RESEARCH ARTICLE

Structural relationship between Adamawa Massif and Hawal basement from high resolution aeromagnetic data, satellite imagery and field work over upper benue trough, Northeastern Nigeria

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ABSTRACT

Structural studies on the relationship between Adamawa Massif and Hawal basement from high resolution aeromagnetic data, satellite imagery and field work over upper Benue trough, northeastern Nigeria was carried out. The high resolution aeromagnetic data was treated using the Oasis Montaj TM software in order to get the Total Magnetic Intensity (TMI) and the residual maps from where analytic signal and horizontal derivative maps were produced. Studies on the satellite data was also carried out, several digital image enhancement techniques such as general contrast stretching and edge enhancement were applied to the SPOT 5 imagery using the ArcGIS software. Major structural trends of the study area from both aeromagnetic, satellite and field data shows that the ENE-WSW, NNE-SSW, NE-SW, and WNW-ESE trends as majors while N-S, E-W, and NW-SE as minors, also the structural trends of the area from the field that were traced on both the aeromagnetic and satellite data shows that NE-SW, NNE-SSW, and ENE-WSW as majors and NW-SE, N-S, and E-W as minors. Based on the above findings it is concluded that the Adamawa Massif and the Hawal basement are probably one giant massive before the Cretaceous.

Key Words: *Adamawa Massif, Aeromagnetic data, Hawal basement, upper Benue trough and Field work.*

INTRODUCTION

Structural relationship between Adamawa Massif and Hawal basement from high-resolution aeromagnetic data, satellite imagery, and field work over the upper Benue trough, northeastern Nigeria was carried out. The total magnetic map was treated by means of the Oasis Montaj TM programming software to get the residual map by polynomial fitting, from where the analytic signal and horizontal derivatives were accomplished. The satellite imagery used for this study is the SPOT 5 with a high resolution of 5 m. Designated field studies of the two basements (Adamawa Massif and Hawal basement) was also carried out. The study area is located between longitude 100:30' - 120:30' E and Latitude 90:00' – 110 :00' N, it covers an area of 48,400 km^2. The upper Benue rift is a significant arm of the Benue trough which branches into two nearly

Perpendicularly the Yola arm trending E-W and Gongola arm trending N-S. It is a linear

Cretaceous sedimentary basin which spreads deep into the African continent and was closely related with the split-up of Africa from South Atlantic, it spread north easterly to attain an approximate length of 1000 Km long and 100 km-700 km wide and houses a thick sequence of shales, sandstones, limestones, coal, evaporates, volcanic and intrusive whose age range from Aptian to Maestrichtian [1,2]. The drainage of this region is realized partly by the Benue river which takes it source eastward from the Cameroons and for the other part by its leading affluent the Gongola river which rises from the Jos plateaus. The upper Benue trough is confined by the Hawal massif to the northeast and the Adamawa Massif to the southeast, both massifs spread into the Cameroon Republic (Figure 1) .

Geology of the area

The study area is a Cretaceous sedimentary basin that forms a constricted band of terranes that expanses eastward and splits into small isolated basins into Cameroon [3]. It is split into the Yola rift the and Gongola rift. The lithostratigraphic units of the Yola rift comprise the Bima sandstones, the Yolde Formation, Dukul, Jessu, Sekule, Numanha, and Lamja Sandstone formations in that order, while the Gongola rift includes the Bima sandstones, the Pindiga formation, Gombe sandstones, and the Kerri – Kerri formation. The basement rocks of the region are, Migmatite- gneiss complex, older granite, and basic rocks.

Previous studies

Investigation of the Upper Benue rift valley system on the foundation of novel geophysical figures gave the result of sediment thickness in the values of 1 km to 2.2 km however the low magnetic values were attributed to regions of dense Cretaceous sediment. Studies on the structure and geodynamic evolution of the intra-continental Benue trough conclude that the Cretaceous Benue trough is a set of pull apart sub-basin produced by sinistral displacement along pre-existing NE-SW transcurrent faults [4,5]. A provincial gravity study of the West African rift system in Nigeria and Cameroun and their tectonic interpretation displays that the crust beneath the lower and middle Benue is approximately 20 km and 25 km, while the crustal extension was 95 km for Benue [6], 65 km for Gongola and 55 km for Yola rift. Research on the aeromagnetic study of part of the Upper Benue

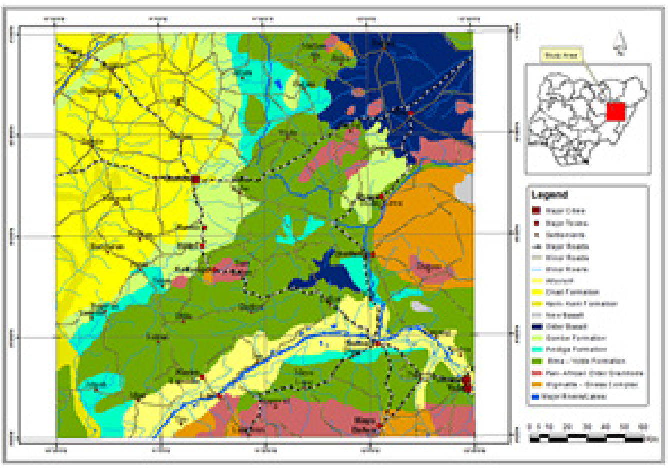

Figure 1) *Geologic map of the study area (modified from NGSA 2006).*

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basin concludes that the basement underneath the trough has a variable depth averaging between 0.5 km - 4.6 km and average magnetization of 0.39 A/m [7], which seems reasonable for a crystalline basement as assumed to lie beneath the Benue trough. Structural studies of satellite imagery over basement rocks of N.E Nigeria and Northern Cameroun [8], discovered that lineaments in the region are attributed to the existence of joints, faults, shearing, deformation, dykes, and veins which are the product of pan-African deformational episodes. Multi-technique graphical analysis of fractures from remote sensing images of basement regions of Nigeria provides evidence of the density of lineament and their usefulness in mineral and groundwater exploration, road and dam construction, and site-sensitive industries like nuclear plants [9].

MATERIALS AND METHOD

The high-resolution magnetic data used in this study were acquired for Nigeria Geological Survey Agency (NGSA) in 2010 as part of a countrywide geological survey. The data has the following specifications, terrain clearance of 80 m, flight line spacing of 500 m and a tie line spacing of 5000 m, sixteen sheets were used for this study [9]. The high-resolution aeromagnetic data were treated using the Oasis Montaj TM software in order to get the Total Magnetic Intensity (TMI) and the residual maps from where analytic signal and horizontal derivative maps were produced. Analytic signal is for all intents and purposes a technique that uses Hilbert transformation and fast Fourier transforms of source field. On this bases [10], developed the notion of 2-D analytic signal or energy envelope of magnetic anomalies. He presented that the shape of the analytic signal of contacts and sheets are independent of the direction of magnetization and the local geomagnetic field [11]. In addition it revealed that it is factual for every 2-D magnetic anomalies. The whole values of the analytic signal of magnetic anomaly is distinct as the square root of the squared sum of the vertical and the two orthogonal products of the magnetic field [12], such that (1)

$$|A(x,y)| = \sqrt{\left(\frac{dT}{dx}\right)^2+\left(\frac{dT}{dy}\right)^2+\left(\frac{dT}{dz}\right)^2} \quad 1$$

Conversely, no transformation to the pole or equator is required in the analytic signal [13]. As stated by analytic signal maps help disclose the anomaly texture and to highlight discontinuities [14], short wavelength anomalies are also enhanced, this is used in outlining the lineament of the area. Horizontal derivative maps are derivative results that expose the anomaly texture and highlight anomaly pattern discontinuities. According to [12], horizontal derivatives can offer higher resolution and greater accuracy at wider line spacing. It is basically significant while trying to map out linear structures such as faults or dykes from magnetic figures. The horizontal derivative of a variant field is considered as the Pythagorean sum of the gradient in an orthogonal direction. If M(x,y) is the magnetic field, then the horizontal gradient magnitude HGM(x,y) as given by [13] (2)

$$HGM(x,y) = \sqrt{(dm/dx)^2 + (dm/dy)^2} \quad 2$$

This function points over magnetic contact on the postulation that the provincial magnetic field and the causative magnetization are vertical, the contacts are isolated and the sources are thick [13].The ridges or boundaries of the horizontal products are acknowledged by the industry generally as being good locations of shallow, vertical body edges. Horizontal derivatives usually deliver a more precise location for faults than first vertical derivatives. The method will produce apparent contacts that are linear and very continuous [13]. The satellite imagery used for this study is SPOT 5 (Figure 6), with a high resolution of (5 m). The data was gotten from the National Centre for remote sensing (NCRS) Jos, the SPOT 5, is polar, circular, sun-synchronous and phased, ArcGis software (9.0) was used for the processing of the satellite data. Several digital image improvement approaches such as general contrast stretching and edge enhancement were useful to the SPOT 5 imagery using the ArcGIS software, the first phase of structural mapping involved mapping and classifying lineaments that could be due to any of the following, contacts between two rock type of contrasting magnetic susceptibility or edges of structures that could be faults or intrusive within the sediments. The second point 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 start digitizing the lineaments, a shapefile was produced 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 perceived from the various data sets on-screen, and a rose diagram of the lineaments for the region was created. Selected field studies of the two basements (Adamawa Massif and Hawal basement) were carried out, structures and other geologic structures such as joints, shear deformation, fault, veins, and dykes were observed and measured, and rose diagram of shear deformation and joints were plotted for the two basements. Materials that were used in the fieldwork comprised a hammer, compass-clinometer, Global Positioning System (GPS), tape, and sample bag [15]. The hammer is the most vital piece of equipment to the geologist in the field, it is used in breaking rocks to obtain samples. The compass is used in measuring directions (strike) and the clinometer for measuring dips. The strike is defined as the line of intersection between the horizontal plane and the planer surface being measured. A simple description of a strike is that it is the trend of zero dips. Whereas dip is the maximum slope of the surface at the right angle to the strike. Measurement is accomplished by putting the compass on the bedding outcrop, the compass is set in the east-west direction, and the clinometer is allowed to move in the vertical plane. The compass edge is positioned on the outcropping surface and moves until the compass-clinometer reads zero. This is the strike (direction) and the position is read via the compass pointer, still retaining the east-west direction the compass edge is placed vertical to the strike (direction), and the angle of dip is always measured at the right angle to the strike. The GPS makes use of satellites in locating stations by reading longitudes and latitudes, likewise, it can be used in locating altitudes. The tape is used in measuring the dimensions of outcrops.

RESULTS

The overall magnetic intensity map of the region, Figure 2 displays anomalies of high and low magnetic intensity values with principal NE-SW and NW - SE trends, with values ranging from 22.5 nT- 325.9 nT. The map displays that the area is composed of the different magnetic regions. The regions are distinguished on the basis of the disparity of the intensity of magnetic response. The northeastern part of the region (around Biu) is characterized by high magnetic response trending NE –SW, to which is restricted at the north and south by relatively low anomalies, (Mallam Ali and Shani, areas). The southwestern parts of the region (Jabieb and close to Karim Lamido) are marginally characterized by medium to high magnetic response trending NE –SW to which is restricted at the north by relatively low anomalies (Yankari, Bangurum areas), the central part is characterized by medium magnetic response trending NE –SW (Kaltungo area). The northwestern part of the study area (Dukku, Gombe, Kumo areas) is made up of low magnetic anomalies. Finally, the southeastern part is characterized by an alternation of high and low magnetic anomalies (Shelleng, Dumne, Yola, and Numan areas). Visual inspection of the aeromagnetic map discloses that the most dominant feature in the study area is NE-SW direction, which is related to the Pan Africa trend. Areas around (Biu, Wade, Kaltungo, Dumne, and Mayo belwa) are characterized by basement rocks hence the high magnetic anomalies as basement rocks are strongly magnetic. While areas around Mallam Ali, Shani, Dukku, Gombe, Yola, and Numan, have low magnetic anomalies, this areas coincide with the sedimentary section (since sediments are weakly magnetic).

From the residual aeromagnetic map, data were residualized (i.e. removal of the regional) leaving only the residual so as to obtain a magnetic response from the upper crust of the earth comprising of the basement and sedimentary unit. The residual aeromagnetic map (Figure 3) illustrates magnetic anomalies similar to that of the TMI map in Figure 4. The dominant trend is in the NE-SW direction, which is related to the Pan Africa trend. The long wavelength features are undoubtedly due to a very deep basement source and are referred to as regional. Small amplitude short

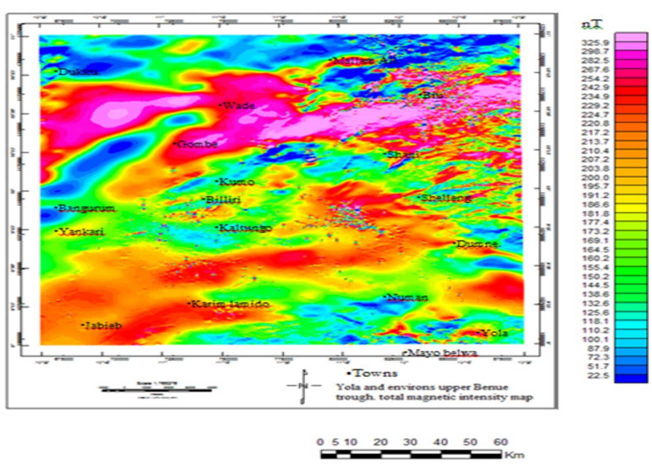

Figure 2) *Total magnetic intensity map of the study area.*

wavelength anomalies are overlaid on these large features. Areas around (Biu, Wade, Kaltungo, Dumne, and May below) are characterized by basement rocks and have a high magnetic response, whereas areas around Mallam Ali, Shani, Dukku, Gombe, Yola, and Numan are characterized by the sediment section of the area and have a low magnetic response. Figure 5 shows the 1st Order horizontal derivative map of the study area with the lineaments and rose diagram. The anomalies of 100.6 nT to -129.8 nT exist as a sequence of areas of magnetic highs and lows. These areas are not continuous but seem like numerous elongated lobes extending over varying distances before being interrupted by the occasional occurrence of short wavelength anomalies that may be due to near surface intrusives, volcanic plugs, basement rocks or thin basaltic flows. Figure 6 shows the SPOT 5 satellite imagery and the lineament map of the study area. (Courtesy of NCRS 2006).

DISCUSSION

The analytical signal and the 1st order horizontal derivative maps with their rose plots are presented in Figure 4 and Figure 5 with the dominant lineament directions of the study area to be ENE-WSW, NNE-SSW, NE-SW, WNW-ESE while NW-SE, NNW-SSE, E-W, and N-S are minors. A

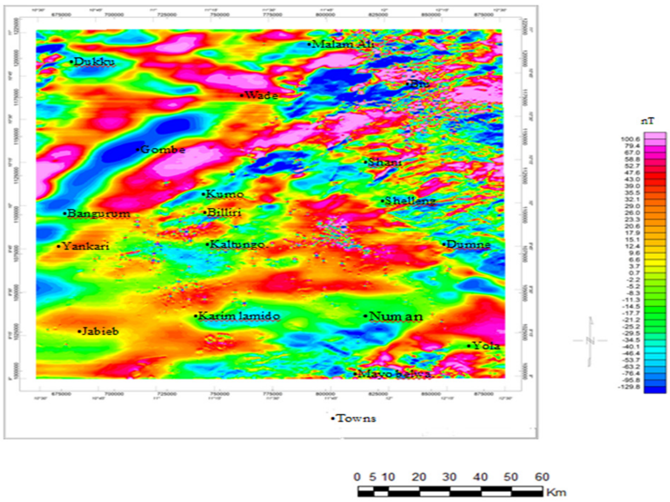

Figure 3) *Residual aeromagnetic map of the study area.*

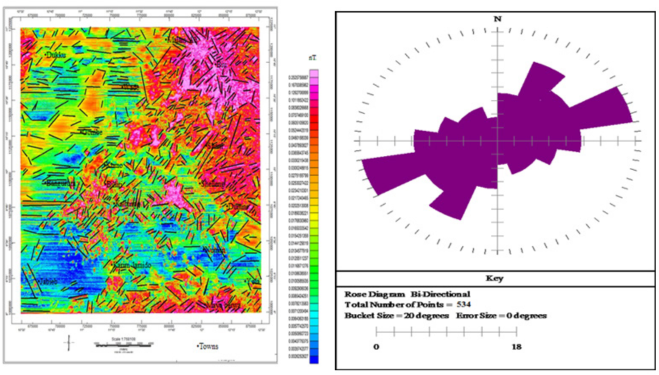

Figure 4) *Analytic signal map of the study area with the lineaments and rose diagram.*

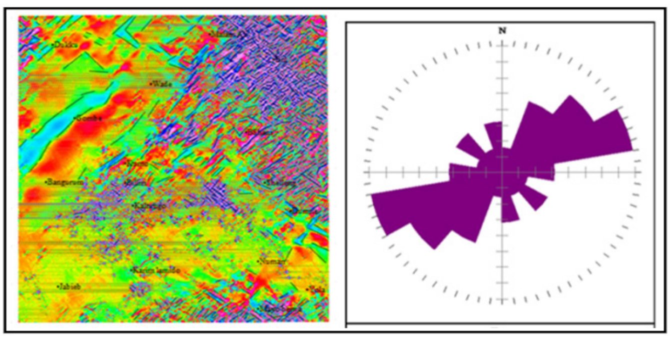

Figure 5) *1st Order horizontal derivative map of the study area with the lineaments and rose diagram.*

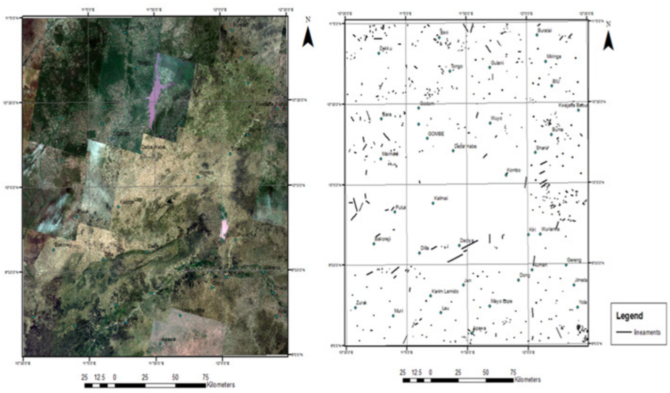

Figure 6) *The spot 5 satellite imagery and the lineament map of the study area. (Courtesy of NCRS 2006).*

remarkable intensification of fractures parallel to the trough margins is in fact to be noted precisely in the Hawal basement and the Adamawa Massif. The basement sediment contact is characterized by magnetic lows. Figure. 6 is SPOT 5 satellite imagery and the lineament map of the study area, a satellite imagery map of the study area, the lineaments extracted from the imagery, display the direction of major lineaments in the study area to be NNE-SSW, NE-SW, ENE-WSW, and WNW-ESE while NW-SE, NNW-SSE, E-W ,and N-S are minors. These lineaments were expressed on the surface as rivers and stream channels observed from the satellite imagery. Lineaments gotten from high-resolution aeromagnetic figures and satellite imagery are the surface and deep expression of those from the field and they have similarities in many cases and are also related to the geology of the region. These lineaments perceived have been accounted for in relation to faults, joints, shear zones, dykes, and veins. These structural trends control the drainage pattern and flow direction of major rivers in the region. Such as the E-W stream at the northern segment of the Modibbo Adama University of Technology Yola, which is also parallel to the direction of the Yola rift basin. The western sector of the Benue river within the rift basin flows in the NW direction, the eastern sector of the Benue river (east of Yola town) flows in a NE direction, also the Gongola river flows along the N-S direction, this point to a probable control by NE, NW, E-W, and NS trending basement faults/shear zones.

Adamawa massif (geology and field work)

Adamawa Massif consists largely of granite and migmatites gneisses; it is located in the southeastern part of the study area, (Mayo-Belwa and environs). The granites of this area comprise equigranular granites, porphyritic granites, and fine-grained granites and are similar in mineral configuration but vary texturally and structurally. The granite is mostly feldspathic granite and highly weathered covering a larger part of the study area. They range from light to pink colored and are medium to coarse-grained in texture. Coarse-grained granites are found around Kona-Manga. They are light to pink colored, coarse-grained in texture, and have a sharp contact with medium-grained granite. The medium-grained granites occurred in Kona-Petel, joints and veins were abundant in these two areas. Migmatites gneiss of the area is of granitic origin alternating with biotite-enriched mafic materials. They are poorly foliated, typically leucocratic, coarse-grained, and display significant variations in structure and texture. The granitic portion of the migmatite is often leucocratic and medium- to coarse-grained. The migmatite is discordant, formed irregular vein injection, and is interlaminated with metamorphic rocks of various types forming the so-called migmatite gneiss complexes. Some of the structures observed in the field are (faults, joints, veins, and dykes). Joints were observed and measured, trending between N80^0 to N140^0 other joint directions are N15^0 and N45^0. Dextral strike-slip faults were observed on the granites of Walowol-Kulaje trending N130^{0}E 50^{0}SW, and another one was observed in the same village trending N140^{0}E 30^0 SW, they are shown in Figure 7. Dykes are discordant igneous rock or solidified magma cutting through the overlying body of a host rock vertically. Fine grain granitic dyke of N70^{0}E and dip 25^0 E was observed on coarse grain granite at Kona-Petel. An N110^{0}E and dip 60^{0}E was found at Kona-Manga, dykes are fairly abundant in these localities, along the foot path that leads out of the village is a dyke that is 1m width and extend to several hundred of meters N140^{0}E and dip 60^0 E, as shown in Figure 8. Veins are fractures filled with remobilized minerals such as, quartz, feldspars or both, they indicate high albeit transient, pore fluid pressure during deformation and are commonly associated with pressure solution seams for instance quartzofeldsphatic veins. At Kona-Manga a N130^0 granitic ridge is variously intruded by quartz veins and vein lets. These veins trend between N65^0 – N160^0 and are displayed in Figure 9. A geologic map of the region produced during the field work is displayed in Figure 9.

The lineaments gotten from high resolution aeromagnetic figures and the satellite imagery shows the major direction of the region to be ENE-WSW, NE-SW, and NNE-SSW while NW-SE, WNW-ESE, NNW-SSE E-W, and N-S are minors. Figure 10, is the structural direction of the region from the field (Adamawa massif) that were traced on both the aeromagnetic and satellite data which shows NE-SW, NNE-SSW, and ENE- WSW as majors and NW-SE, N-S, and E-W as minors.

Figure 7) *Dextral strike-slip faults on granite at Walowol-Kulaje.*

Figure 8) *Quatzofeldsphatic dyke and vein on coarse-grained granite at Kona-Manga.*

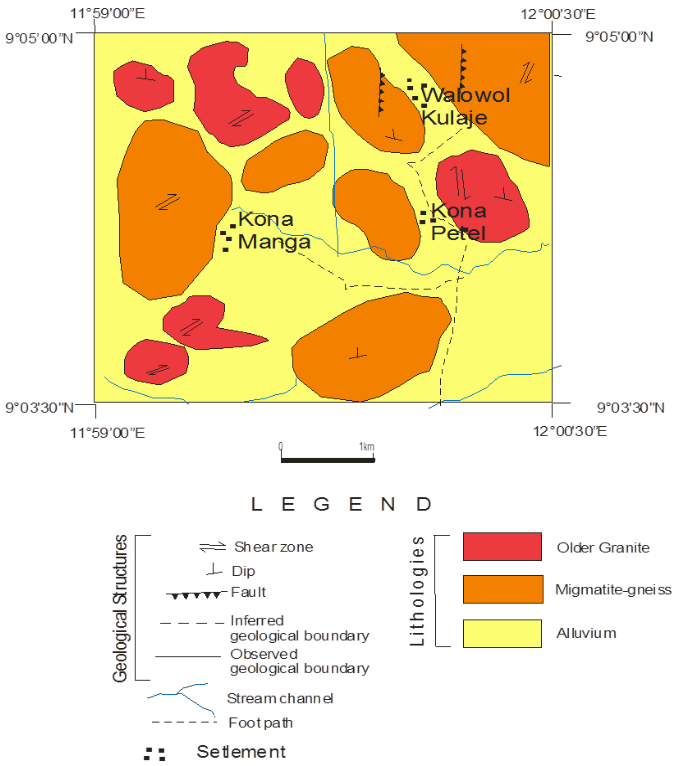

Figure 9) *Geologic map of Mayo-Belwa area (Adamawa Massif) from field studies.*

Hawal basement (geology and field work)

The Hawal basement it is located in the northeastern part of the area, (Dumne and environs), three different rock types were recognized, they are Granite gneiss, Migmatite gneiss, and older granites. The Granite gneisses are the most dominant gneissic rocks in the area. In some places, particularly at the base of the hills, the rocks grade into migmatitic gneiss. Texturally, the rocks are coarse-grained and consist of alternating bands of mafic and felsic minerals with quartz and orthoclase feldspar contents. They are variedly invaded by pegmatite veins, as seen close to Wuro-Kitaku. The rocks generally outcrop sandwiched between migmatites and granites at Dumne, and Wuro-Kitaku. Migmatite gneiss occurs in varying compositions and textures. They are medium to coarse-grained and weakly foliated with regular or discontinuous and sometimes folded bands as observed south of Dumne. Two major varieties of migmatites, the veined and the pegmatite types outcrop in the area. The Older Granites of this area comprise the granodiorites, porphyritic and coarse-grained granites. Figure 12 shows the dextral strike-slip faults on Granite gneiss at Wuro-Kitaku The granodiorites crop out more conspicuously at the foot of the small isolated hills, associated with porphyritic granites as observed at Dumne and Wuro-Kitaku. Most of them occur as in-situ boulders but some occur in a hillock range showing gradational interaction with the porphyritic granites and sharp contact with gneisses. The granodiorites are mostly porphyritic but sometimes are medium to coarse-grained and are affected by widespread spheroidal weathering as seen south of Dumne. The porphyritic granites outcrop in many locations in the area south of Wuro-Kitaku with its scattered boulders on the slopes and the base of hills. Some of the structures observed in the field are (faults, joints, veins, and dykes). Joints were observed and measured trending between N40^0 to N350^0 other joints' directions are N8^0, N15^0, and N25^0. The quartz veins and lenses occur crisscrossing the basement rocks, especially the granites. They are small and are of varying width, and display great irregularities in their form. They occasionally thin out, widen or bend in their course. Significant among the quartz veins are those at Dumne and Wuro-Kitaku, they trend from N 22^0 to N 45^0. Faults were observed both at Dumne and Wuro-Kitaku, trending N150^{0}E, 50^{0}SW, and N120^{0}E, 42^{0}SW, they are shown in Figure 11 . A Pegmatite dyke of N70^{0}E and dip 25^0 E was observed on coarse grain granite at Wuro-Kitaku, as shown in Figure 12. Also a N140^{0}E and dip 60^{0}E was found at the back of the hill at Wuro-Kitaku,

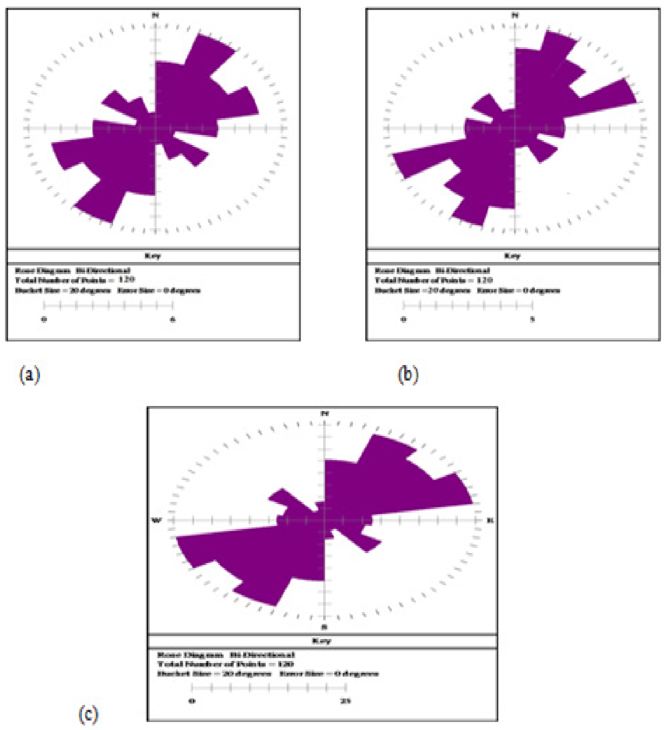

Figure 10) *Rose diagram of structures from Adamawa massif traced on (a) aeromagnetic (b) satellite imagery and (c) measured from the field.*

(Figure 13), is the geologic map of Dumne area (Hawal basement) produced from field studies.

The lineaments extracted from this research display the major direction of the area to be ENE-WSW, NE-SW, and NNE-SSW while NW-SE, WNW-ESE, NNW-SSE, E-W, and N-S, are minors. Figure 14 are the structural trends of the area from the field (Hawal basement) that were traced on both

Figure 11) *Dextral strike-slip faults on Granite gneiss at Wuro-Kitaku*

Figure 12) *Pegmatite dyke on coarse grain granite at Wuro-Kitaku.*

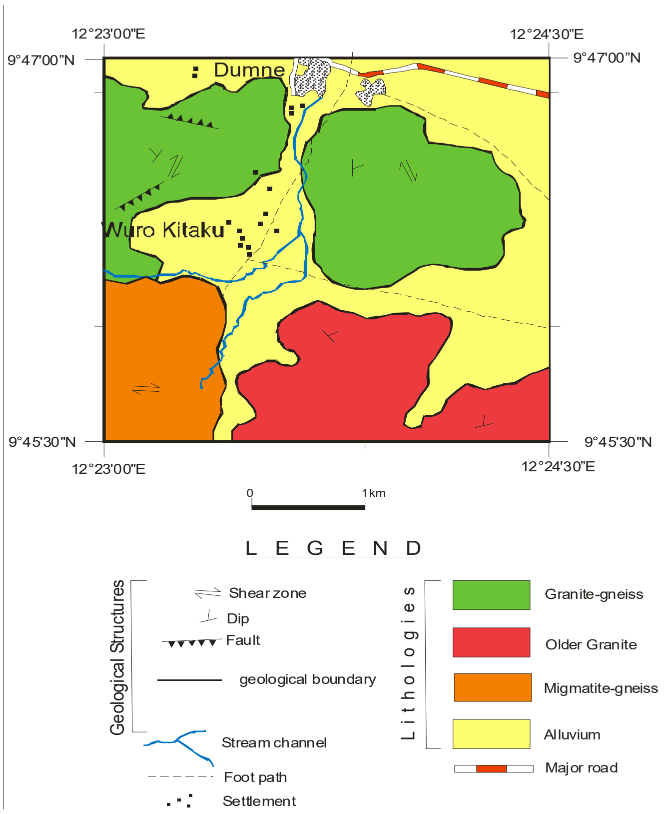

Figure 13) *Geologic map of Dumne area (Hawal basement) from field studies.*

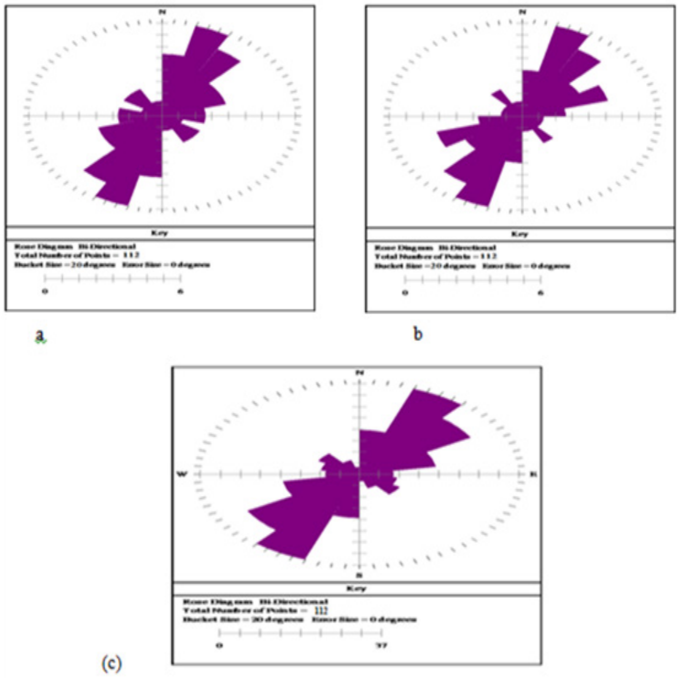

Figure 14) *Rose diagram of structures from Hawal basement traced on (a) aeromagnetic (b) satellite imagery and (c) measured from the field.*

the aeromagnetic and satellite data the results shows the NE-SW, NNE-SSW, and ENE- WSW as majors and NW-SE, N-S, and E-W as minors.

CONCLUSION

Major structural trends of the study area from both aeromagnetic, satellite, and field data display ENE-WSW, NNE-SSW, NE-SW, and WNW-ESE trends as majors while N-S, E-W, and NW-SE as minors, also the structural inclinations of the region from the field that were traced on both the aeromagnetic and satellite data show that NE-SW, NNE-SSW and ENE-WSW as majors and NW-SE, N-S, and E-W as minors, which resemble the structural inclination of the Benue trough and also show structural affinity with the Nigeria basement complex as reported by different workers. The above findings conclude that the Adamawa massif and the Hawal basement are probably one giant massive before the Cretaceous.

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