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Interpretation of Subsurface Structures over Part of Northwest Basement Rocks, Nigeria Using Magnetic Method

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Abstract

High resolution aeromagnetic data were interpreted for subsurface structures in part of Northwest basement complex, Nigeria. The study area lies between longitudes 5^0 00′ E to 6^0 00′ E and latitudes 10^0 00′ N to 10^0 30 ′N. It covered two aeromagnetic sheet 40 and sheet 141 with a total area of 6,050 km^2. The magnetic data were analysed to detect and identify fractures, fault and structural contact in the area. First vertical derivative and center for exploration targeting methods were used for the data analysis. The first vertical derivative was used to identified and sharpen the magnetic anomalies associated with geologic features. These anomalies were linear magnetic features. Magnetic lineament were prominent at Kontagora, Bomi, Tegina, Kagara and Zungeru in the study area. The center for exploration targeting (CET) method was used to detect fractures/fault and structural contact in the study area. The fractures and fault identified from CET were prominent with high density of structural contact at Kagara, Tegina and Zungeru at the southwestern part of the study area. Magnetic lineaments (fracture/fault) were observed trending northeast direction. These could be deep or near surface fractures and faults or linear geologic structures.The observations in trend and location of the fracture/fault and the structural contact from CET analysis all agreed with the anomalies identified in the study area through derivatives. These *structures and structural contacts could be associated with near surface intrusion which suggests mineralization potentials in the area. The fracture/fault could serve as potential area for ground water exploration and their trend could also represent the tectonic trend that affects the study area and the Nigeria basement complex at large. This study will serve as a guide for further geotechnical study in the area.*

***Keywords**: Lineament; anomalies; Fracture/fault.*

Introduction

Subsurface structures are fracture, fault and joint (geologic structures) that could host ground water, mineral deposit and can cause significant settlement in building construction. The knowledge of the structural architecture of subsurface structures, the distribution and orientation of fault and shear zones, their formation and possible reactivation during the structural revolution and tectonic condition is a key to understanding the formation, origin and location of mineral deposits as well as exploration and finding a new target (Saalmaan 2007). A substantial part of Niger State, North Central Nigeria Figure 1, was studied using derivatives and center for exploration targeting (CET) in magnetic method. This method was applied to identify fractures, fault and structural contacts**.** The study area covers two aeromagnetic sheets with total area of 6,050 km^2. It is bounded by longitude 5^0 00′ E to 6^0 00′ E and latitude 10^0 00′ N to 10^0 30′ N. The regional and local controls of mineralization are mainly structural, made up of a system of transcurrent and subsidiary faults and other structures of Pan African age (Ho and Groves, 1987). The regional faults were probably the main conduits from which the mineralizing fluids were subsequently focused into the subsidiary structures. The research area Figure 2, fall within the northern basement rocks of Nigeria.

The occurrence of the magnetic mineral in the rocks of the study area, allows the application of first vertical derivative method and center for exploration targeting (CET) analysis in identifying fractured and fault basement rocks. The application of enhancement techniques such as derivatives, fourier filtering and others, contribute to the geologic interpretation of the magnetic data (Korhnen, 2005; Oladundoye *et al.*, 2016).

The aim of this research is to identify subsurface geologic structures that could cause engineering, building construction problem and also favored ground water, mineralization in the study area. The specific objectives are to identify fracture/fault zones in the study area and enhance magnetic anomalies in the area. This research study will serve as guide for building and engineering construction.

Geologic setting of the study area.

The study area can be viewed in terms of two principal lithologic units. The oldest unit consists of Precambrian Basement rocks at the northeast, southeast, and Northwestern part of the study area. The second unit consists of cretaceous to recent sedimentary rocks of Bida basin which overlie the Precambrian basement unconformable at the southwestern part of the study area (Figure 2). The Cretaceous sediment is dipping to the southwest reaching a thickness of 1.72 km (Udensi, 2002; Maigwara and Udensi, 2014).

The schist belt (metasediments and metavolcanics) that overlie the basement rocks of Nigeria were predominant in the central part of the study area. The fine to coarse grain granite rocks was dominant in the study area Figure 2. The schist belts boundaries have been described as metamorphic fronts, Mylonite and rift bounding faults (Haruna *et al.*, 2012). The basement rocks are characterized by granite to granodiorite and amphibolites rocks (Udensi *et al.*, 1986). The basement complex of north central Nigeria has heterogeneous assemblage. These include migmatites, gneisses, schists and series of basic to ultrabasic metamorphosed rocks. Granitic rocks and gneisses cut across one another and are characterized with coarsed texture. Geometrically they occur as dykes, sill lenses and phenocrysts. The Pegmatites are several meters long. The major structural trend in the basement is essentially northeast – southwest and follows the tectonic trend of the schist belt (Udensi *et al.*, 2003). The study area is bounded at the southwest by the Cretaceous sediment of Nupe Basin.

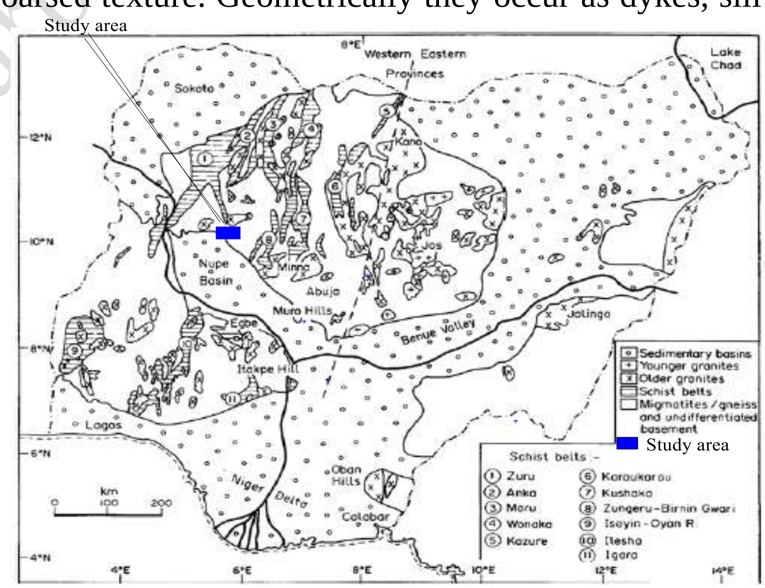

Figure 1: Geologic map of Nigeria showing the study area (after Obaje, 2009).

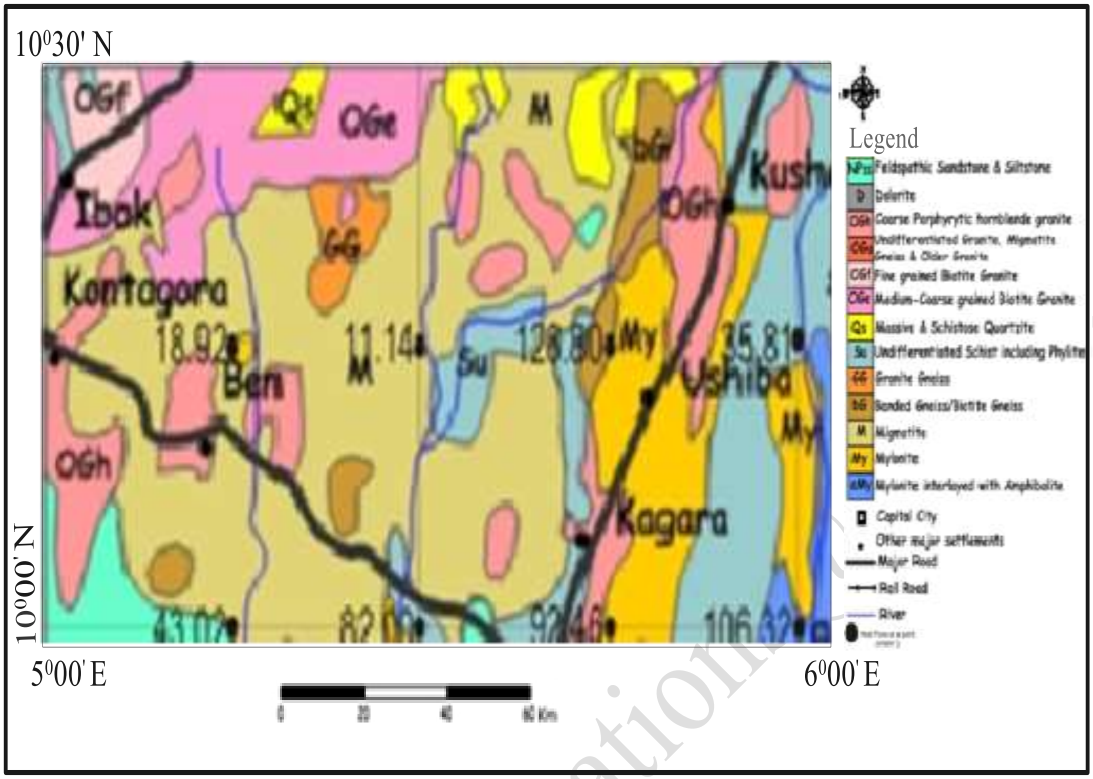

Figure 2: Geologc map of the study area, after NGSA, 2006

Materials and Methods

The materials used in this study include high resolution aeromagnetic data of sheet 140 and 141 covering the study area. The magnetic data were collected by FUGRO airborne services for Nigeria geological survey agency between 2003 to 2010 (MMSD, 2011). The data were flown at a mean terrain clearance of 80 m and profile line spacing of 500 m.

Methods

The magnetic data was analyzed using Oasis montaj version 8.3 for the production of total magnetic intensity (TMI) map of the study area. The data was reduced to equator and further analyzed using various techniques suitable to achieve the designed objectives. The first vertical derivative tends to sharpen the edges of anomaly and enhance shallow features and therefore tends to give a sharper image than the total field intensity map. Thus, smaller anomalies are more readily apparent in areas of strong regional disturbance (Gleason *et al.*, 1996). The first vertical derivative was used to delineate high frequency features more clearly where they are shadowed by long wavelength, low frequency anomalies. The expression is given as (Gleason *et al.*, 1996)

$$\text{FVD} = \frac{dT}{dz} \tag{1}$$

Where, T is the potential field anomaly.
dz = is the derivative in vertical direction.

The first vertical derivative values involve transforming the residual magnetic field intensity values into frequency domain, using first Fourier transform (FFT) method. The fast Fourier transformed data are then multiplied with a first vertical derivative filter (K^n) (Blakely, 1995), where k is the wave number in the frequency domain and n is the order of the filter. The product obtained is transformed back to the space domain to obtain the first vertical derivative values.

The centre for exploration targeting (CET) analysis contains tools that were used for texture analysis, lineation detection, lineation vectorisation and structural complexity. These are versatile algorithms useful for grid texture analysis, lineament detection, edge detection, thresholding, and identifying areas of structural complexity.

The two texture analyses tools were Entropy and Standard deviation. These tools provide analysis of local texture through windowed filtering of the grid data. The Entropy provides a measure of the textural information within localized windows or neighbourhoods in a dataset. It measures the statistical randomness of a neighbourhood data values by first quantizing the data into discrete bins and then analyzing the total number of distinct values resultant from that quantization. Given a specified number of bins, n, for each cell i, in a $k * k$ sized neighbourhood, form a histogram and compute the entropy as follows:

$$E = -\sum_{i=1}^{n} P_i \ \log P_i \tag{2}$$

The probability p is obtained after normalizing the histogram of n bins.

The output grid comprises real values indicating the amount of randomness exhibited by the texture in the neighborhood centered about each cell. Regions exhibiting high statistical randomness are considered high in entropy whereas regions of little randomness have low entropy.

The standard deviation provides an estimate of the local variation in the data. At each location in the grid, it calculates the standard deviation of the data values within the local neighbourhood. Features of significance often exhibit high variability with respect to the background signal. For a window containing N cells, whose mean value is μ, the standard deviation σ of the cell values x_i is given by:

$$\sigma = \sqrt{\frac{1}{N}} \sum_{i=1}^{N} (x_i - \mu)^2 \tag{3}$$

Result and Discussion

Qualitative interpretation describes the results and explanation of the major features and geological structures, including lineaments identified from the interpreted maps covering the study area. These structures give rise to the evident anomalies. Magnetic trends, lineaments (structures) and domains of varying intensity and frequency content were identified. Magnetic boundaries and lineaments were identified from derivative and CET analysis.

The total magnetic intensity (TMI) map (figure 3), represents all the magnetic effect in the area. There are variations in magnetic intensity values which suggest a wide variety of different magnetic properties. The regions with high magnetic effect were denoted with H and regions with low magnetic effect were denoted with L. These magnetic effects are due to the magnetic strength and magnetic susceptibilities of different rock types in the study area. The southwestern part is predominantly characterized with low magnetic response.

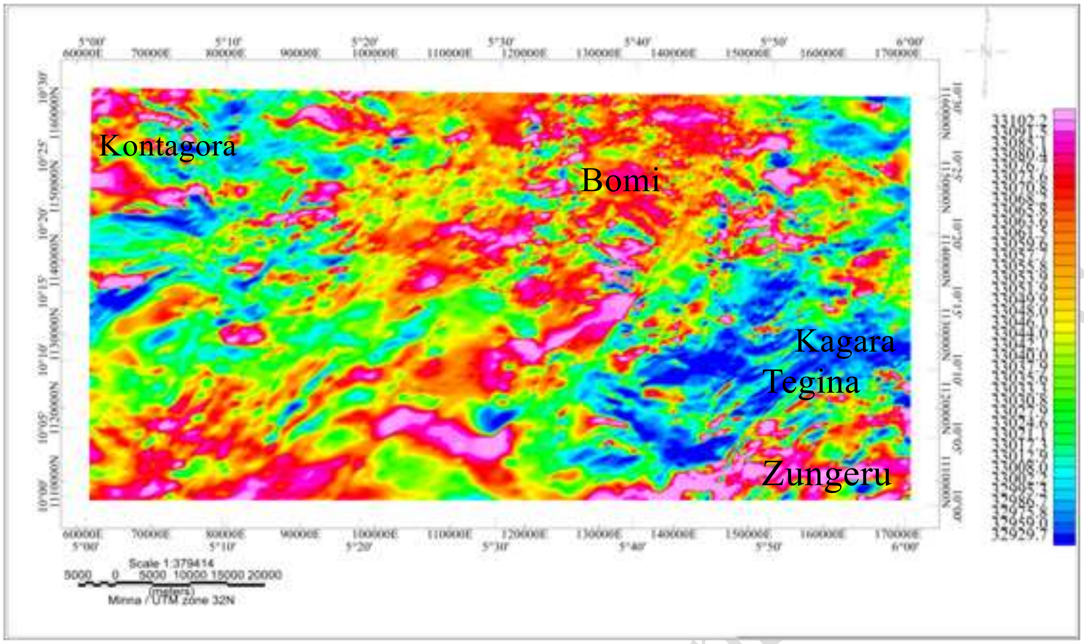

Figure 3: Total field magnetic map of the study area.

Structural Analysis and Trend

The first vertical derivative was used to sharpen and identified the near surface magnetic anomalies associated with shallow geologic features. Magnetic lineament were prominent at Kontagora, Kagara, Tegina and Zungeru in the study area (figure 4). The magnetic lineaments were visually observed trending northeast – southwest and east - west direction with major lineament striking in the NE/SW (Figure 4). These magnetic lineament could be deep or near surface fractures and faults or lnear geologic structures

Lineament from CET analysis

The subtle lineaments (fractures/fault) identified from CET analysis were dominant at the northwest, northeast and southeastern part of the study area (Figure 5). This fracture/fault could be associated with ground water and near surface intrusion which suggests mineralization potentials at Kagara, Tegina and Zungeru in the study area (Figures 5a and 6). According to Ho and Groves, 1987; the regional and local subsurface structures,were made up of a system of faults and other structures of Pan African age. The magnetic lineaments produced from center for exploration targeting (CET) analysis (Figure 5), agreed in location, shape and trend with the subtle magnetic anomalies observed on the derivative map (Figure 4). This is in agreement with the work of Olorunsola and Chukwu (2018). The structural contct and structural maps (Figures 5b and 6) highlights high density of structural contacts (fault and joints), which include junctions and intersections of different structures and locations where structures have significant orientation changes. These structural contacts were dominant at Kagara, Tegina and Zungeru (Figures 5b and 6). The structural contact agreed with the point at which the fracture/fault changes it orientation (Figure 6).

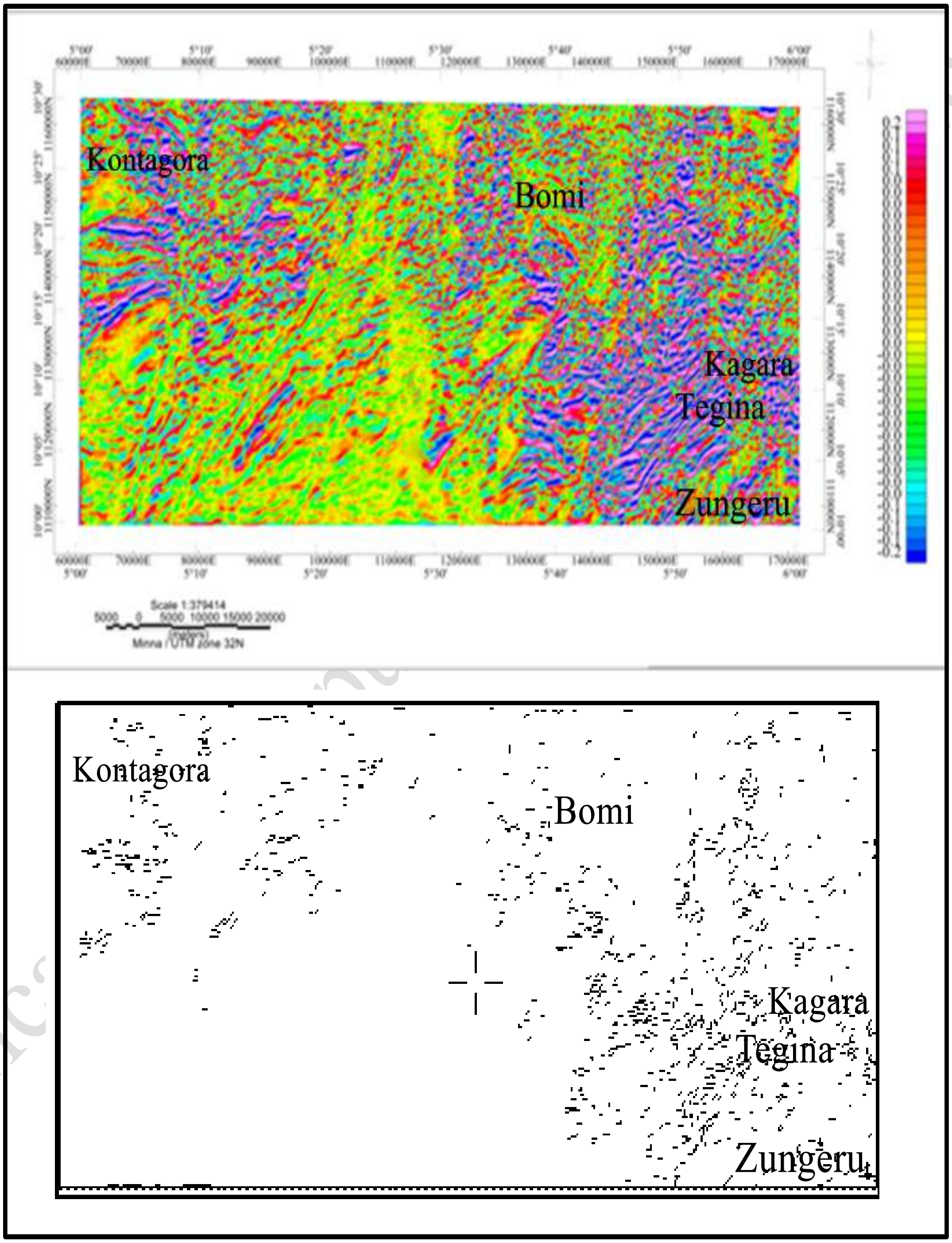

Figure 4: First vertical derivative map showing the lineament in the study area.

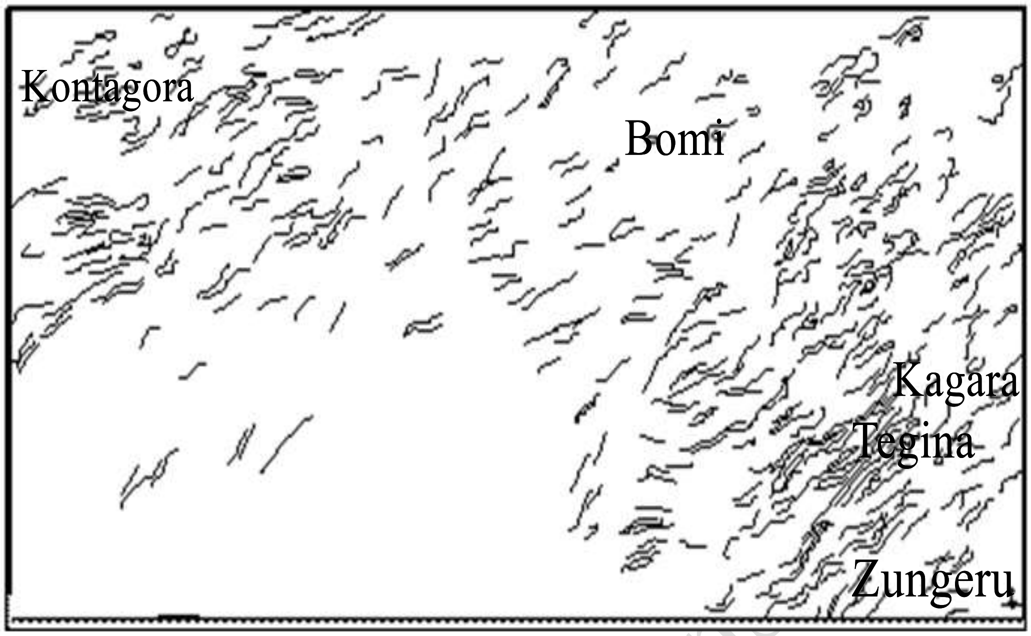

Figure 5a Lineament (CET) map of the study area.

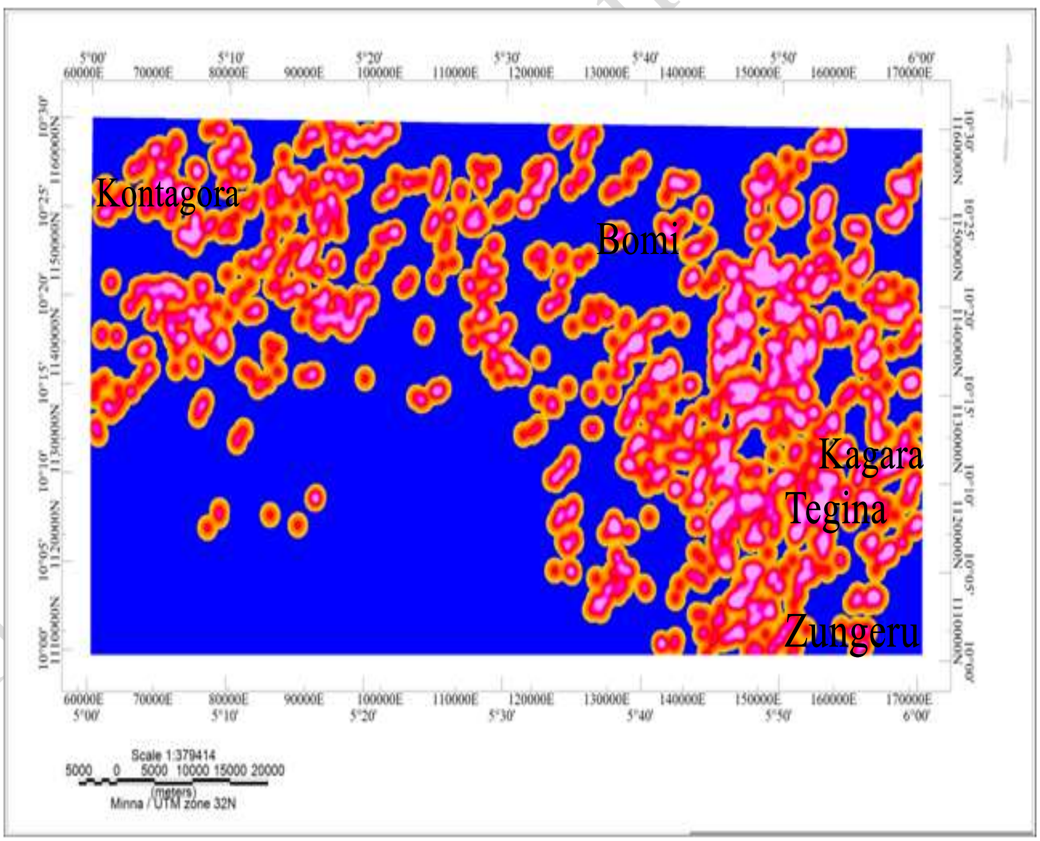

Figure 5b Structural contact map of the study area.

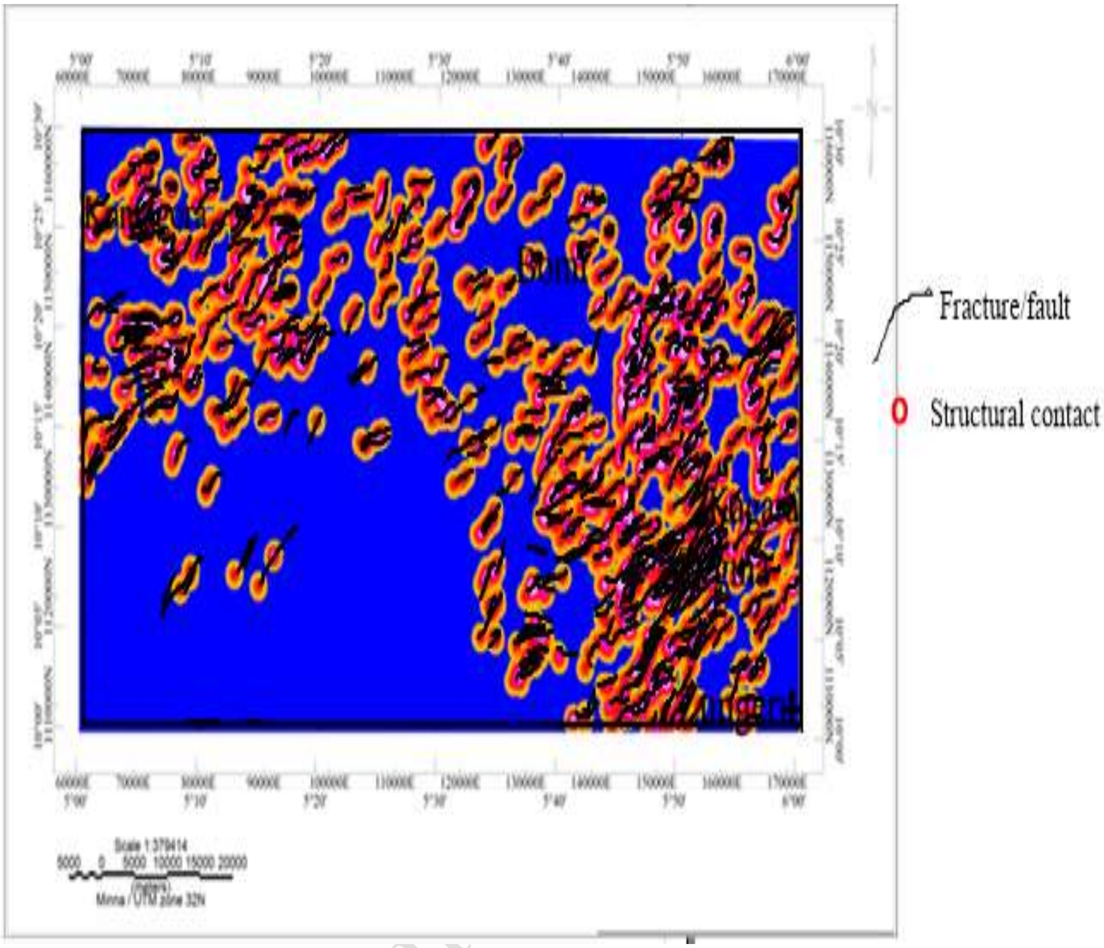

Figure 6: Structural map of the study area.

The high presence of fractures and faults at the northwest, northeast, southeast suggest the basement region while the few presence of fracture/fault at the southwest suggest the sedimentary region in the study area {Figure 5 and 6). These could suggest the boundary (contact zone) between the two major rock types around southern prt of Kontagora in the study area (Figures 2, 5, and 6).
The observed fracture/fault in the study area, serve as conduit for ground water and solid mineral deposit in the basement areas (Figure 5a) and could serve as hydrocarbon trap in the southwestern part of the study area (Northern part of Bida basin) (Usman *et al.,* 2018). The rose diagram (Figure 7) shows the structural tend in the northeast – southwest. This trend could also represent the major tectonic trend that affected the study area and the Nigeria basement complex at large (Figure 7). This is in agreement with the work of Olorunsola and Chukwu (2018); Maigwara and Udensi (2014) and *Udensi et al.* (2003).

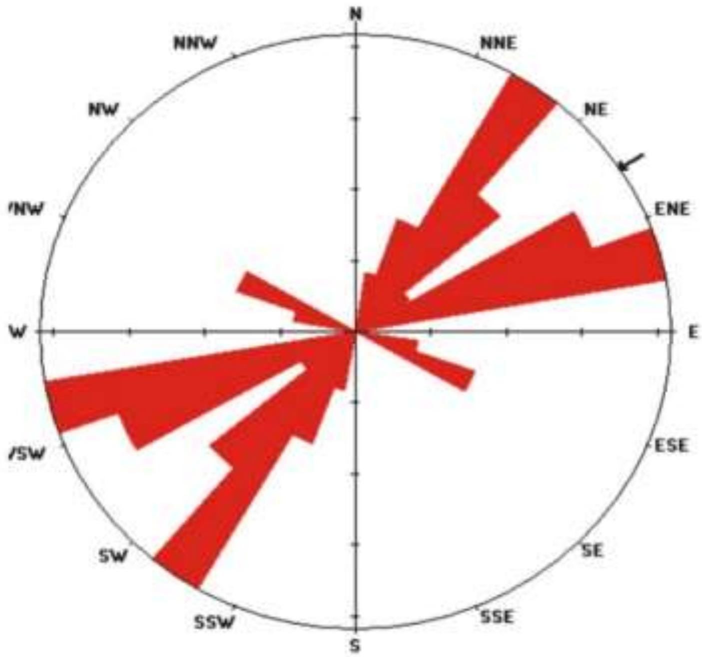

Figure 7: Polar plot for the structural map of the study area

Conclusions

The near surface magnetic lineaments enhanced by first vertical derivative were dominant around Kontagora, Kagara, Tegina and Zungeru at the Northeast and Southeastern part of the study area. The general trend of the lineaments was in the northeast – southwest. This trend were parallel to the Northeast – Southwest trend of Nigeria basement rocks which was belived to be the result of Pan African tectonic event (Udensi *et al.*, 2003).

The structural map of the study area was produced by integrating the subtle magnetic structures (fracture and fault linear structures) and their structural contacts produced from center for exploratin targeting (CET) analysis. These structures shows a close correlation in location and trend with the linear anomalies from first vertical derivative. These structures were dominant and have high density around Kagara, Tegina and Zungeru at the southeastern part of the study area. They have several trend that are common in both Precambrian and Cretateous rocks of the study area. The orientation of these structural trend shows the major trend in northeast – southwest. This trend agreed with the regional trend analysis that inferred the direction of propagation of stress during the tectonic activity (Ajakaiye *et al.*, 1991). The fault/fracture were the potential host for ground water and soild minerals (Ekwueme and Matheis, 1995). According to Ho and Groves, 1987; the regional and local structures were made up of a system of faults and other structures of Pan African age. TYhese structures could cause significant settlement in engineering and building constructions. This research study could serve as a guide for further geotechnical and engineering study

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