THE INTERNATIONAL JOURNAL OF
SCIENCE & TECHNOLEDGE

Interpretation of Aeromagnetic Data Using Tilt and Total Horizontal Derivative Over Parts of Nasarawa and Environs, North-Central Nigeria

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Abstract:
*Interpretation of High-resolution aeromagnetic data over Nasarawa and Environs was carried out to determine structures, contacts and edge boundaries of magnetic sources.These methods use the principle that anomalies at all levels and the rate of change in magnetic susceptibility in the horizontal **(x)** and vertical **(y)** directions can be resolve simultaneously, the result revealed two prominent contacts that coincide with paleo structures in the study area, other magnetic anomalies that depict structural disturbances are also present and correspond with the products of Pan African deformational episode. Faults were interpreted along linear aeromagnetic anomalies and breaks in anomaly patterns. Many linear features correspond to topographic features, such as drainages, a few of these are inferred to be fault-related, which may reflect structural transition between rift basins, these identified trends are attributed to tectonic activities in the area. These show that the basement complex rocks are heavily faulted, fractured and invaded by dykes, veins and sills, this could be as result of the multiple deformational episodes/ tectonic activities that occurred in the area. Result of the tilt derivative reveals that the Romanche and Chain fracture zones have continental extensions and are likely to control the major NE – SW fracture system in the basement complex rocks of north central Nigeria and along the Benue Trough.*

Keywords: *Tilt derivative, horizontal derivative, pan African, orogeny and nasarawa*

1. Introduction

The study area is located between longitudes 8^0 00`E and $10^0$ 00`E and latitudes 7^0 30`N and $9^0$ 30`N in north central Nigeria (Fig. 1). The area is part of the Middle Benue Trough that is noted for hosting economic minerals, it covers an approximate area of 48,400 km^2, and covers farmlands, villages, towns, game reserves, natural reserves etc. The area lies east of the federal capital Abuja. Topographically, the study area is hilly at the northern fringes and drained mainly by river Benue and its tributaries in the southern part, it is characterized by moderate relief with high granitic hills generally extending several kilometers, having the NE – SW direction and forms several peaks of relatively higher elevation than the surrounding rocks. Despite the hilly nature of some part of the study area, there are still good road networks, foot-paths and tracks in the area. Major roads found in this area provide access road to the southeastern part of Nigeria and some other communities in the study area such as Akwanga, Nasarawa-Eggon, Lafia, Keana, Awe, Doma, Shendam, Pankshin to mention few. There are other minor roads that provide access to smaller settlements, farms, rivers and streams. The area is marked by two distinct climatic conditions, temperatures in this area range from 20°C - 27°C, while at night, temperatures could be as low as 10°C, Months of March to June experienced increasing temperatures as the rainy season set in sometimes daily temperature could be above 35°C. The rainy season lasts usually from May/June to September/October depending on the rainfall pattern for the particular year, with mean annual rainfall of 1560mm. The dry season is usually heralded annually by the dry, cold Harmattan winds and occurs between November and March. After the departure of the Harmattan and in the absence of rain, the hot sunny season with temperatures exceeding 27^{o}C sets in (Balogun, 2003). The mean annual temperature of the area is 20^{o}C.

The Tilt and TotalHorizontal derivatives are familiar concepts, the methods have been used extensively by Fairhead et al, (2004), Verduzco et al. (2004) and Ogunmola et al., 2015.These processing techniques were applied to the high resolution aeromagnetic data to enhance magnetic signature of shallow and deeper sources in the study area, the methods are useful for mapping and delineating the sub-surface structure to shed more light to the geology of the area.

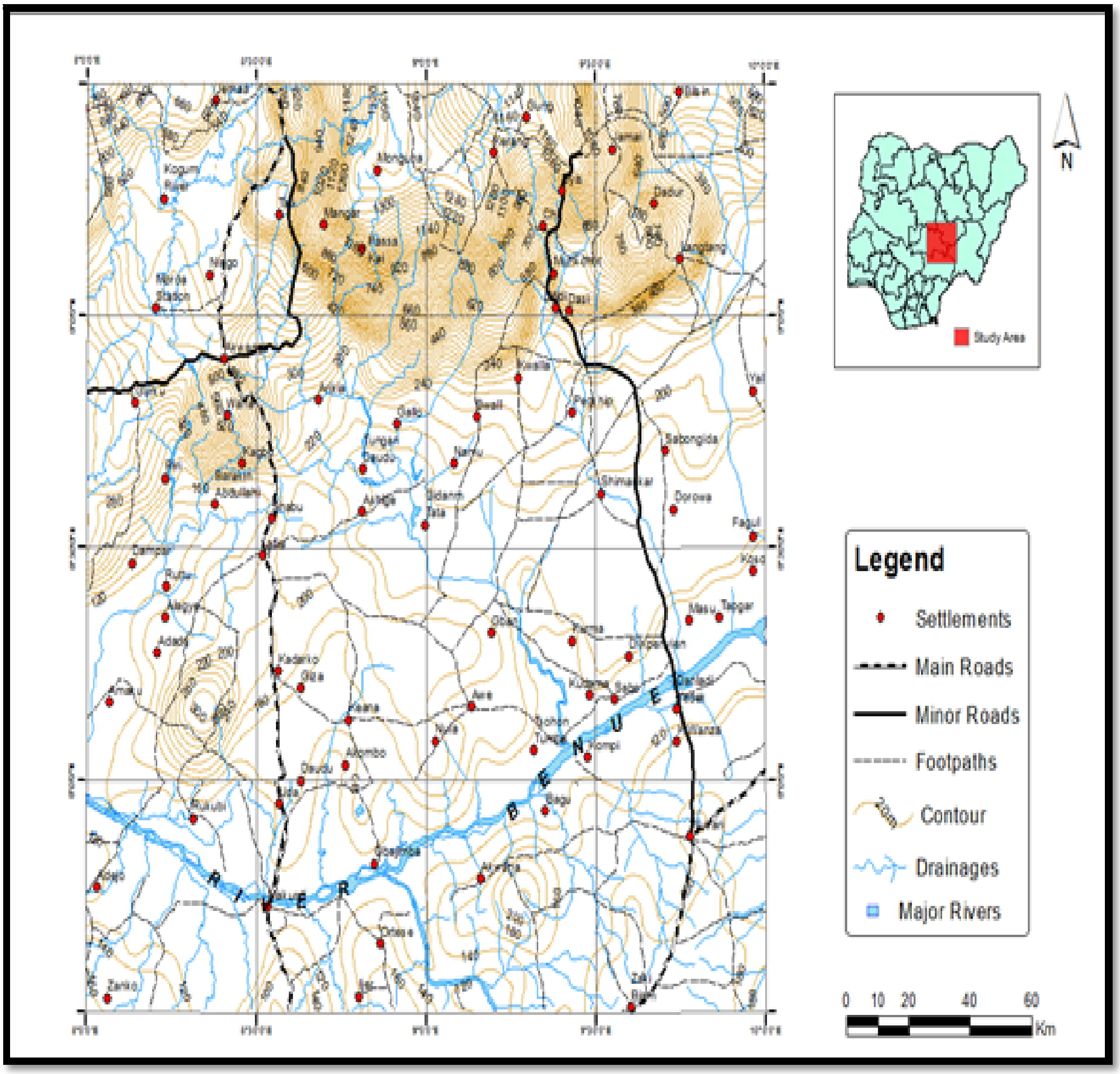

Figure 1: Topographic Map of the Study Area (After United State Geological Survey.2012)

2. Geology of the Study Area

The study area lies within the Basement complex of North-central Nigeria and the Cretaceous sediment of the Middle Benue Trough (MBT). The Basement complex of North-central Nigeria, is part of the Pan-African mobile belt extending from Algeria across the south Sahara to Nigeria, Benin and Cameroon Republics (Fig. 2). Evidence from the eastern and northern margins of the West African Craton indicates that the Pan-African belt evolved by plate tectonic processes which involved the collision between the passive continental margin of the West African Craton and the active continental margin (Pharusian Belt) of the Tuareg shield about 600 Ma. The basement complex rocks units in the area include granulitic gneisses, migmatite and older granite. The Jurassic (145-210Ma) Younger granites in the study area are high level, anorogenic granites; they mainly consist of microgranites and biotite granites, porphyries and rhyolites which outcrop at the northern fringes. The geology of the Middle Benue Trough has been described in some details by Offodile., (1976). The oldest rocks belong to the Asu River Group: a mixture of lava-flows, dykes and sills representing the first middle Albian episode into the Benue Trough. The Awe Formation marks the beginning of the regressive phase of the Albian Sea, it consists of transitional beds of flaggy, whitish, medium to coarse-grained sandstones interbedded with carbonaceous shales or clays from which brine springs issue continuously (Ford 1981; Offodile 1980). The Keana Formation resulted from the Cenomanian regression, which deposited fluviodeltaic sediments in the Lafia-Awe area. This formation consists mainly of crossbedded, coarse-grained feldspathic sandstones. The sandstone is generally poorly sorted and occasionally contains conglomerates and bands of shales and limestones towards the top. Ezeaku, Agwu and Lafia Formations are also present, and these represent the Turonian to Early Maastrichtian sediments in the MBT. The Ezeaku Formation comprises essentially of calcareous shale, micaceous fine to medium-grained friable sandstones, with occasional beds of limestone. The ConicianAgwu Formation consists mainly of black shale, sandstones and local coal seams. The MaastrichtianLafia Formation is the youngest formation reported in the Middle Benue Trough and consists of coarse-grain ferruginous sandstones, red loose sand, flaggy mudstones and clays (Offodile 1976). Tertiary- Recent volcanic rocks which consist of the Basalts, Trachyte, Rhyolite, and newer basalts of Sura volcanic line also occur in the area.

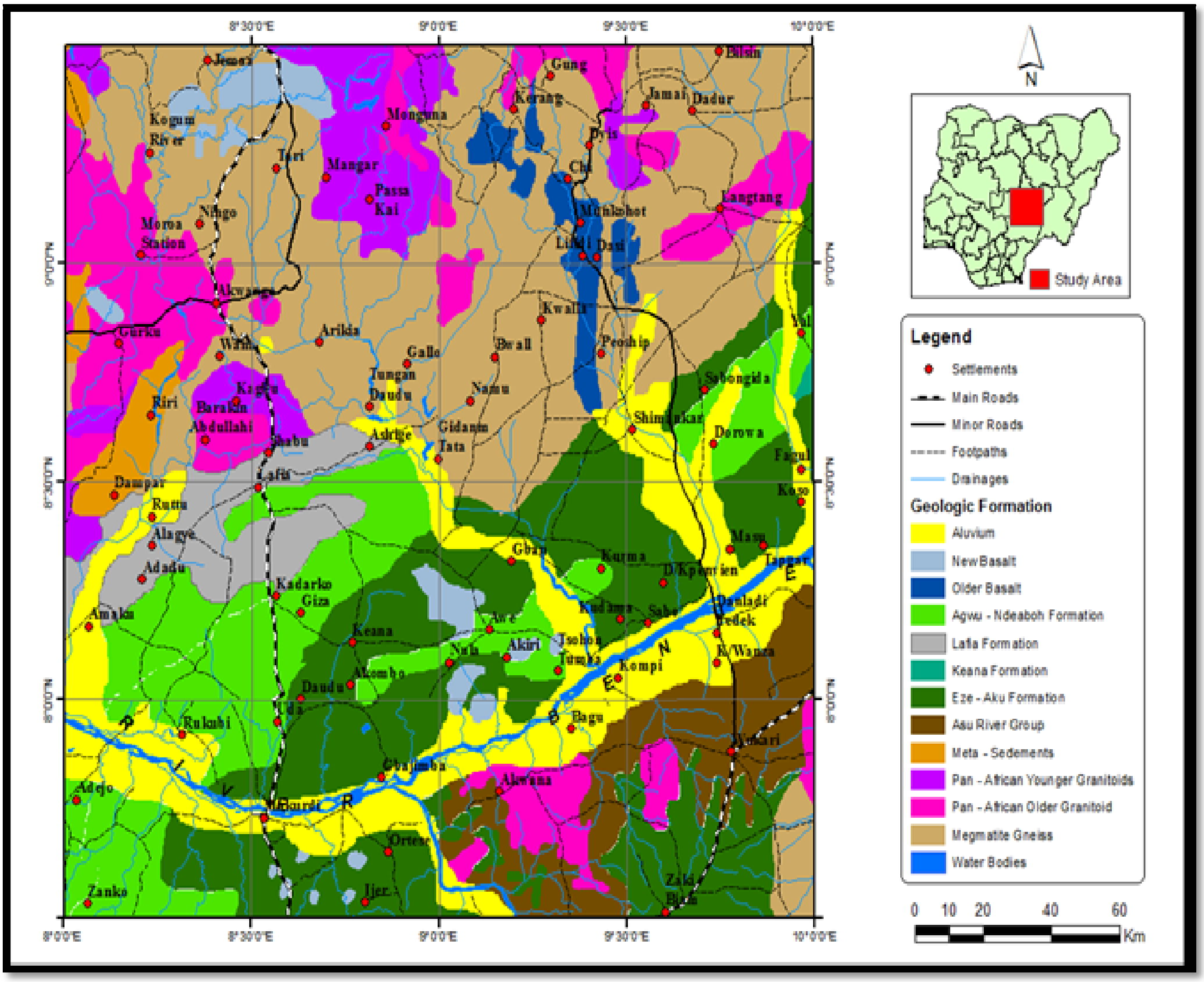

Figure 2: Geological Map of the Study Area (Adapted from the Geologic Map of 2006)

3. Materials and Method

The high resolution aeromagnetic data (HRAM) used for this present work was obtained from the Nigerian Geological survey agency Abuja, which had acquire digital data for the entire country between 2005 and 2009, The airborne survey was carried out for the Nigerian Geological Survey Agency by Fugro airways services, the surveys was flown at 500m line spacing and at an average flight elevation of 80 m along NW – SE direction, and published in form of grid (digital form) on 30` by 30` sheets. The IGRF has been removed from the data. Sixteen sheets were assembled for this work with each square block representing a map in the scale of 1:100,000. Each square block is about 55 x 55 km^2 covering an area of 3,025km^2 hence the total area studied is about 48,400km^2, the digital data was acquired as merged unified block and were extracted from the map using Geosoft Viewer software.

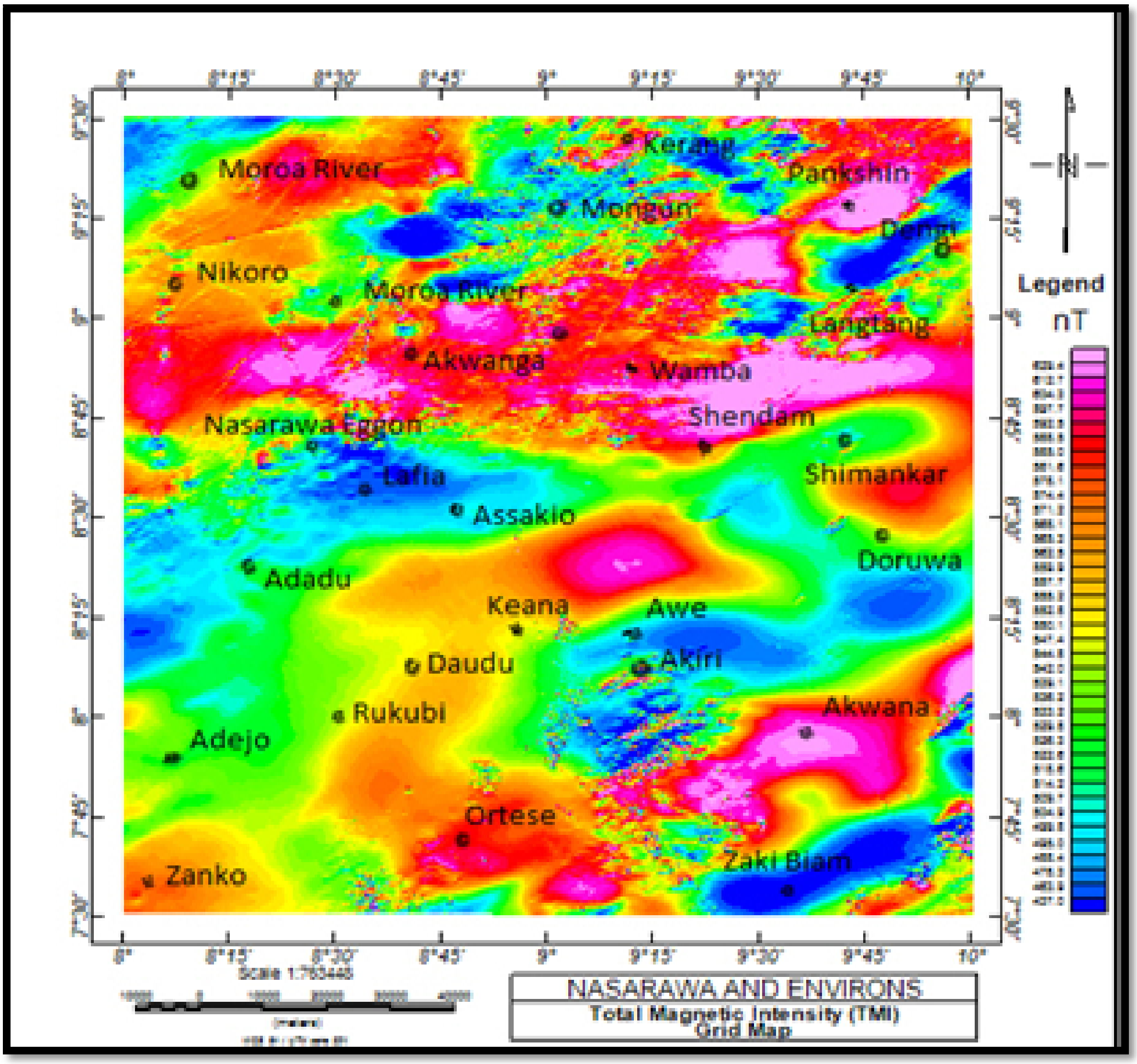

Figure 3: Total Magnetic Intensity Grid Map of the Study Area (to Obtain the Actual Total Magnetic Field Value, Add 32,500 Nt to the Values Shown in the Key)

3.1. Reduction to the Equator

The total magnetic intensity (TMI) data from the study area was reduced to the equator, this is because Nigeria is situated at low magnetic latitude. Geomagnetic field of the earth at latitudes close to the equator is horizontal and weak (Leu, 1982), due to undesired distortion of the shapes, sizes and locations of the magnetic anomalies which makes it difficult to resolve structures that are trending north–south. Reduction to the equator was performed to center the peaks of magnetic anomalies over their sources. This operation was carried out using geosoftsmagmap based on the formula:

$$L(\Theta) = \frac{[\sin(I) - i \cdot \cos(I) \cdot \cos(D-\Theta)]^2 \times (-\cos^2(D-\Theta))}{[\sin^2(Ia) + \cos^2(Ia) \cdot \cos^2(D-\Theta)] \times [\sin^2(I) + \cos^2(I) \cdot \cos^2(D-\Theta)]^{3f\,(/Ia/ < /I/ \,.\, Ia = I}} \quad (1)$$

Where:

I = geomagnetic inclination

Ia = inclination for amplitude correction (never less I)

D = geomagnetic declination

Parameter: Ia = Inclination to be used for the amplitude correction. Default is 20 degrees. If /Ia/ is specified to be less than /I/, it is set to I.

This can make the data easier to interpret while not losing any geophysical meaning.

3.2. Tilt Derivative

The tilt derivative is a good processing tool for the enhancement of magnetic data. It computes the ratio of the vertical derivative to the total horizontal derivation to determine structures, (fault, fractures and folds), contacts and edges or boundaries of magnetic sources, it also enhances both weak and strong magnetic anomalies of an area, which has been defined as the tilt angle to give a positive result (Miller and Sinh, 1994). The mathematical expression for this technique is given by:

$$\text{Tilt derivative } TDR = \tan^{-1}\left[\frac{VDR}{THDR}\right] \quad (2)$$

This method uses the principle that anomalies at all depth can be resolve simultaneously, to enhance the magnetic signatures of shallow and deeper geologic features, the tilt derivative has an advantage because, sometimes there could be a deeper source in the midst of some shallow sources and because the tilt angle is always within the range of $-\pi / 2 < \text{Tilt} < \pi / 2$, the depth of the source will have no effect on the transform, so therefore can show a maxima over anomaly sources. The magnetic field responses computed from the geological models were performed by limiting the $\tan^{-1}$ component of the expression between a range of +1.57 and -1.57, this provides an automatic gain control (AGC) that amplifies signals that are low, which makes the Tilt derivative a powerful method for RTE and RTP data (Verduzco et al., 2004).

The tilt derivative was applied to total magnetic intensity data RTE using Geosoft Oasis Montaj software, the data was later exported as a shape file and gridded in ArcMap and this produces the tilt derivative grid map (fig. 4). The result is a representation of shallow and deeper geologic surface features such as faults, fractures, and joints that were not evident in the total intensity magnetic data, the tilt derivative grid map also shows consistency in magnetic anomalies (lineaments) in the NE-SW, NW-SE, NNE—SSW, NNW-NNE, E-W and N-S directions. But of special interest are some magnetic anomalies trends (lineaments), A-A', B-B' identified to be linear and continuous in the area.

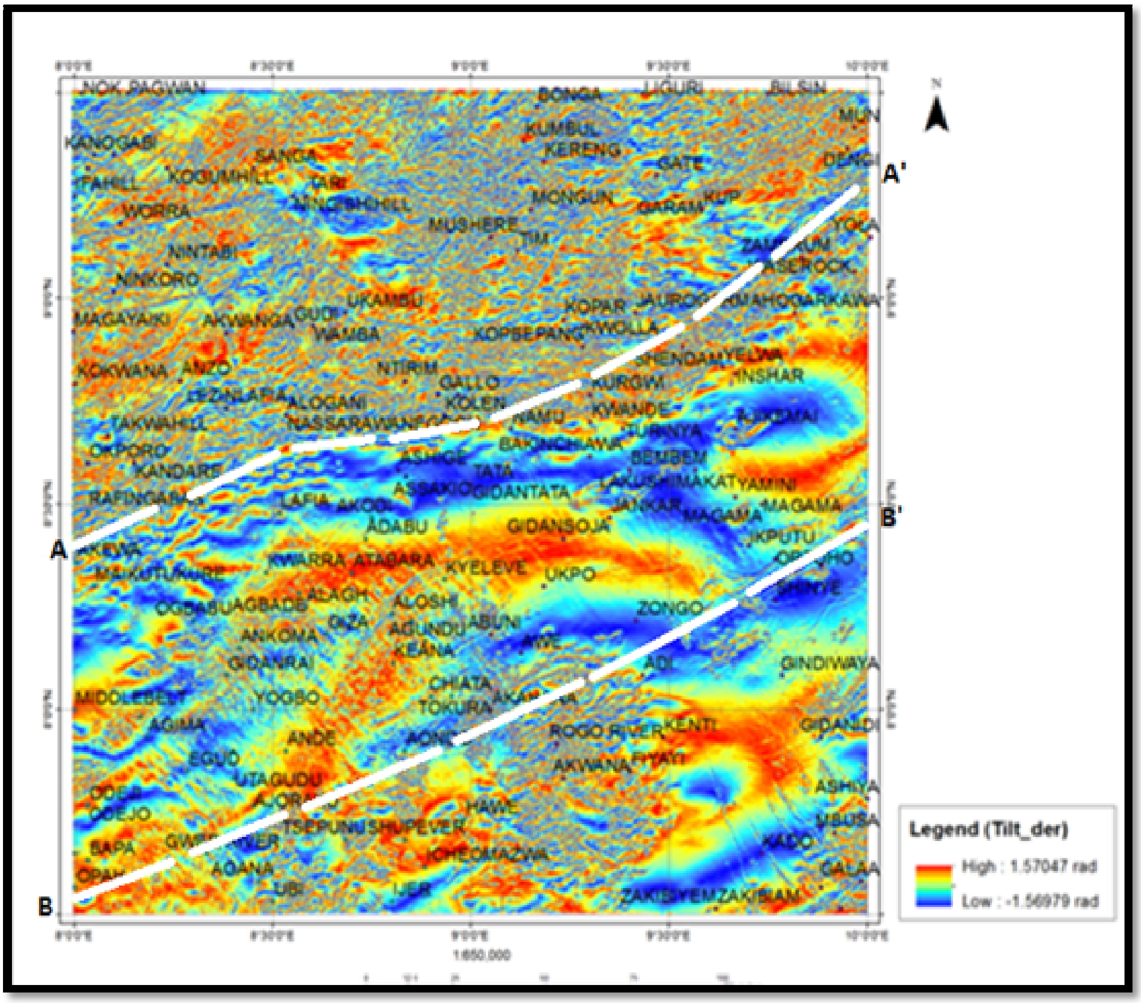

Figure 4: Tilt Derivative Grid Map of the Study Area.AA' BB', Are the Paleo-Structures Envisaged to Have Passed Through the Study Area as Noted by Ajakaiye Et Al. *(1991) AA' BB' Represents the Romanche, Chain Paleo-Structures Respectively*

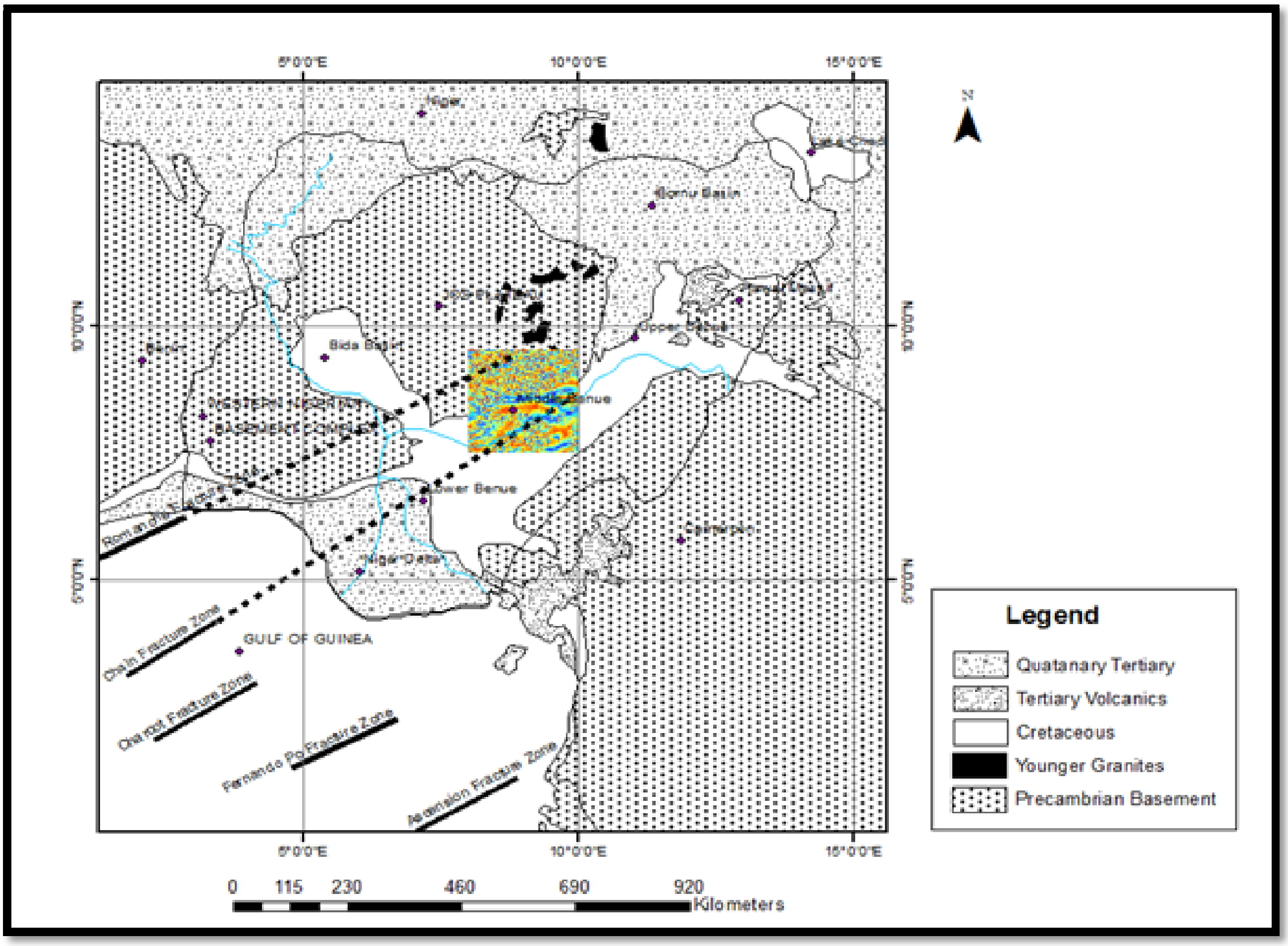

Figure 5: Geological Map of Nigeria Showing Ocean Fracture Zones and the Grid of the Tilt Derivative of the Study Area (Modified from Benkhelil Et Al, 1989)

3.3. Total Horizontal Derivative

The total horizontal derivative method is also shown to be a useful technique in the transformation of magnetic anomalies, it measures the rate of change in magnetic susceptibility in the horizontal (x) and vertical (y) directions and produces a resultant grid in which there is no change in the frequency content of the TMI and the total gradient but the spectral phase of the gradient changes (Cordell and Grauch, 1985). The technique is a good edge detector because it computes the maxima over the edges of the structures and they appear like rail lines along narrow features. The mathematical expression involved is given by:

Full (or Total) Horizontal derivative THDR = $\sqrt{\left[\frac{\partial T}{\partial x}\right]^2 + \left[\frac{\partial T}{\partial y}\right]^2}$

The method is insensitive to noise and aliasing and the gradients are all positive thus, making this derivative easy to map. This is because strike direction of the contacts can be estimated accurately within small windows.

The total horizontal derivative technique was applied to total magnetic data of the study area using Geosoft Oasis Montaj software, the data was exported as a shape file and gridded in ArcMap and it produce the total horizontal grid map (fig.6).

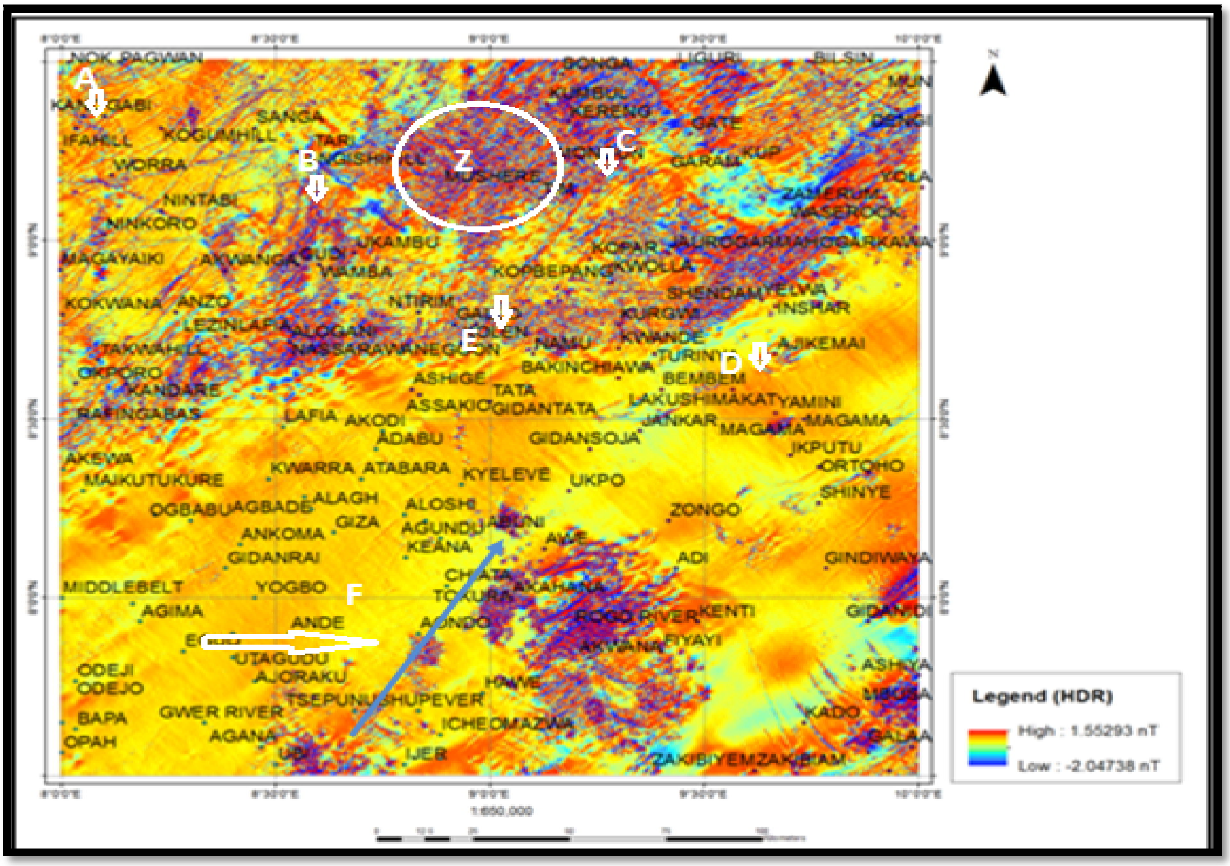

Figure 6: Total Horizontal Derivative Grid Map of the Study Area

To identify the role of terrain in causing aeromagnetic anomalies, a qualitative comparison of terrain (fig.7) digital terrain model versus aeromagnetic maps was done, and it revealed that magnetic anomalies in the study area follow the trends of the topography.

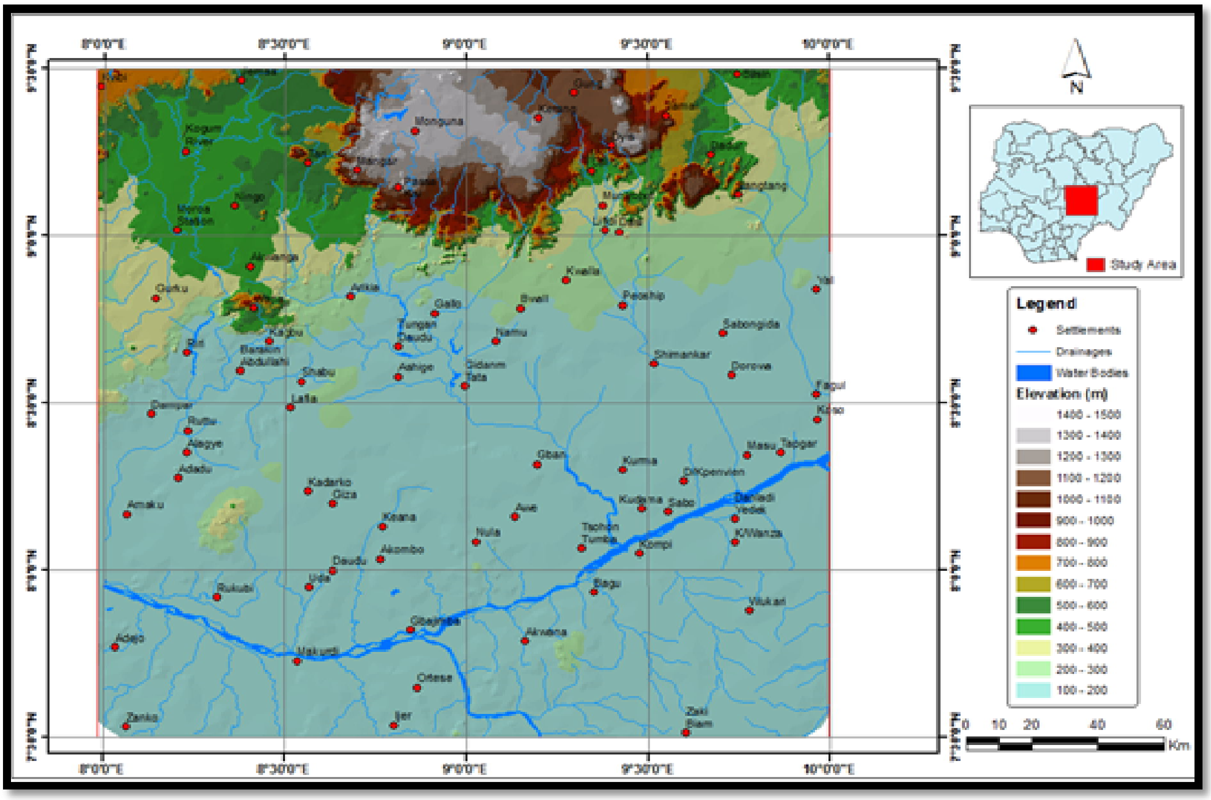

Figure 7: Digital Terrain Map of the Study Area after United States (U.S.) National Aeronautics and Space Administration (NASA) 2010

Highlands and lowlands in the area were also analyzed using the Digital Elevation Model as shown in fig.8

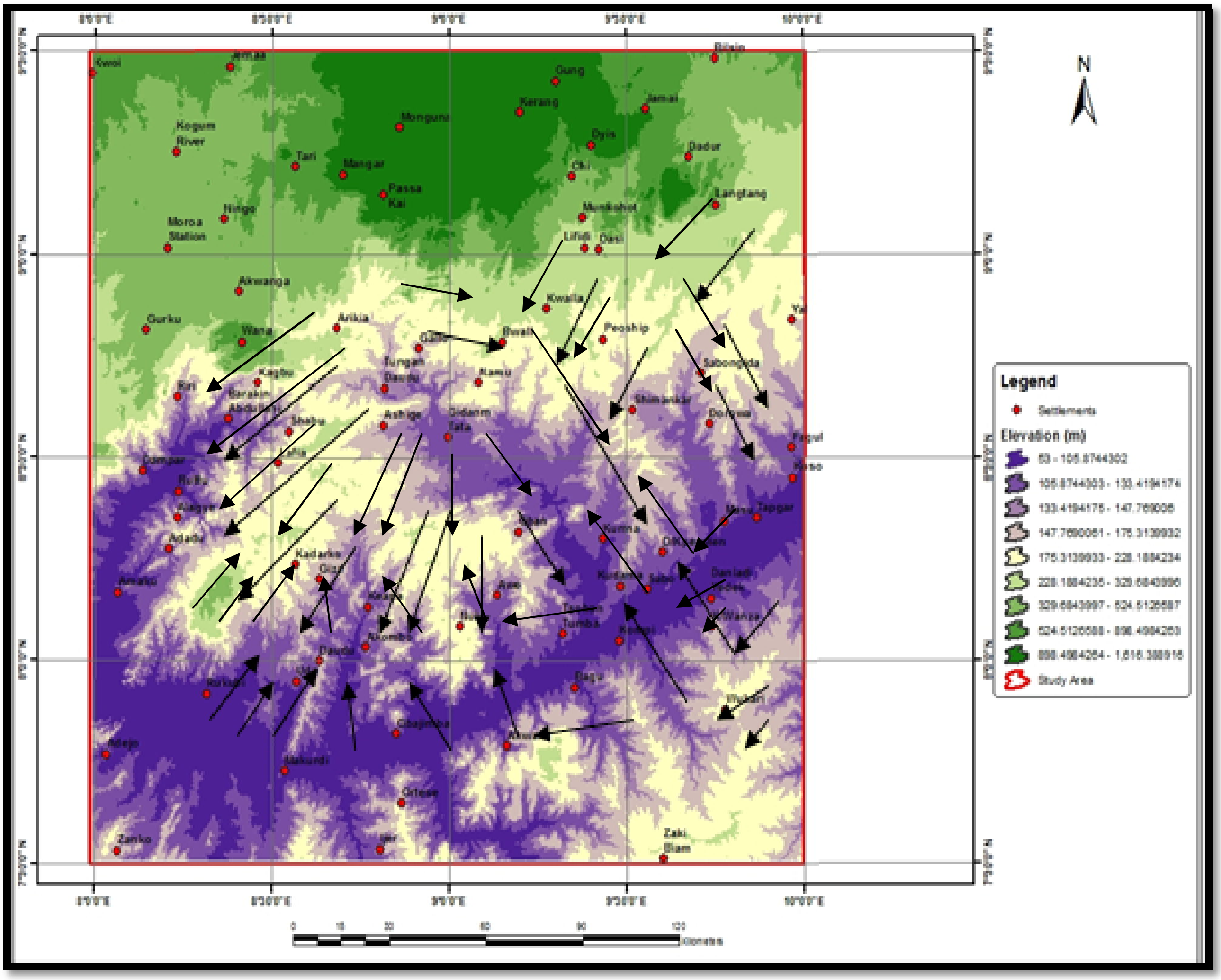

Figure 8: Digital Elevation Model of the Study Area after United States (U.S.). National Aeronautics and Space Administration (NASA) 2010.Elevation Map of the Study Area Showing That the Drainage Pattern Is Structurally Controlled as Shown by the Black Arrows

4. Discussion of the Results

The magnetic intensity over Nasarawa and Environs showed magnetic signature in the form of colour ranges with red as high and blue as low with clear disposition of different zones with distinct anomaly ranges. The difference in magnetic relief between each two adjacent magnetic highs and lows suggest a comparable variation in Lithology Bird., (1997). Bearing this in mind, prominent magnetic relief between two adjacent magnetic highs and lows, elliptical closures and nosing were identified on the magnetic map. These features represent geologic anomalies/lineaments.

Result of tilt enhancement technique revealed two prominent contacts that are linear and continuous that trend in the NE-SW direction. These trends correlate with the deductions of Ajakaiye et al., (1991), which suggested very strongly that magnetic lineaments with definite characteristics exist within the Nigerian continental masses, these lineaments coincide with major structural trends such as the Benue trough in Nigeria, fractures in the Oceanic crust of West Africa, Eburnean syncline in the Ivory coast and can be traced to lineaments in Guyana and eastern Brazil. They show that the onshore lineaments in the West Africa are the extensions of the St. Pauls, Romanche, Chain and Charcoat fracture zone. The fracture zones are believed to be part of major zone of weakness in the crust that predate the opening of the Atlantic Ocean and were reactivated in the early stages of continental rifting. Two of the fracture zones are believe to pass through the study area, these are the Romanche and Chain fracture zones represented as (A-A') and (B-B') as shown in the diagram (Fig. 4), The Romanche and Chain fracture zones are also thought to have continental extensions and are likely to control the major NE – SW fracture system along the Benue Trough.

Result of the total horizontal derivative technique revealed magnetic anomalies (lineaments) in the NE-SW, NW-SE, NNE—SSW, NNW-NNE, E-W and N-S directions, except that the N-S lineaments are more pronounced as evident by numerous north-south-striking fractures at the northern part of the study area, prominent at the north-western part, west of Ningo is major lineament that controls Kogum River denoted as (A) and River Moroa denoted as (B), other rivers and stream channels controlled by the N-S trend that suggests much correspondence with the topographic map (fig 1) include River Langtang denoted as (C), River Shimankar denoted as (D), and River Sabon Gida (Dep). River Gallo is controlled by a major trend in the NE-SW direction at the north central part denoted as (E),also revealed is a major fracture at the extreme northern part of the study area around Kerang denoted as (Z), which could be the major tectonic event that control the formation of the volcanic rocks in the area. This results also revealed that the emplacement of the granite plutons seems to have been controlled largely by NE – SW fractures, based on the consistency in structural trends of the magnetic anomalies in the study area when compared with the geologic map (fig. 2), it then suggests that the granite suites in the area are concordant plutons. At the southern part of the study area, aeromagnetic patterns have less correspondence with topographic patterns, suggesting that the majority of magnetic sources represent volumes of rocks that are mostly buried. The total horizontal derivative seems to reveal most trends that were not evident in the total intensity map. Evident also on the total horizontal derivative map are isolated bodies at the extreme south denoted as (F) that are aligned in the NE-SW direction, these correspond well with the volcanic intrusion in the geologic map of the area, it then implies that the volcanic intrusion that were emplaced in the area due to Compressional folding during the mid-Santonian tectonic episode utilized the existing fractures. The emplacement of basalt which is found at the extreme south of the study area, has produced similar magnetic feature or lineaments (NE-SW direction) with those found on the basement. This suggests that the basalt emplacement followed the pre-existing fracture zones on the basement. This laid credence to the suggestion by Benkhelil et al (1998) that, sedimentary structural features of the Cote d'Ivore-Ghana Marginal Ridge (CIGMR) and those of the Benue trough developed as a result of basement-seated trans current faults.

On the other hand, the digital terrain model (fig.7) revealed that magnetic anomalies in the study area follow the trends of the topography or they are elevation depended. As revealed by several linear features at the northwestern portion of the study area. The digital terrain model showed that, 45% of the study area is topographically highland with some outcrops, which is in agreement with the magnetic derivatives in this study. It was also observed that, most complex outcrops on the digital terrain model trends NW-SE and NE-SW, which is in line with structural trends in the area most especially rocks of northeastern basement complex.

The digital elevation map shows the highlands and lowlands in the study area as displayed in (Fig.8). The elevation ranges from 50 to 818 m with a mean value of 434 m. On the average, about 60% of the area falls within lowlands which coincide with the Middle Benue Trough and its river channels, the high elevations shown at the northern part of the area are associated with the basement rocks. Inspection of the digital elevation model shows good correspondence with the result obtained from the tilt and total horizontal derivative map, these maps also gives a well-defined basement-sedimentary boundary which implies that the maps can be effective tools as indicator of abrupt changes in magnetic continuities over the study area.

This study has shown that the basement complex rocks in this area are heavily faulted, fractured and invaded by dykes, veins, sills and igneous rocks; this could be a as result of the multiple deformational episodes/ tectonic activities that occurred in the study area. Lineaments in the NE-SW, NNE-SSW, NW-SE, NNW-SSE and N-S directions were mapped, with NE-SW as the dominant trend, which is related to Pan African Orogeny. This confirms that, the Nigerian basement is polycyclic, believed to be the results of at least four major orogenic cycles of deformation, metamorphism and remobilization corresponding to the Liberian (2,700 Ma), the Eburnean (2,000 Ma), the Kibaran (1,100 Ma), and the Pan-African cycles (600 Ma) (Ogezi, 1977; Ajibade et al., 1989), and that the first three cycles were characterized by intense deformation and isoclinal folding accompanied by regional metamorphism, which was further followed by extensive migmatization. The Pan-African deformation was accompanied by a regional metamorphism, migmatization and extensive granitization and gneissification which produced syntectonic granites and homogeneous gneisses (Abaa, 1983). Late tectonic emplacement of granites and granodiorites and associated contact metamorphism accompanied the end stages of this last deformation. The end of the orogeny was marked by faulting and fracturing (Gandu et al., 1986; Olayinka, 1992. Most mineral deposits are related to some type of deformation of the lithosphere, and most theories of ore formation and concentration embody tectonic or deformational concepts,(O'Leary et al., 1976; Ananaba & Ajakaiye, 1987). Some lineament patterns have been defined to be the most favourable structural conditions in control of various mineral deposits (Megwara & Udensi, 2013), in line with this therefore, any mineral exploration programme should take cognizance of the tectonic features observed in this study.

On the evolution of the Benue Trough, unlike the other basins which overlie either the continental margin or lie directly on a continental basement, the Benue Trough is entirely intracontinental with some relationship with the Gulf of Guinea. Its formation and evolution were at least partly controlled by the nascent oceanic structures of the equatorial Atlantic. The Benue Trough evolution is thus related to the basement fragmentation, block faulting, subsidence and rifting, during the early cretaceous separation of Africa and South America (Grant, 1971). Results obtained from the geophysical investigation assisted in the update of information existing in the study area. This study has shown that the interpreted basement ridge in the central part of the study (Basement-Sedimentary contact/Transition zone) in the tilt derivative has been recognized to form alignment with the deep-sea transform/fracture zone system recognized as Romanche transform/fracture zone/paleo-structures. The walls of the inland extension of the underlying ridges coincide with the inferred onshore projection of the two major extensions of Romancheand Chain transform faults. These fracture zones appear to play major roles in the deformation and rifting of the middle Benue basin. The transform fracture zone could be responsible for the strike-slip deformations resulting into the graben-horst patterns which influence deposition of sediments from major rivers draining the area from the north to the southern basin margins. It is likely that during the Aptian-Albian times the active portions of these fractures or oceanic faults were still close enough to the Abakaliki axis to cause the observed tectonic, magmatism and metamorphic phenomenon.

5. Conclusion

Structural analysis using aeromagnetic data over parts of Middle Benue Trough and the basement rocks of north central Nigeria was carried out to highlight linear structures and infer the effects of such features on the tectonic events in the surveyed area. Magnetic anomalies (Lineaments)obtained from tilt and total horizontal derivative revealed the concentration at the northern fringes in the NE-SW, SE-NW, NNE—SSW, NNW-NNE, E-W and N-S direction, the NE-SW is the dominant trend in the area related to the Pan-African orogeny. This could signify intense fracturing of the basement in this zone, some of these trends and lineaments could be pegmatite that could host mineralization. The magnetic lineaments of Fig.6 are mainly attributed to Precambrian basement fractures which were initiated prior to the formation of the Benue rift, areas of high lineaments density in the study could be investigated further for mineral deposits.

6. Acknowledgements

The First author wishes to thank Geosoft Inc. South Africa for providing the software which I used for my Ph. D. Research work. Thanks are also due to the department of Geology, Modibbo Adama University of Technology, Yola for the practical application of this work.

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