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Depth Estimation, Structural Features and Mineralization from High Resolution Aeromagnetic and Satellite Data over Yola Arm of the Upper Benue and Adjoining Basement Regions, Northeastern Nigeria

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Abstract

High-resolution aeromagnetic and satellite data investigation was carried out over Yola arm (upper Benue) and adjoining basement regions of northeastern Nigeria, in order to carry out depth estimations structural features and mineralization potentials of the area. Total intensity magnetic map was processed using the *Oasis Montaj* ™ programming software to get the residual map, analytic signal and tilt depth methods. Results show that the depth estimates are in the range of 1.2 to 4.4 km. These outcomes are similar to what has been obtained by previous researches in the study area. Satellite data processing was done using the arcGis software, in order to understand the structural frame work and mineralization potentials of the area. The structural features of the area are NE-SW and NW-SE which are pan African and pre pan African events.

Keywords: *Magnetic data; Mineralization; Satellite data; Structural features; Tilt depth.*

1. Introduction

The use of high resolution aeromagnetic and satellite data over the Yola Trough and adjoining sectors of the basement blocks was done (Fig.1) for depths estimation, structural features and mineralization potentials. The study area is located between longitude 12^0 00'-$13^0$30'E and Latitude 8^0 00'–10^0 00'N, which is the Yola arm of the Upper Benue Trough, and it trends in the E-W direction. The Upper Benue Trough, is an important arm of the Benue Trough, it is formed by several sub basins of which evolution and distribution were closely controlled by a fracture system where the N55^0E Benue trend is dominant in the entire Trough and the surrounding basement. A compressive phase of late Maestrichtian age is responsible for the fracturing and folding of the cretaceous cover. The style and direction of folds are greatly influence by the basement structures. Evidence of tensional movement are also known in the Yola arm, this is why the major river in the area exhibit a "V" shape channel due to control by the NE-SW and NW-SE fracture system [1].

The Benue Trough was subjected to several depositional cycle characterized by the deposition of sedimentary rocks of varied composition and closely related to the structural evolution of Gulf of Guinea [2-3].

The drainage feature of this region is the Benue River which takes it source eastward from the Cameroons and for the other part by its main affluent the Gongola River which rises from the north central high lands composed of crystalline rocks. The Yola arm of the upper Benue trough is bounded by the Hawal Massif to the north and the Adamawa Massif to the south. Both Massifs extend into Cameroon Republic. Major towns in the area are Yola, Sugu, Song, Ganye and Toungo.

1.1. Geology of the area

The study area is part of the Yola Arm of the Upper Benue Trough and some sectors of the adjoining basement terrain which are contiguous to the Yola trough. The Trough is a Cretaceous sedimentary Basin that forms a narrow band of terranes which stretches eastward and splits into small isolated basins in Cameroon. The sedimentary rocks are mainly shales, sandstones, limestones, siltstone and clay, extrusive rocks are found within the sedimentary basin and in the basement. The basement rocks are Precambrian in age and consist of granitoids, basic intrusions and metamorphic rocks.

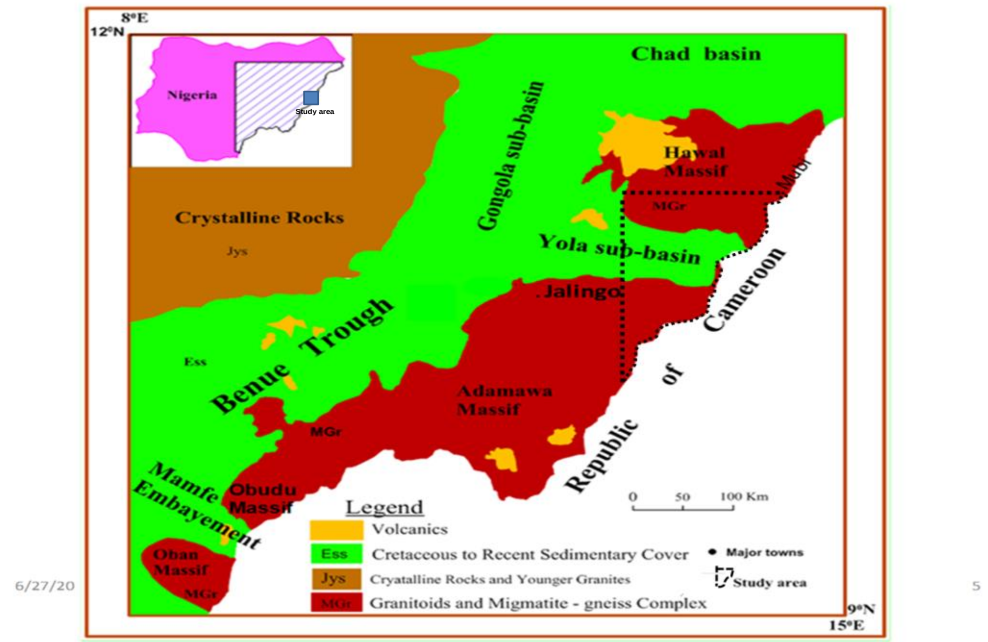


Fig.1. Regional geological map of Nigeria's eastern sector showing location of study area. Adapted from [4]

1.2. Previous studies

In 2006, Bassey [5] carried out structural study of satellite imagery over basement rocks of N.E Nigeria and Northern Cameroun, and the study revealed that lineaments in the area are attribute to the presence of joints, faults, shearing, deformation, dykes and veins which are product of pan African deformational episode.

In 1982, Benkhelil [6] studied the structure of the Upper Benue valley and concluded that folds and faults characterized the area which varies in size, style and more slightly in direction. Similar research was carried out by Benkhelil [7] where he analyzed the structure and geodynamic evolution of the intra continental Benue trough an concluded that the cretaceous Benue trough is a set of pull apart sub basin generate by sinistral displacement along pre-existing NE-SW transcurrent faults.

In 2014, Kwache *et al.* [8] studied the Geology of Dumne Area in Southeastern Hawal Massif, Northeastern Nigeria. Their result shows that the area is underlain by gneisses, migmatites, Older Granites and Tertiary basalts with granite gneiss dominating.

In their work, Opara *et al.* [9] studied the lineament and tectonic interpretation over Abakiliki area, evidences from airborne magnetic and landsat (ETM) data, the study revealed that lineaments identified in the area have principal trend directions in the NE-SW, NW-SE, N-S and E-W directions with the NE-SW trend direction been the dominant.

2. Materials and method

The high resolution aeromagnetic data used in this study were acquired for Nigeria Geological Survey Agency (NGSA) in 2010 as part of a country wide geological survey. The high resolution aeromagnetic data has the following specifications, terrain clearance of 80 m, flight line spacing of 500 m and a tie line spacing 5000 m. The sheets with the following index numbers were used for this study: 175, 176, 177, 196, 197, 217 and 218. The high resolution aeromagnetic data was processed using the *Oasis Montaj* ™ software in order to get the total magnetic intensity map and the residual maps. Other filtering employed are analytic signal and tilt depth methods. Tilt depth method is a simple method of estimating the depth to magnetic source bodies (assuming a vertical model) from contours of the magnetic tilt angle map [10]. The magnetic tilt method is a normalized derivative based on the ratio of the vertical and horizontal derivatives of the reduced to the pole field. The method assumes that the source structures have vertical contacts and there is no remanent magnetization and the magnetization is vertical. The tilt method was first described by [11], and further refined by [12] and is defined as

$$\theta = tan^{-1}\left[\frac{\partial M}{\partial z}/\frac{\partial M}{\partial h}\right] \quad (1)$$

where $\frac{\partial M}{\partial H} = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2}$ (2)

and $\frac{\partial M}{\partial x}, \frac{\partial M}{\partial y}, \frac{\partial M}{\partial z}$ are the first order derivatives of the magnetic field M in the x, y, and z directions.

Among the interesting properties of the tilt angle is the nature of the arctan trigonometric function, which restrict all tilt angles to values between -90^0 and +90^0 regardless of the amplitude of the vertical or the absolute value of the total horizontal gradient.

From equations 1 and 2, it is derived that

$$\theta = tan^{-1}\left[\frac{h}{z_c}\right] \quad (3)$$

where z_c is the depth to the top of contact on the basement.

Equation (3) indicates the tilt angle above the edges of the contact is 0^0 when h=0 and equal to 45^0 when $h = z_c$ and -45^0 when $h = -z_c$. Thus, the zero contour delineates the spatial location of the edges of the magnetic source "whilst the depth to the source is the physical distance between this zero contour and either the -45^0 or the +45^0 contour or their average. Therefore, half the width of the -45^0 to +45^0 contours provides an immediate estimate of the depth to basement". The two principal advantages of this method are its simplicity both in its theoretical derivation and its practical application. It also provides both a qualitative and a quantitative approach to interpretation by allowing the interpreter to visually inspect (spatially analyze) the tilt depth map to identify locations where depth estimates may be compromised by interfering magnetic anomalies and location where more reliable depth estimates can be made. By virtue of using first order derivatives, the method is potentially less sensitive to noise in the data than methods using second order derivatives.

While the airborne satellite data was obtained from the National Centre for Remote Sensing (NCRS) Jos, the data obtained is SPOT 5, which is polar, circular, sun-synchronous and phased. SPOT 5 was launched on May 4, 2002. The interpretation of satellite imagery map of the study area was carried out in order to understand the structural frame work and geometry of the area which can be an aid to further exploratory work. Structural studies involve extracting lineament/structures from high resolution satellite imagery map. The accuracy of extracted lineament depends strongly on the spatial resolution of the satellite imagery, higher resolution imagery results in a high quality lineament map. The spot 5 sensor provides imagery with a higher resolution of (5m) than the Nigeria satX sensor which has a resolution of (25 m), the ArcGIS software was used for this exercise.

Several digital image enhancement techniques such as general contrast stretching and edge enhancement were applied to the SPOT 5 imagery using the ArcGIS software. The first stage of structural mapping involved mapping and identifying lineaments that could be due to the contacts between two rock types of contrasting magnetic susceptibility or edges of structures that could be faults or intrusive within the sediments.

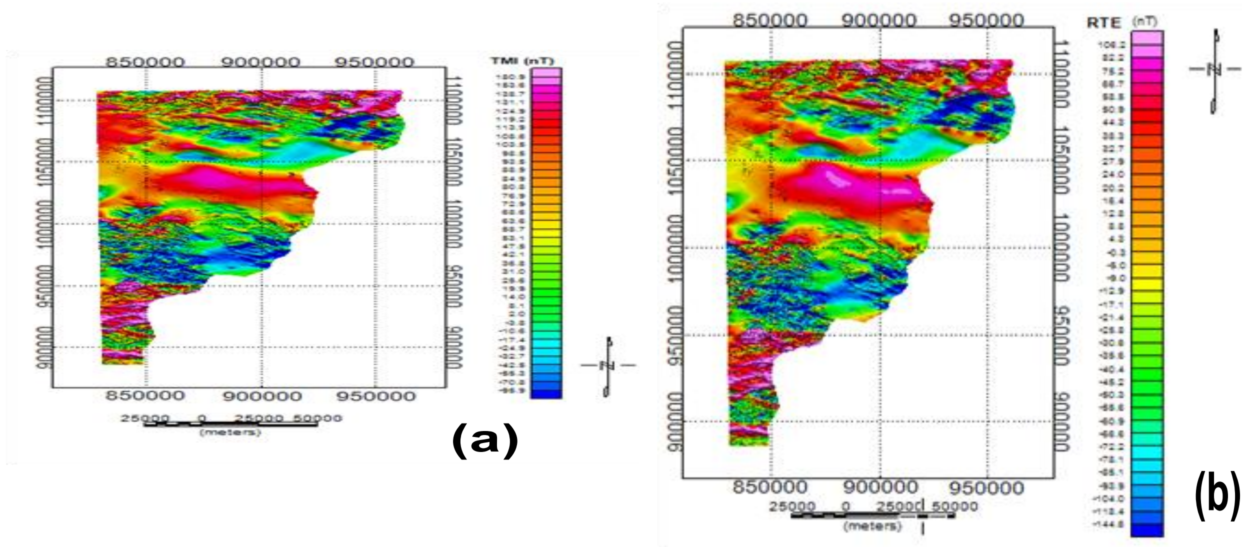
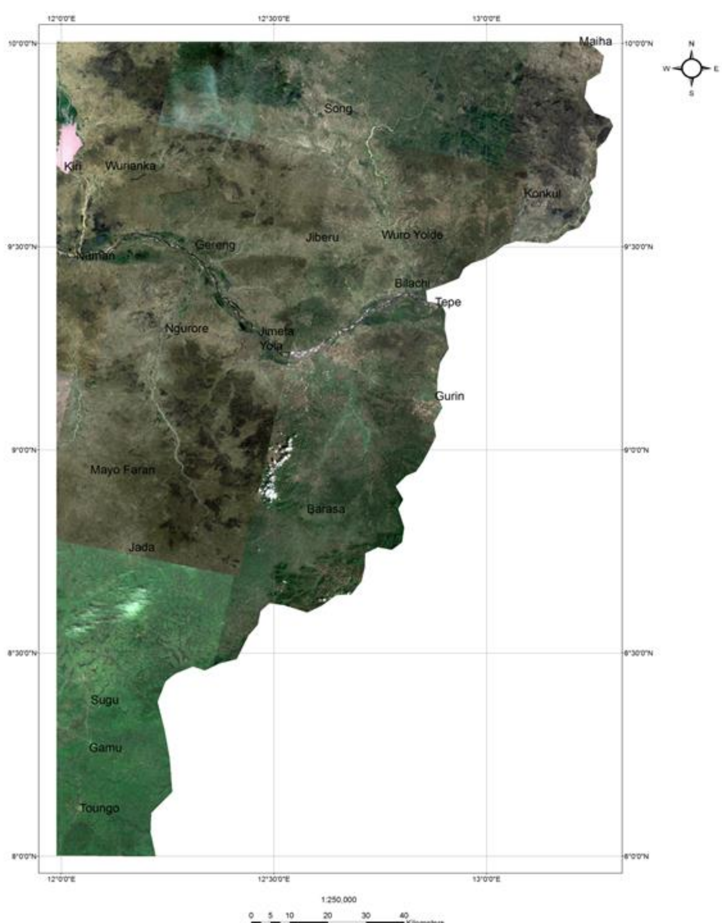


Fig. 2a and b. Total magnetic intensity and residual maps of the study area respectively



The second stage of the mapping involved identifying lineaments from the image and digitizing them on-screen and saving them as a feature class in a geodatabase. To achieve this, all the various data sets were displayed in ArcMap and by studying one layer at a time and comparing with other layers in the GIS environment. To start digitizing 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 of the lineaments within the study area was created in Georient software.

Fig. 3. The spot 5 satellite imagery map of the study area [13]

3. Result and discussion

Figures 4 and 5 showed the tilt angle map with aeromagnetic data and also extrapolated, at zero with + 45 and -45, contours, and depth to basement contours map respectively. Depth estimates range from 1.2 to 4.4 km. Maximum depth are found in the central part of the study area where the magnetic basement attain a depth of 4.4 km as shown in figure 6, these are places around the Benue river.

The northern part of the study area has a basement surface that is generally shallow, while the southern part of the study area has intermediate to shallow depth sources. This basement topography is consistent with what is obtained from the power spectrum of the study area [14].

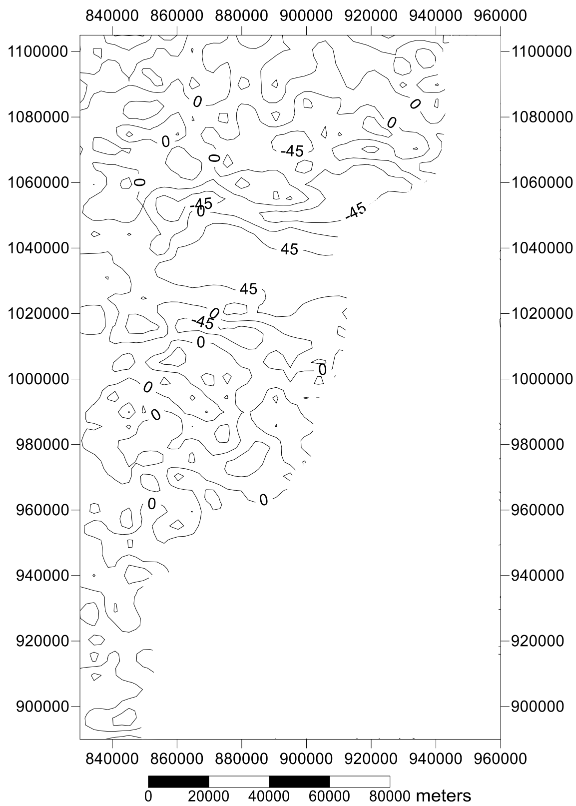


Fig. 4. Tilt Angle (in degrees) for only the srea with aeromagnetic data

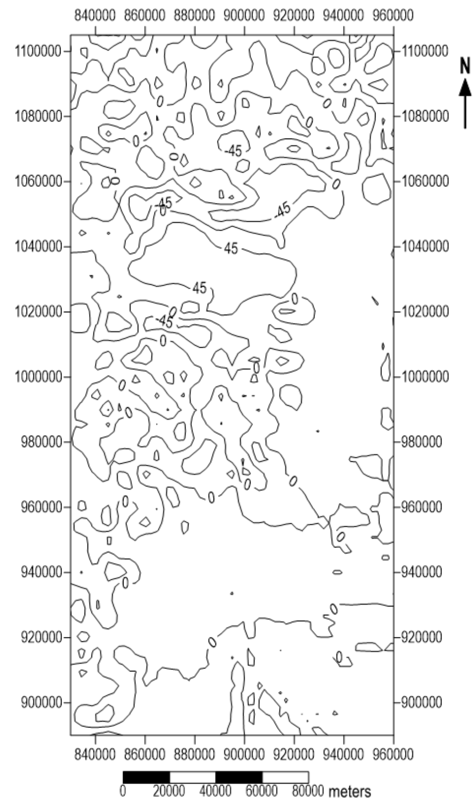


Fig. 5. Tilt Angle (in degrees) extrapolated over the entire area

The lineaments extracted from the image Spot 5, (Fig.3) range in length from 300 m to 3 km, Figure 7 is the structural map of the study area, with the rose diagram. Several faults were also mapped out within the study area such as a sinistral fault observed between Zumo and Maiha and a dextral fault close to Ganye.

The main fracture trends are gathered around the general direction of 45^0 and 315^0. Apart from these main trends the principal sub-direction are 60^0 and 300^0, followed by 65^0 and 325^0. On a regional scale the general main trend of 45^0 and 315^0 parallel the main axis of the Benue trough and that of its lateral troughs. Field measurements showed that there are faults, joints and order structures in the area. The faults were identified based on striation and slicken sides with the NE-SW and NW-SE dominant trends as shown from the rose diagram. According to [1] these set of faults constitute part of conjugate set of lineaments that controls the flow direction of the Benue river. [7, 15] observed the occurrence of strike slip faults conjugate around compressive direction of 60^0 and 50^0 reverse to thrust faults in the upper Benue trough, in view of the fact that the basement dykes usually follow direction of the main fracture trend, it must be assumed that the earliest formation of the actual fracture pattern goes back to late post crystalline time. There is no evidence to suggest that certain trends were developed in later times.

This is particularly true for the trends parallel to the axis and to the margins of the Benue trough. The authors are of the believe that these trends actually apparently predated the formation of the trough, and consequently they may have had a certain influence on its orientation. Low fracture density has been notice in the central part of the area, this may also be indicative of considerable thickness. On the other hand, a considerable intensification of the fracturing in the border zones seems to have derived directly from the formation of the trough. A remarkable increase of fractures parallel to the trough margins is in fact to be noted namely in the Hawal basement and the Adamawa Massif i.e northern and southern part of the study area.

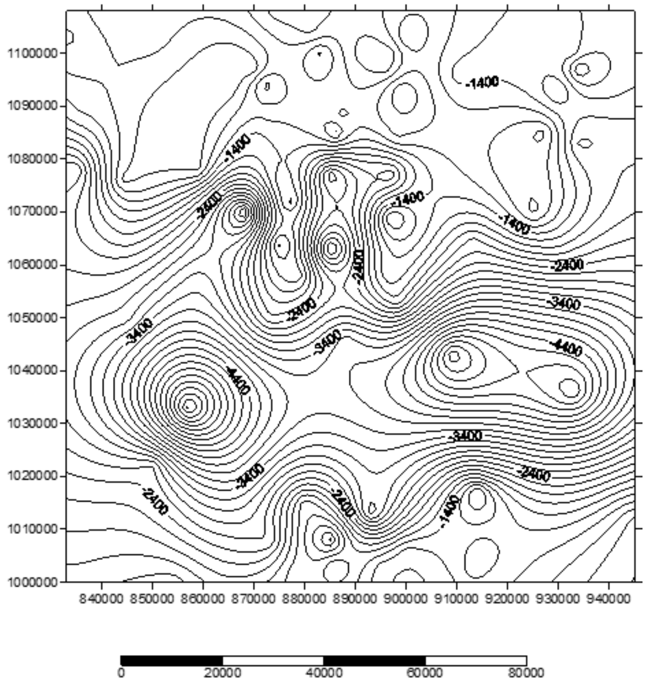


Fig. 6. Depth to basement contour map computed using tilt depth method

The result of the lineament density map of the study area is shown in (Fig.8), has two major zones of high density of lineaments and they all fall within the adjoining basement complex areas respectively. The map also gives good evidence of the general characteristics of the fracture pattern, showing in particular its great homogeneity over the area independent of the various geologic formations therefore these areas should be targeted for mineral exploration

This means that, except for local structural features, the main fractures are derived from the basement even in the sedimentary realms. With regard to fracture density it is to be noted that the basements show a greater high to the Cretaceous sediments, even though the latter are exposed to a much longer period of fracturing. A clear decrease of fracturing is to be noted in the Cretaceous sediments as shown in Figure 7, because major part of the joints and faults are older than the Cretaceous, part of the fracturing may therefore have been absorbed and rendered invisible in the upper part of the formations. The lower fracture density may also be indicative of considerable thickness in some places.

In 2011, Halilu [16] studied the stream sediment for barite mineralization around Tola, area in Mayo Belwa L. G. A. part of the Adamawa Massif, and found out that barite concentration is very low in the area, while manganese, molybdenum, chromium, lead, tellurium, lanthanum and iron, have high concentration as a result of weathering of different rock types which release these elements to the surrounding streams and major rivers. Geological and geochemical results reveal that the porphyritic granites of the area are their major source. Fault, fracture, and veins in filled with quartz are probably acting as a structural control on the concentration of these elements and their distribution pattern is mostly in the NW – SE direction. In 2014, Kwache [17] studied the composition and industrial quality of Dumne barite occurrence N.E Nigeria and found out that the barites in the area are of industrial quality. Geological and geochemical results reveal that the granites and gneisses of the area are their major source. Fault, fracture, and joints are probably acting as a structural control of the barites and their distribution pattern is mostly in the E-W direction. Faults fractures and shear zones of N40°E-N45°E are the dominant deformational features found in Dumne area of the Hawal basement complex, according to [14]. They trend in the NE-SW and E-W. Rock crystal mineralization occurs as detrital deposit in the NE-SW trending faults/joints in the granites.

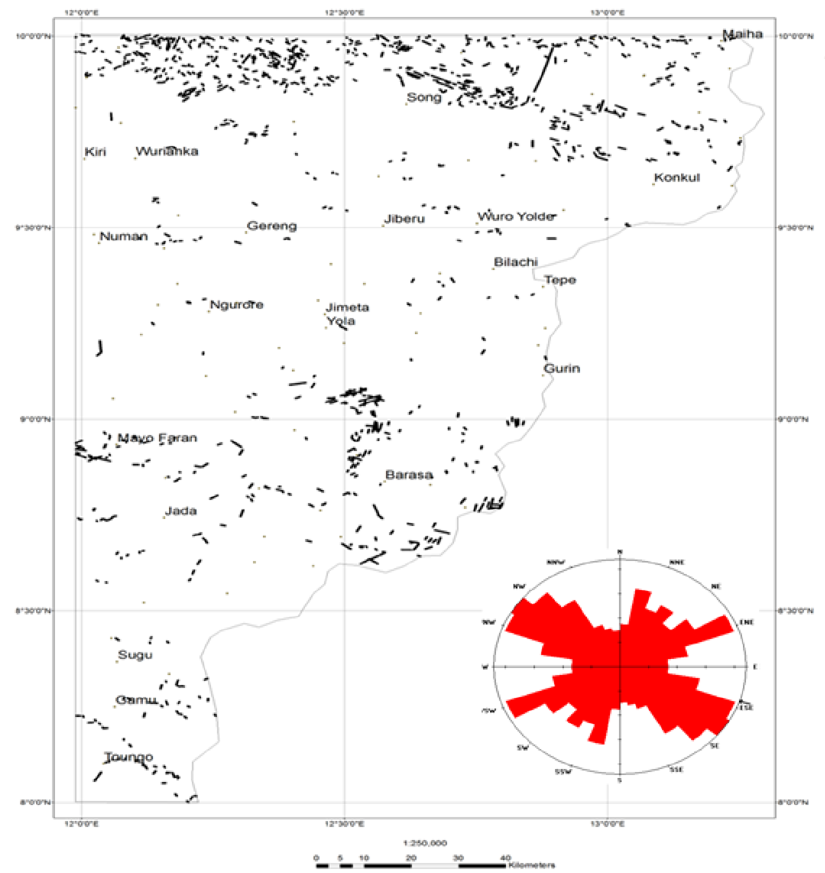


Fig. 7. Lineament map of the study area, with the rose diagram from satellite imagery (n= 207)

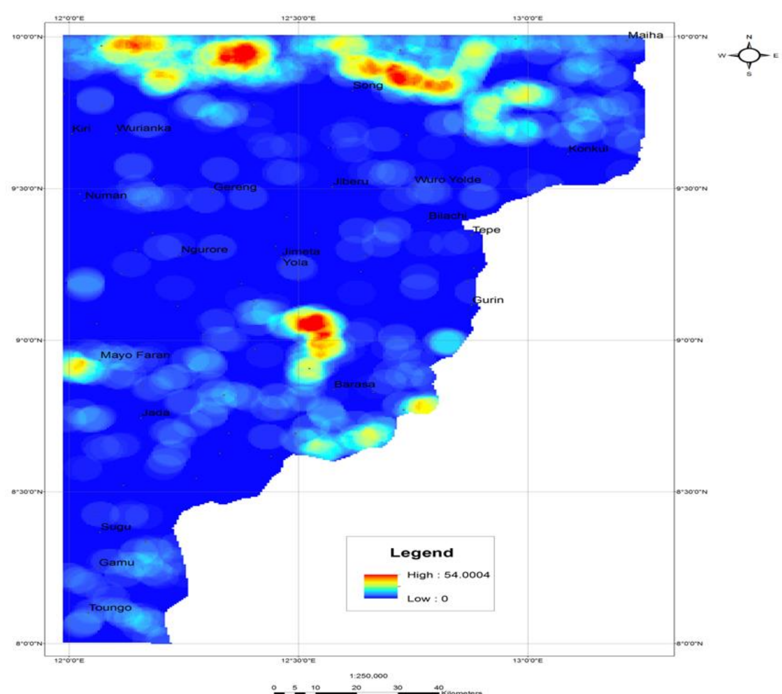


Fig. 8. Lineament density map of the study area

4. Conclusion

High resolution aeromagnetic and satellite data were used for this study in order to determined depths estimation, structural features and mineralization potentials of the area. The tilt depth method is a simple method of estimating the depth to magnetic source bodies. The magnetic tilt method is a normalized derivative based on the ratio of the vertical and horizontal derivatives of the reduced to the pole field. The method assumes that the source structures have vertical contacts and there is no remanent magnetization and the magnetization is vertical. Depth estimations are in the range of 1.2 to 4.4 km. These results are similar to what has been obtained by the same authors in their previous paper. The structural features range in length from 300 m to 3 km. Field measurements showed that there are faults, joints and order structures in the area, the faults were identified based on striation and slicken sides, several faults were also mapped out within the study area such as sinistral and dextral faults. The lineament density map and areas where lineaments intersect are particularly advantageous in modern exploration geosciences in that they offer a quick glance at the spatial distribution of the density of lineaments and thus provide a useful data base in mineral exploration, these should be targeted for mineral exploration in the area. The significance of lineament studies lies in its applicability to mineral exploration, since the same or similar condition exist for ore bearing fluids in basement areas of the world [18]. The trend of the lineament extracted from this study area are similar to those that occur in the Nigerian basement complex, and it has been suggested that they may be related to deep seated structures within the underlying basement. Some known areas of mineral occurrences have been observed to correlate with zones of high lineament density. Major lineaments observed have been accounted for in terms of faults, joints and dykes. Most of these important minerals mentioned above are mined illegally, the government should as a matter of urgency stop the illegal miners and mandate its relevant agencies both at the state and federal level to carry out detail survey of both regional and local structures most especially regionally deep seated faults and local fault intersections that are deeply inclined, these can conduct ore bearing fluids from deep to shallow sites. Many regional and local fault structures can be traced from the basement rocks onto the adjacent sedimentary rocks. Detailed structural and geologic studies of these areas should be carried out for possible bigger occurrences that are currently not known.

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