RTE magnetic map (Fig. 7) but with lower amplitudes and frequencies. This regional RTE magnetic map brings out the major trends affecting the deep-seated structures of the study area. These structures nearly possess the N-S, NE-SW and E-W, as the main structural trends, beside the NNW-SSE and NNE-SSW trend, but in less significant order. These anomalies show sharp contacts in various degrees with the surrounding magnetic features, which exist at Kabba, Lokoja, Koton-Karfe and Katakwa. The sources of these anomalies may be due to basic or ultrabasic intrusions. There is also, relatively large, negative and relatively broad magnetic anomalies were encountered within Ageva fault (limestone deposits) and represented by the blue, green and yellow colors, ranges. They may be correlated with (Fig. 3). subsurface acidic rocks.

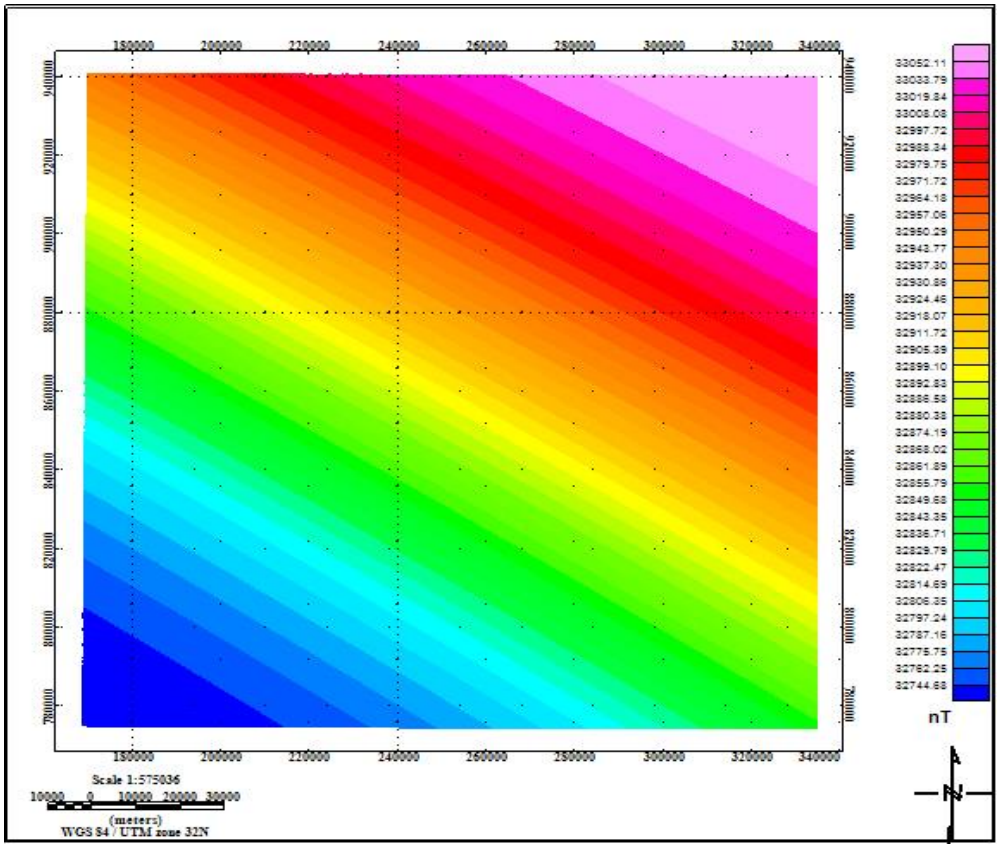


Figure 5: Regional magnetic anomaly map of the study area

Residual (High-Pass) magnetic map

The residual RTE magnetic-component map (Fig. 6) shows the sudden changes in the magnetic relief, always accompanying the shallow-seated geological features and/or bodies. As well as clearly shows some clusters of positive and negative magnetic anomalies with local variation in both frequency and amplitude of these anomalies. Generally, these variations may be due to the difference in their compositions and/or their relative depths of their sources. The number of magnetic anomalies of strong and high amplitudes were encountered at banded iron deposits, in the E-W, NE-SW and N-S direction, represented by the yellow, red and magenta color and ranges between -50.54 nT and 316.59 nT.

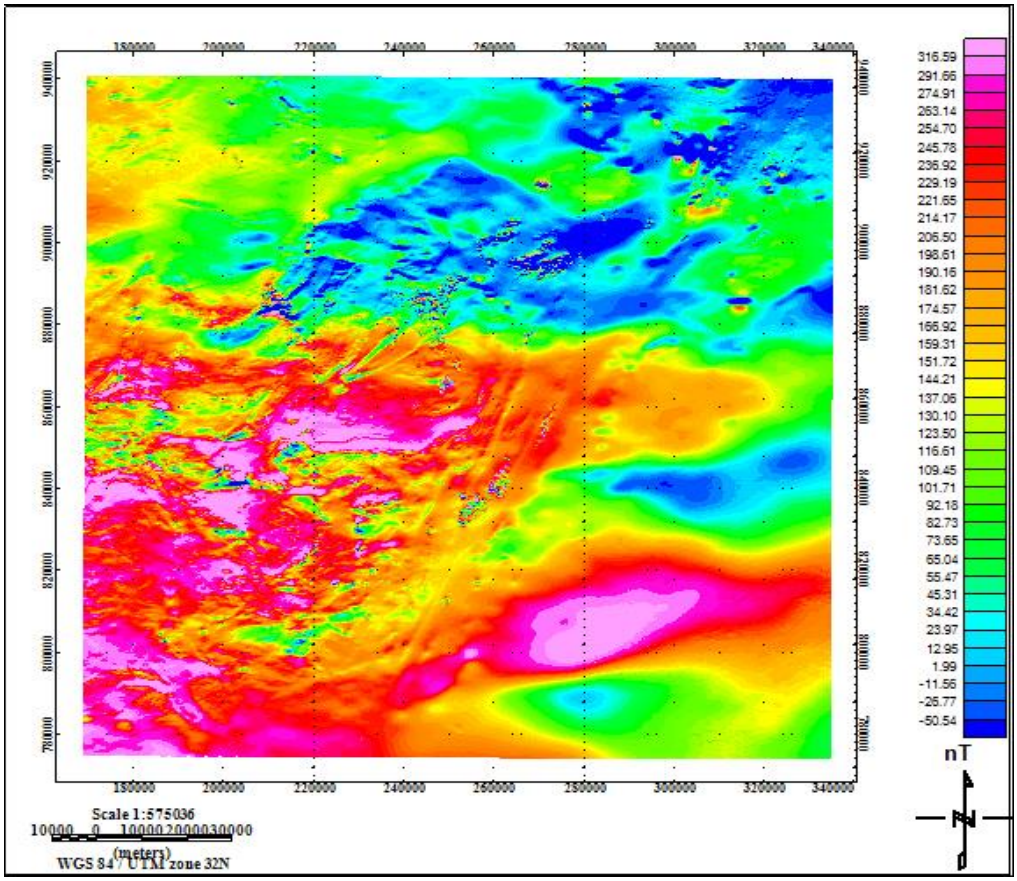


Figure 6: Residual magnetic anomaly map of the study area

Edge detection method

This section discusses the qualitative aspects of enhancement approaches based on total gradient and first vertical derivative (analytic signal); the method is described in the following manner.

Total gradient (analytic signal) method

The analytic signal of the total field reduces the magnetic data to anomalies whose maxima mark the edges of the magnetized bodies if the sources are resolvable (Nabighian, 1984; Roest *et al.,* 1992; MacLeod *et al.,* 1993) but appear as cluster of highs for a combination of nearby sources, regardless of the regional magnetic field direction and source magnetization. The analytic signal map is very useful for delineating magnetic source location at shallow subsurface levels. The analytic signal map of the aeromagnetic anomaly of the study area is represented in Fig. 8. The highs in this map are associated with magnetic sources. The analytic signal method, known also as the total gradient method, produces a particular type of calculated magnetic anomaly enhancement map used for defining the edges (boundaries) of density geologically anomalous density or magnetization distributions. Mapped maxima (ridges and peaks) in the calculated analytic signal of a gravity or magnetic anomaly map locate the anomalous source body edges and corners (e.g., basement fault block boundaries, basement lithology contacts, fault/shear zones, igneous and salt diapairs, etc.). Analytic signal maxima have the useful property that they occur directly over faults and contacts, regardless of structural dip which may be present, and independent of the direction of the induced and/or remnant body magnetizations. The function used in the analytical signal of the magnetic field, defined by Reid *et al.,* (1990). The analytical signal analysis map was obtained from the (magnetic) anomaly maps using (Geosoft) software. The technique was performed

on either two dimensional (map) or one dimensional (profiles). The main objectives of the analytical signal process are to (1) locate boundaries of density/or (susceptibility) contrast from gravity/or magnetic data. (2) transform data so that anomaly peaks centered over their sources. (3) determine depth to- source information particularly effective in the one-dimensional case. (4) locate the edge of sources in areas of low magnetic latitude (often used as an alternative to reduction to the equator).

First Vertical Derivative Technique

This technique acts as a filter arises from the fact of the first differentiation with respect to the depth in order to emphasize the local-shallower anomalies on the expense of the larger regional ones. The technique is considered to be useful for defining the edges of the bodies and amplifying the fault trends. This technique was applied on RTE magnetic maps, using mathematical formula after Schwartz, (1974), at various radii from 1 to 5 km, space interval of 1 km, in order to emphasize the anomalies caused by small features on the original map. The significance of vertical derivatives is locating the position of the density or magnetization boundaries were given. The RTE-TMI image contains all the anomalies both shallow and deep sources. Therefore, first vertical derivatives (FVD) filtering was used to suppress unwanted sources that were obscured by broader regional trend. In this case, it accentuates short wavelength components to sharpen the edges of the anomalies; tends to reduce anomaly complexity and allow clearer contrast between the geologic unit sand causative structures like lineaments/faults and smaller trends (Fig. 9).

Structural Mapping of Satellite Imagery

The analysis and interpretation of remote sensing imagery are determined by the objective of the interpretation (Ogunmola *et al.,* 2015). The term lineament was first used by Hobbs (1904) who defined "lineaments as significant lines of landscape that reveal the hidden architecture of rock basement. O' Leary *et al.,* (1976) defined "lineaments as a mappable, simple or composite linear feature of a surface whose parts are aligned in a rectilinear or slightly curvilinear relationship and which differ from sub-surface phenomenon". The lineament mapping based on structural trend analysis over the Nigeria confluence and its environs has been on the spatial and directional attributes of their assemblages. The ArcMap has the capacity to integrate different data sets that have the same spatial reference to extract information that may be common or different among the various data sets. All the various data sets including the SPOT 5 and DEM, the curvature, drainage, and the shaded relief maps were displayed in ArcMap and mapping was done by studying one layer at a time and comparing with other layers in the GIS environment. The geological map was useful because it showed the distribution of rock types on the surface. One of the memorious advantages of working in a GIS environment using different data sets is the opportunity to examine features that are spatially referenced. A feature that is less pronounced in one data set can be more noticeable in another data set and this can be better studied in a GIS environment. In order to digitize the lineaments, a shapefile was created in ArcCatalog and it was set to the same coordinate and spatial reference as the other data sets. The digitizing tool was then used to map out the lineaments observed from the various data sets on-screen. A rose diagram was created in Georient software. Several processing operators such histogram equalization and filtering were carried out on the images in ArcMap 10.3 so as to enhance the interpretation of the linear features. The filters applied include the line horizontal, line vertical, line diagonal right and line diagonal left each of which enhances the interpretation of the lineaments that trend in their direction. Extreme care was taken not to interpret cultural features such as roads, irrigation canals, topographic ridges and other linear features that are not fracture related as lineaments during the course of lineament identification.

Lineament Density

Lineament density maps display the distributions of the lineaments in two-dimensional maps. Karcz (1978) defined lineament density as the summed length of lineaments within a specified unit area of a grid. The lineament density maps of the area were computed for each section of cell of the source data using the total lineaments lengths contained within each unit section. The area was divided into equal area grids of 36 blocks (6 columns and 6 rows). The number of lineaments in each grid were counted and recorded. A lineament that extended into another domain boundary was counted within the grid area extended into it. The numbers were assigned to the centre of each grid area and then contoured at appropriate intervals. The maps are shown as Interpolated contour pseudo representations of the lineament density maps.

RESULTS AND DISCUSSION

Reduction to magnetic equator (RTE)

The Reduction to equator (RTE) of the total magnetic intensity (TMI) map (Fig. 10) shows positive magnetic intensity value as high as 33165.31 nT which dominated the western and extended towards the southern and southwestern part of the study area. Similar feature is noticed at the northwestern part of the study area striking NE-SW direction. The north, and northwestern parts of the study area is dominated by rocks with intermediate to high magnetic intensity (Ajakaiye *et al.,* 1981). The intermediate to high magnetic intensity correlate with the Katakwa, Kotan-karfe, Dekina, Idah and Auchi within the study area. The RTE map (Fig. 7) shows variation in the magnetic intensity, possibly indicating variations in mineral composition of the rocks in the study area. The northern part of the map is dominated by fairly lower magnetic intensity (32885.40 to 32973.12 nT) which can be depicted as the limestone within the sedimentary infills. This feature is also observed at the eastern region of the map with a trend of approximately E-W direction and at the northwestern part showing a trend in same direction. Intermediate magnetic intensity (32990.78 to 33042.81 nT) feature is seen at the central and northwestern part of the map trending almost in E-W direction. This body with intermediate magnetic intensity is considered around Lokoja and Ayegunle. Features with high magnetic intensity (33051.93 to 33165.31 nT) was observed at the southwestern and southeastern part of the map showing a trend of NE-SW direction. The high magnetic intensity was observed to correlate with the igneous intrusion.

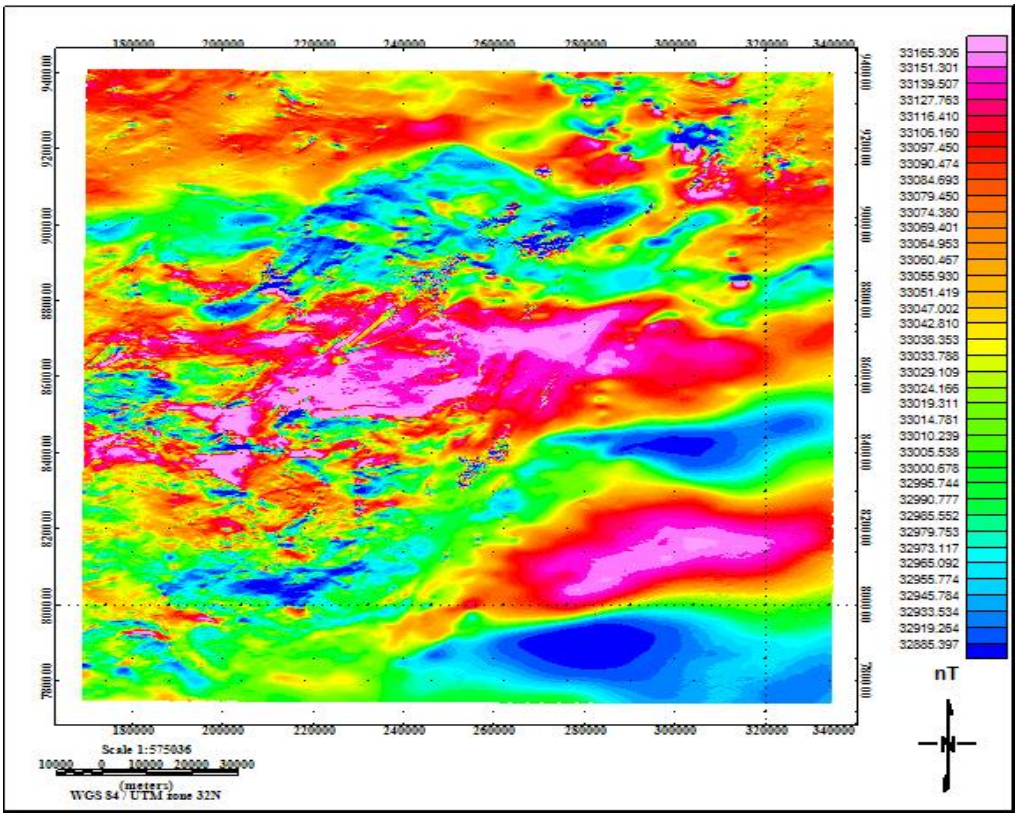


Figure 7: Reduction to magnetic equator (RTE) anomaly map of the study area.

Total gradient (analytical signal)

To know the source positions of the magnetic anomaly regardless of direction and remnant magnetization of the sources effects that are mostly associated with the RTE, the analytical signal filter was applied to the RTE grid. The significant characteristic of the analytical signal is that, it is independent of the direction of the magnetization of the source. Moreover, the amplitude of the analytical signal can be related to the amplitude of magnetization. The most significant concentrations of mineral deposits in an area are correlated with high analytical signal amplitudes (Reeves, 1998). Figure 18 (analytical signal map) shows that, the most prominent features are the high analytic signal amplitude that runs in an approximately NE-SW direction along the southeastern part of the area and small segment around the northwestern border of the area. Three major magnetic amplitude zones i.e high magnetic amplitude zone (0.186 to 0.381 nT/m) which are defined around Kabba, Lokoja, Auchi and Katakwa, intermediate magnetic anomalous zone (ranges from 0.005 to 0.13 nT/m) around Konto-Karfa and Aiyeguinle and low magnetic anomalous zone (0.14 to 0.149 nT/m) at Dekina, Allomo and Idah, were delineated (Figure 8). These three different amplitude zones are based on the magnetization contrast, produced by varying mineralogy composition and depth of the magnetic sources.

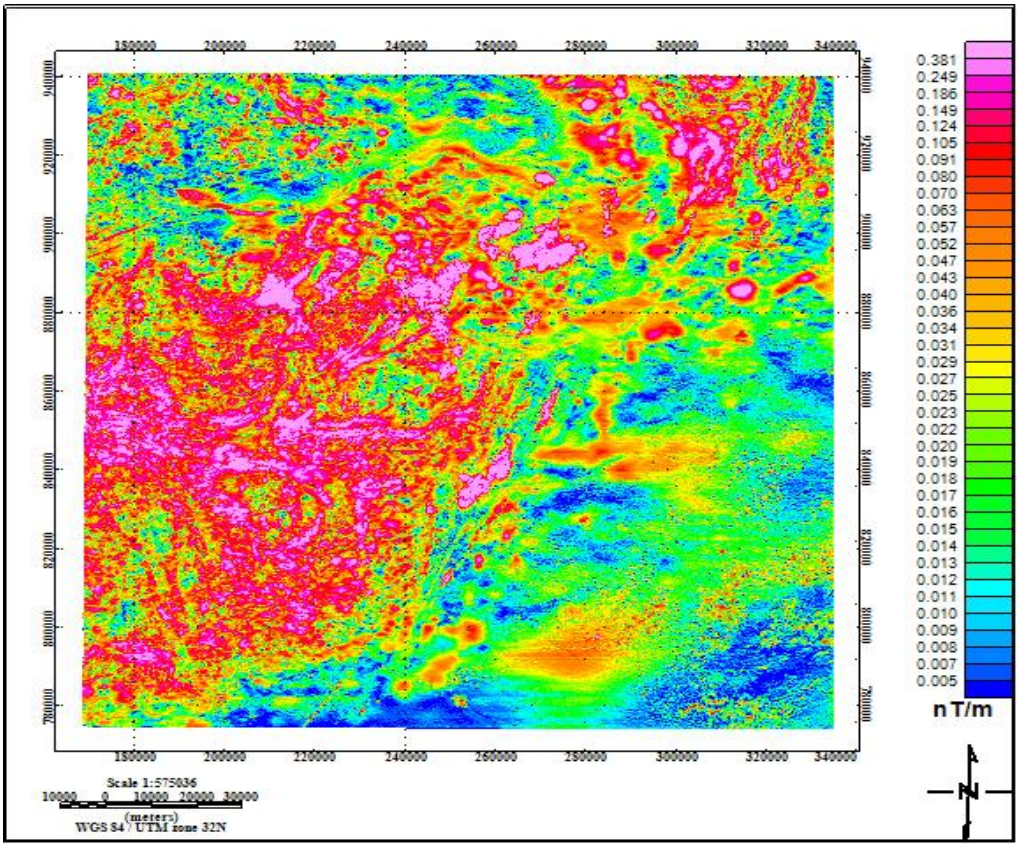


Figure 8: Analytic signal map of the study area

First Vertical Derivative (FVD)

The first vertical derivative filter decreases with more regional anomalies and rather enhance local magnetic responses which are interpreted as structures in the area. A grey scale is applied to the first vertical derivative of the RTE map. This helped in the identification of features such as lineaments/faults, contacts, edges and trends of various rocks. The grey scale of the first vertical derivative (FVD) image of the RTE gridded data (Figure 9) enhanced the image by showing major structural and lithological details which were not obvious in RTE image (Figure 7). Prominent lithological contacts observed are: the Kabba-Lokoja limestone (see block cells extraction) boundaries with other Formation. Others, highlight areas occupied by Kotan-karfe, Dekina, Ida, Auchi, Katakwa the Aiyegunle and Allomo respectively. The Kabba-Lokoja boundaries are well defined when compared with others in the area.

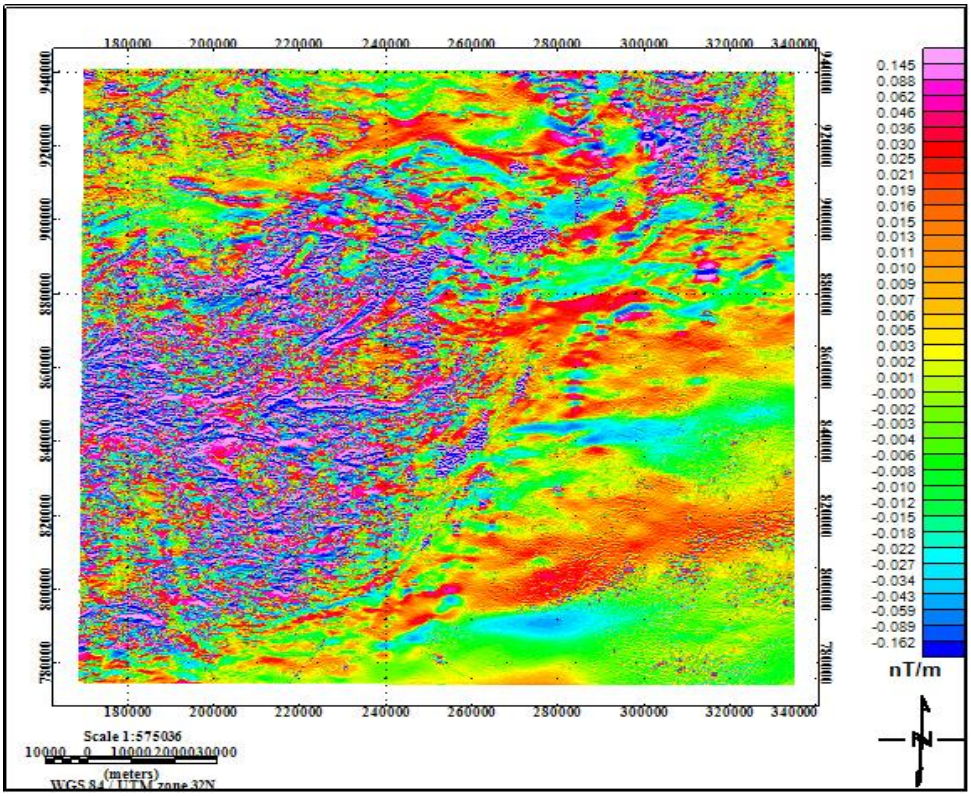
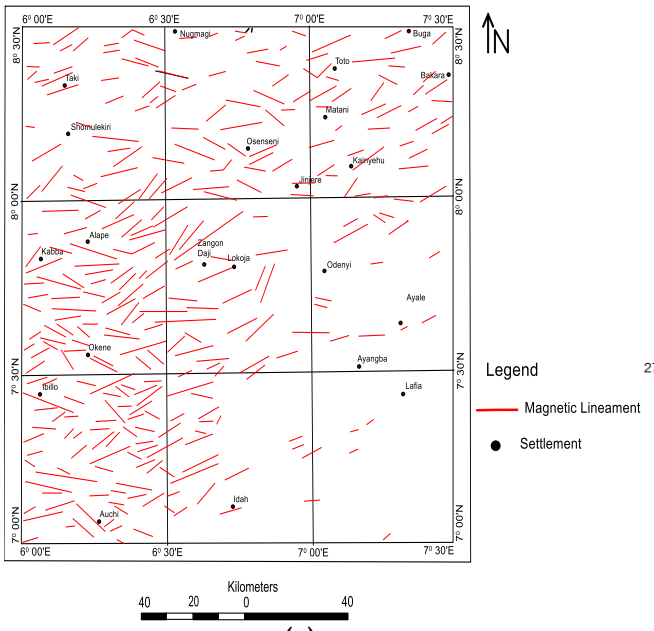


Figure 9: First vertical derivative map of the study area

Structural trend analysis of lineaments

The lineaments extracted from the satellite image ranges from 400 m to 31 and are mostly from the basement part of the study area (Fig. 10c). The deduced structural maps (Figs. 10(a-i)), represent the fault system dissecting the area. The deduced fault planes of the different directions are grouped every 6° around the north for their length percentage L% and represented by Rose diagrams. The results of fault system deduced from both magnetic, satellite and drainage maps, were represented in the form of rose diagram as shown in (Figs. 10(b,d,f,h)). The results indicate that, most of the predominant directions are N 65° E this trend is the most predominant direction in the investigated area according to its characteristics making a mean strike of N 65° E. This trend has a strong relation to trends deduced from RTE magnetic maps. The second predominant trend is N 70° E which is related to Benue trough trend. The third predominant trend is N 88° E trend that is related to River Benue. The least predominant is the SE-NW trend that related to the Pan-African orogeny. It can be stated that the area has been affected mainly by at least four major tectonics orogenic cycles of deformation of which Pan-African orogeny is the last affected the study area (Obaje, 2009). The age pattern suggests that the parent magma were locally derived from several simultaneous high level magma chambers connected to a common deeper source (Alkali, 2013). Rose diagrams were created from the lineaments maps and presented as directional trends on 30° orientation class intervals in Grapher5 (2004) environment. Lineaments' orientation and the geological structure is shown in the (Figure 10 (a, c, e, g, i)) are intimately related to the tectonic action. The movement is thus thought to be in response to the NE extension and SW compression as sources of shear strength, according to the lineament pattern. The direction of tectonic activity, notably compression caused by the opening of the Niger-Benue Rivers, which are thought to have been created during the Pan-African orogeny, is consistent with the structural pattern that has been interpreted.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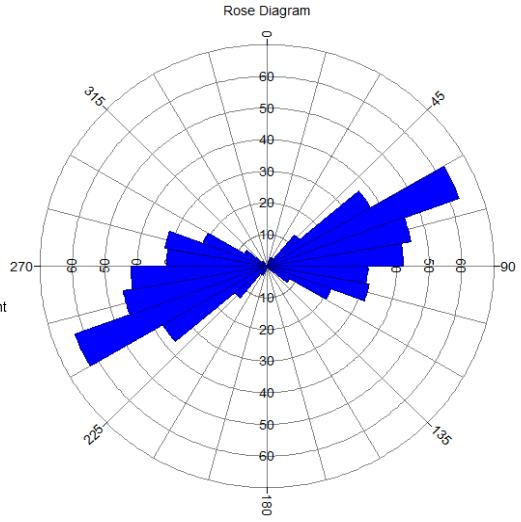
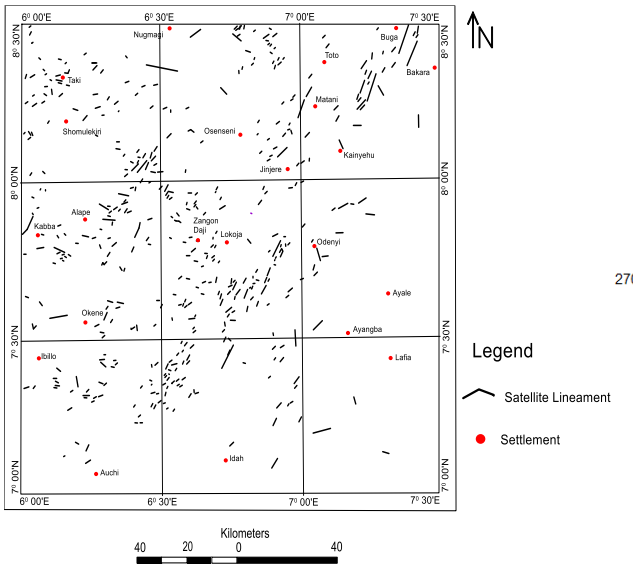
40 20 0 40

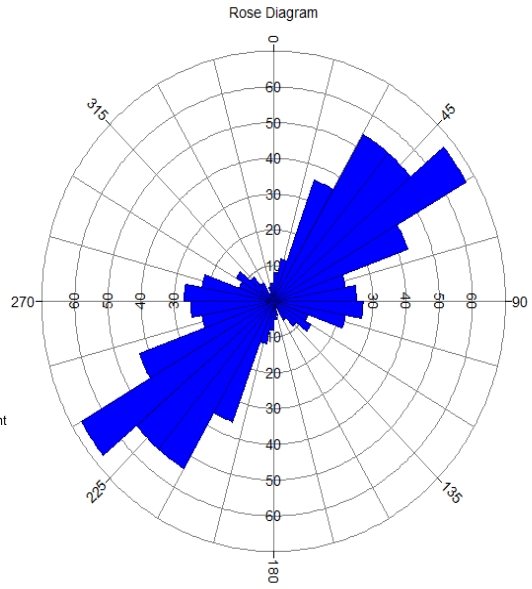
(a)


Rose Diagram
0
45
90
135
180
225
270
315
10
20
30
40
50
60

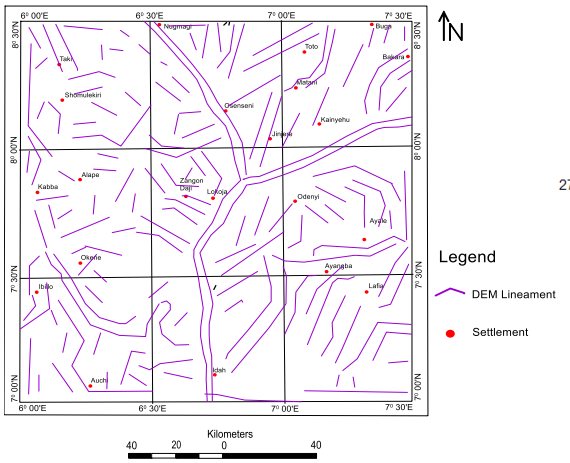
(b)


6° 00'E
6° 30'E
7° 00'E
7° 30'E
8° 30'N
8° 00'N
7° 30'N
7° 00'N
Nugmagi
Buga
Toto
Taki
Bakara
Matani
Shomulekiri
Osenseni
Kainyehu
Jinjere
Alape
Kabba
Zangon Daji
Lokoja
Odenyi
Ayale
Okene
Ayangba
Ibillo
Lafia
Idah
Auchi
N
Legend
Satellite Lineament
Settlement
Kilometers
40 20 0 40

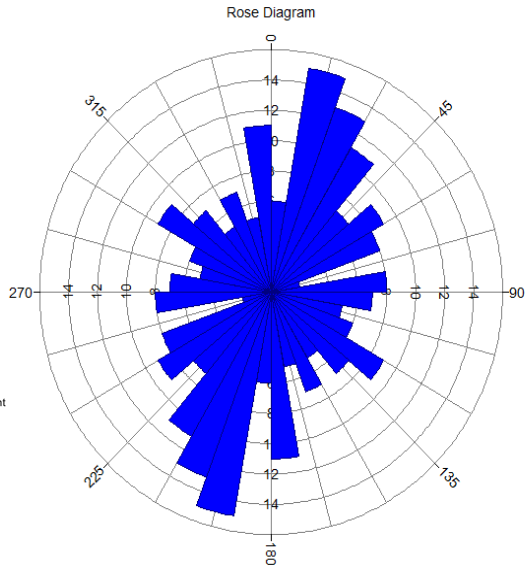
(c)


Rose Diagram
0
45
90
135
180
225
270
315
10
20
30
40
50
60

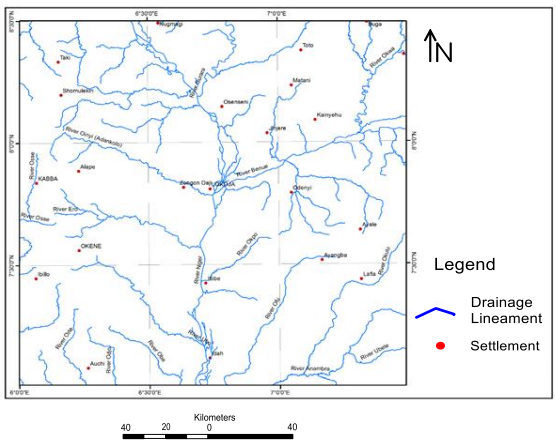
(d)


N
Legend
DEM Lineament
Settlement
Kilometers
40 20 0 40

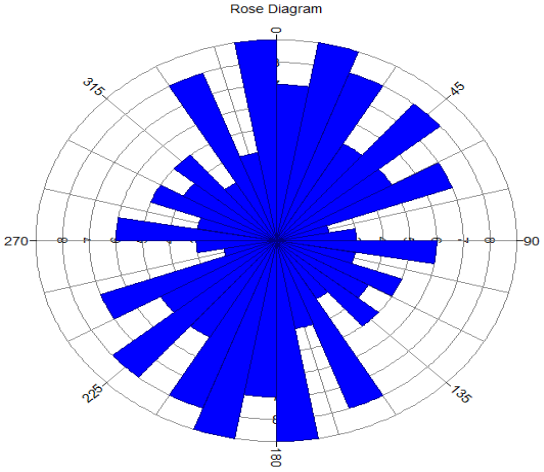
(e)


Rose Diagram
0
45
90
135
180
225
270
315

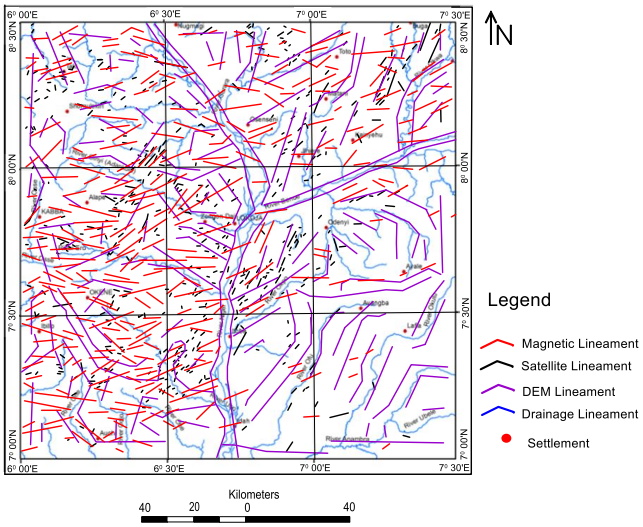
(f)


N
Legend
Drainage Lineament
Settlement
Kilometers
40 20 0 40

(g)


Rose Diagram
0
45
90
135
180
225
270
315

(h)


N
Legend
Magnetic Lineament
Satellite Lineament
DEM Lineament
Drainage Lineament
Settlement
Kilometers
40 20 0 40

(i)

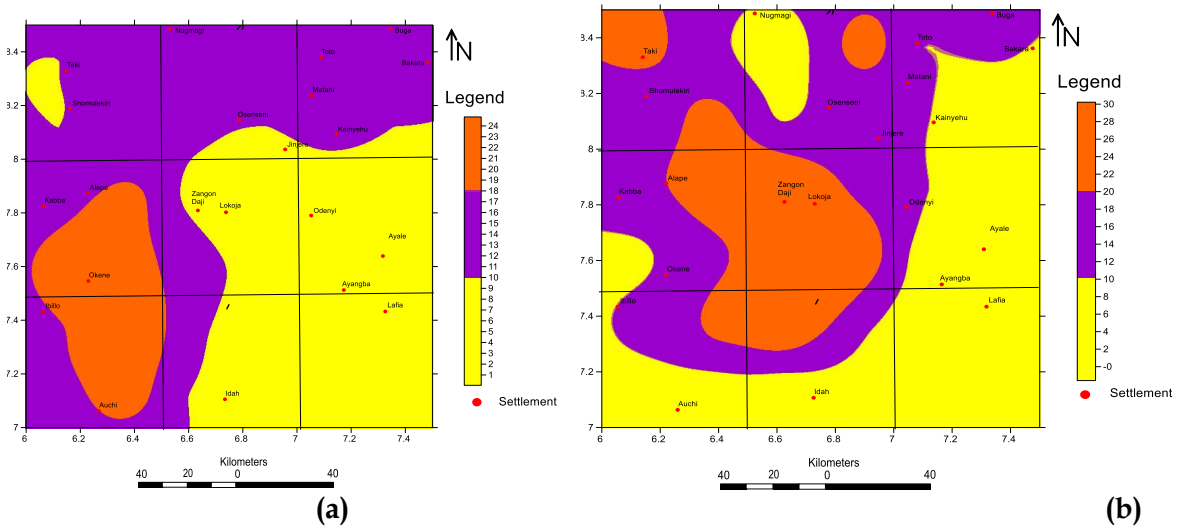
Figure 10: (a) Lineament map extracted from aeromagnetic data of the study area **(b)** Rose plot for magnetic Lineament of the study area **(c)** Map of Lineaments from satellite imagery of the study area **(d)** Rose plot for satellite Lineament of the study area. **(e)** Map of Lineaments from DEM imagery of the study area. **(f)** Rose plot for DEM Lineament of the study area **(g)** Drainage map of the study area **(h)** Rose plot for Drainage Lineament of the study area **(i)** Map of Combined Lineaments of the study area.

Table 1: Summary of Lineament Orientation Trends in the Study Area.

Data Type	Number of Trends	Orientation Description				
		1^0	**2^0**	**3^0**	**4^0**	**5^0**
Drainage	5	a=N 30^0 E b= N 5^0 W	a= N 45^0 E b= N 30^0 W	N 65^0 E	N 85^0 E	a= N 65^0W b= N 55^0 W
Satellite	5	N 55^0 E	N 45 E	N 65^0 E	N 85^0 W	N 75^0 W
DEM	5	N 15^0 E	N 20 E	a= N 30^0 E b= N 5^0 W	a= N 55^0 E b= N 55^0 W	N 85^0 E
Magnetic	4	N 65^0 E	a= N 75^0 E	N 55^0 E	N 75^0 W	

Lineament density maps

The results of interpolated lineament density data are extracted from drainage, satellite, digital elevation model, aeromagnetic and combined lineament maps were overlays to infer their structural trends in relation to the emplacement of the study area (Fig. 19 to 23). Figure 23 is a 2D map produced from combined lineament density data of the area. The map shows three zones of high density of lineaments around the western, central (basements complex) and small portion of the north with a density values ranging from 42.00 to 56.00. The intermediate lineament density structural values (24.00 – 41.00) envelope the high values structural units and fall within the northwest and southwest regions while the low values (8.00 to 23.00) aligned along the NE – SW direction around the east and southeast area.



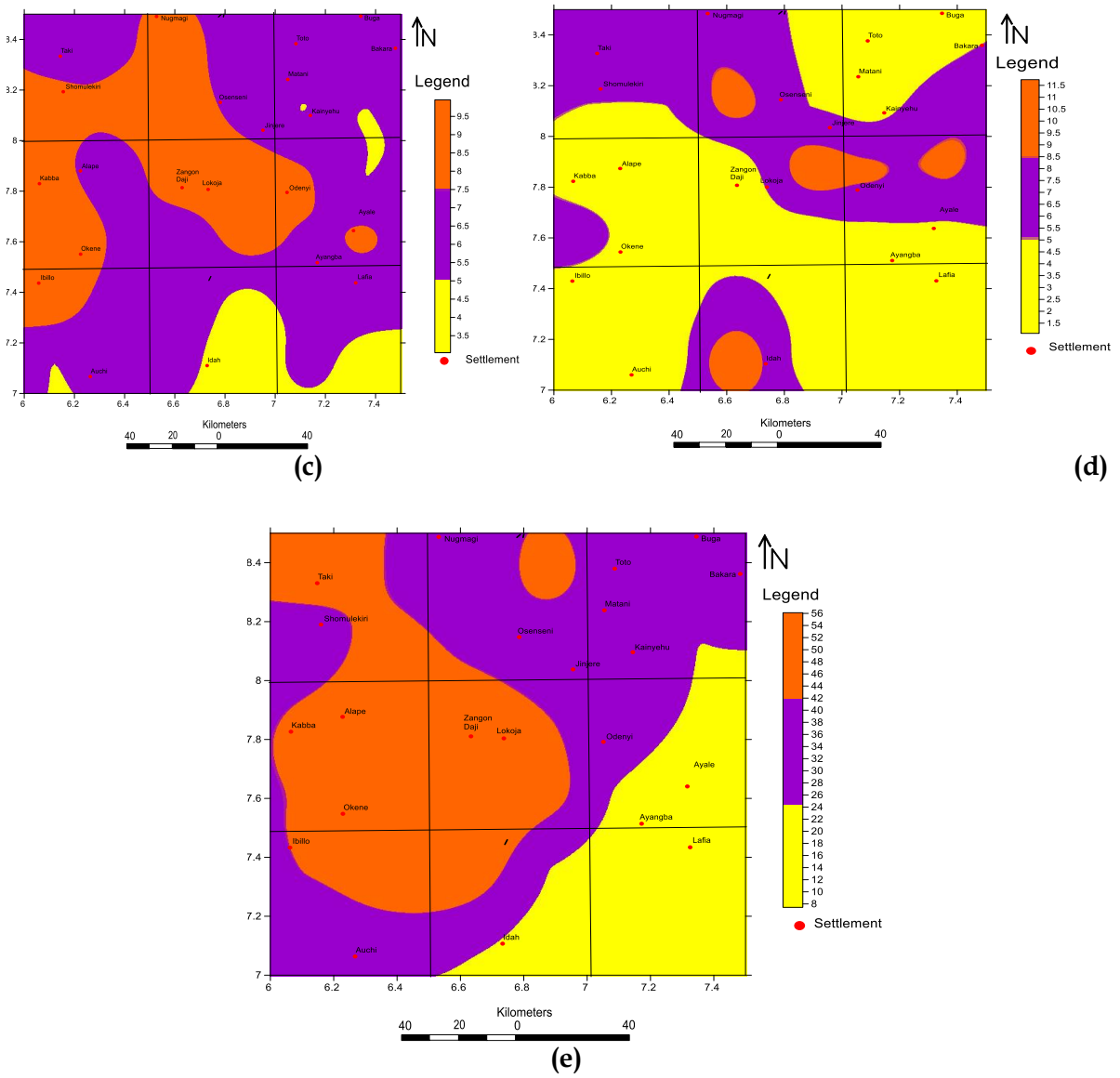


Figure 11: (a) Magnetic Lineament density map of the study area. **(b)** Satellite Lineament density map of the study aree **(c)** DEM Lineament density map of the study area **(d)** Drainage Lineament density map of the study area **(e)** Combined Lineament density map of the study area.

CONCLUSION

Aeromagnetic data and satellite imagery acquired over the Nigeria confluence and environs were analysed. Four data sources of lineaments were identified, mapped and overlaid to form the fifth source of lineament data. We have shown a robust assessment on the data quality and specifically, the application of lineament trend analysis. Analysing lineament azimuths in the form of rose diagrams and their associated statistics allow for a quantitative measurement to be placed on the study. Rose diagrams aid in identifying populations similar to a 2D radially-averaged power spectrum, but rather than frequency we analyse strictly the azimuth. Structural lineament analysis indicates the major trend of the structural lineament is NE – SW, ENE -WSW and NNW – SSE. The lineament azimuths are assessed as rose diagrams this is an alternative method in the frequency domain to flight path. The drainage pattern of the study area is dendritic and structurally controlled. The density and orientation of the fracture lines revealed areas of greater lineaments development in Kabba, Alape, Okene, Ibillo, Lokoja, Zangon Deji and Taki axes occurring over the surface expression of the

basement complex and other rocks unit. The TMI high within the basin section may result from basement rock uplift beneath.

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