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Magnetic Study Of Sangere Loko And Environs,Hawal Massifs, Northeastern Nigeria.

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Abstract: *The study area is part of the Hawal Basement Complex, Nigeria's northeast exposure of Precambrian rocks. It is located between longitude $12^0 30'$E to $12^0 40'$E and latitude $9^0 45'$N and $9^0 49'26.4''$N covering an area of about 171 km^2. The research work was carried out with the aim of identifying possible sub-volcanic basic rocks in the area and to see the possibility of occurrence of economic mineral deposits in the study area. The magnetic survey was carried out using the G-856 proton precession magnetometer, which measures the magnetic field of the earth. The data was processed and interpreted qualitatively and quantitatively. From the results obtained, the area is characterized by high and low amplitude anomalies. The high magnetic value in the study area is primarily due to sub-volcanic basic rocks. Areas of low or negative anomalies are interpreted in terms of granites and migmatite-gneiss. They may also be due to susceptibility variation in lithologies or both. The magnetic anomalies trends in the N-S, E-W and NE-SW directions and are consistent with the major structural trends in the basement. The E-W trending anomaly is consistent with the structural orientation of the E-W Yola arm. The study confirms the presence of sub-volcanic basic rocks in the area, whose depths range from <10 m below the surface to about 400 m.*

Keywords: *Anomalies, Basic Rocks,Magnetometer, Magnetic Study,Sub-volcanic,SangereLoko*

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I. Introduction

The study area occupies part of sheet 197 Zummo NW (1:50,000). It is located between longitude 12°30'E and 12°40'E and latitude 9°45'N and 9°49'26.4''N as shown in Figure 1 covering an area of about 171 km^2. Accessibility to the area is by road and footpath.

The Hawal Basement Complex is characterized by high grade metamorphic rocks, pervasive migmatizations and extensive granite plutonism. Most of the migmatization has been dated at 580±100ma ([1]). Hawal Basement complex consists of deeply dissected and rugged hills which in some places are over 800m above sea level forming the major basement complex unit in the Northeastern region of Nigeria.

This study focused on the subsurface geological and structural studies based on the qualitative and quantitative interpretations of the ground magnetic data collected during the fieldwork that was carried out in April, 2013. The magnetic survey was designed in such a way that deep insight into the depth to magnetic sources in the study area was delineated. The data acquisition technique requires measurements of the magnetic intensities at discrete points along traverses regularly distributed within the area of interest so as to cover enough segment used to determine the geology and the structural history of the study area.

A geological investigation of southern sector of Hawal Basement (SangereLoko) and environs was carried out with the intention of studying the earth's magnetic field in the area and to see the possibility of occurrence of economic mineral deposits in the study area. The study area is part of Nigeria's northeast exposure of Precambrian rocks that are relatively the least investigated of the country's basement terrains ([2]).

Tertiary basic extrusives and intrusives belonging to Cameroon Volcanic Line magmatic rocks are found in Song, Biu and Michika areas (as extrusives). Evidences of near surface (intrusives) occurences of these rocks were observed by some geologists ([3] and [4]) in the southern sector of the Hawal Massif.

However, no detailed information about sub surface distribution of these intrusivestogether with the subsurfacestructural features of the area is clearly unveiled. Hence the need for the present study using ground magneticmethod.

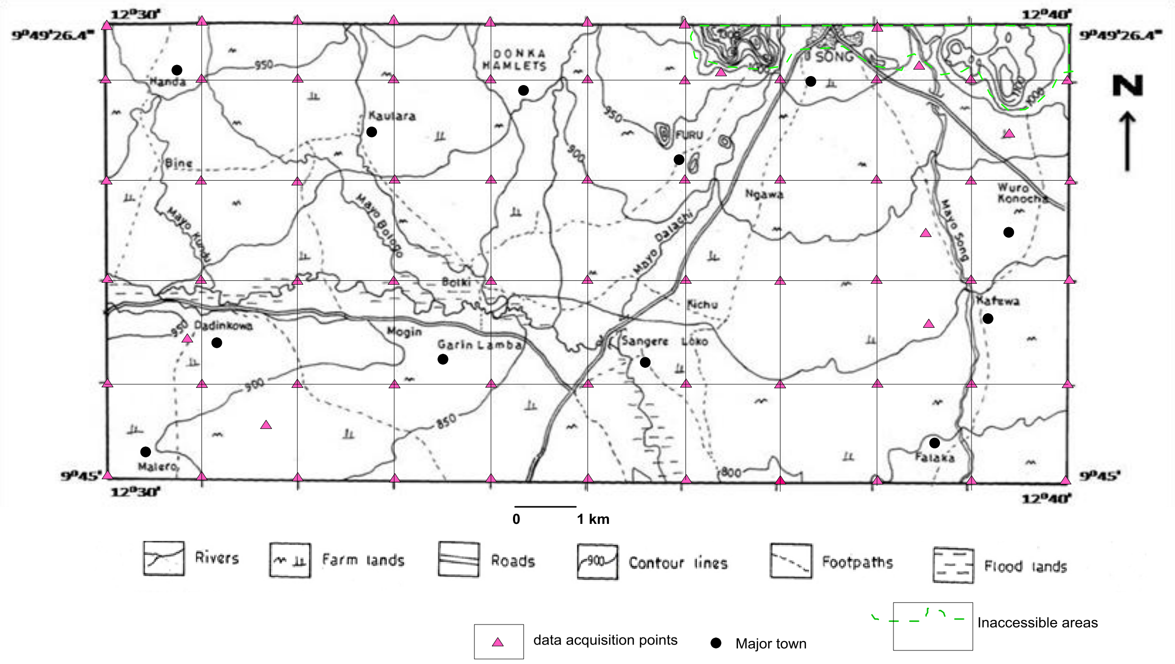

Figure 1: topographical map of the study area with data acquisition points (modified from [5]).

II. Previous Works

Early studies on the Nigerian Basement complex were done by the colonial geologist between 1940s and 1960s as published in the various Geological Survey of Nigeria bulletins. Related geosciences works have been carried out in the area or in the surrounding areas of Hawal Massif. These include the work of [6] which divided the eastern basement complex of Nigeria into four; the Mandaramountain, the Atlantic Mountain, the Shebshi Mountain and the Adamawa massif. [7], gave some details on the basement rocks of Nigeria in which he classified them as consisting of migmatites, gneiss, diorites, porphyritic granite, volcanic rocks and young alluvial deposits. [8], analysed the aerial photographic and aeromagnetic data over Guyuk area northeastern Nigeria. Their results shows the presence of two depth source bodies, namely a deeper magnetic source body at the range of 1900m was identified with the basement, while the shallower magnetic source body at the range of 512 - 670 m was attributed to near surface intrusion and low lying river valleys. [3], studied the geology of Song area in southern Hawal Massif, northeastern Nigeria. They concluded that granite gneiss constitutes the predominant rock types in Song area and other rocks include granites, migmatites, older granites and basalt. [4], studied the structure of Madagali hills of northeastern Nigeria from airborne magnetic and satellite imagery data, coupled with ground geological mapping and showed that this basement region is polygenetic and has experienced magmatism and structural deformation. [9], interpreted a tectonic linear magnetic anomaly over Chiboknortheastern Nigeria and gave a depth to causative body of 2.65 km; the Chibok linear magnetic anomaly is said to be an extension of major Benue Trough fracture zone, invariably oceanic fracture zones into Hawal Basement. [10], studied the brittle deformational features of Michika area, Hawal Basement Complex northeastern Nigeria and the study revealed a terrain of metamorphic rocks (gneisses) extensively intruded by deformed Pan African granites. [11], studied mass wasting in Song area of the Hawal Basement, northeastern Nigeria and concluded that the rocks in the study area are highly fractured due mainly to tectonism.

[12], carried out a digital filtering of aeromagnetic maps for lineament detection in Hawal Basement Complex of northeastern Nigeria, and concluded that the area has several lineaments of NE-SW, NW-SE, and N-S trends, with depth estimation of 1.75 km, 12.09 km and 84.8 km for shallow, intermediate and deep sources. [13], carried out a radiometric mapping of Song and environs, Hawal basement complex northeastern Nigeria, and concluded that areas of high amplitude correlates with granites, those with low amplitude correlates with basalts. Intermediate amplitude correlates with metamorphic rocks. The work has also shown that sub-cropping or un-exposed near surface rock could be mapped based on radiometric anomalies.

III. Geology of the Study Area

The geology of the study area has been presented by [3]. According to these authors, the major groups of rocks found are gneisses, migmatites and granites. Gneisses are the dominant rocks and are highly intruded by a series of granitic, pegmatitic and some basic intrusions as shown in Figure 2. The gneissic rocks consist of varieties of predominantly granitic composition and textural variation. The rocks generally outcrop between migmatites at the base of the slope and granites on top ([3]). The tertiary basalts which are extrusive volcanic rocks and are made up of fine-grained predominantly of ferromagnesian minerals ([14]). Basalt flows in the area are part of the Cameroon volcanic line outcropping in Nigeria ([15]). Significant exposures are found along river channels ([4]). Some of the basic rocks in the study area are inferred (sub-volcanic basalt).

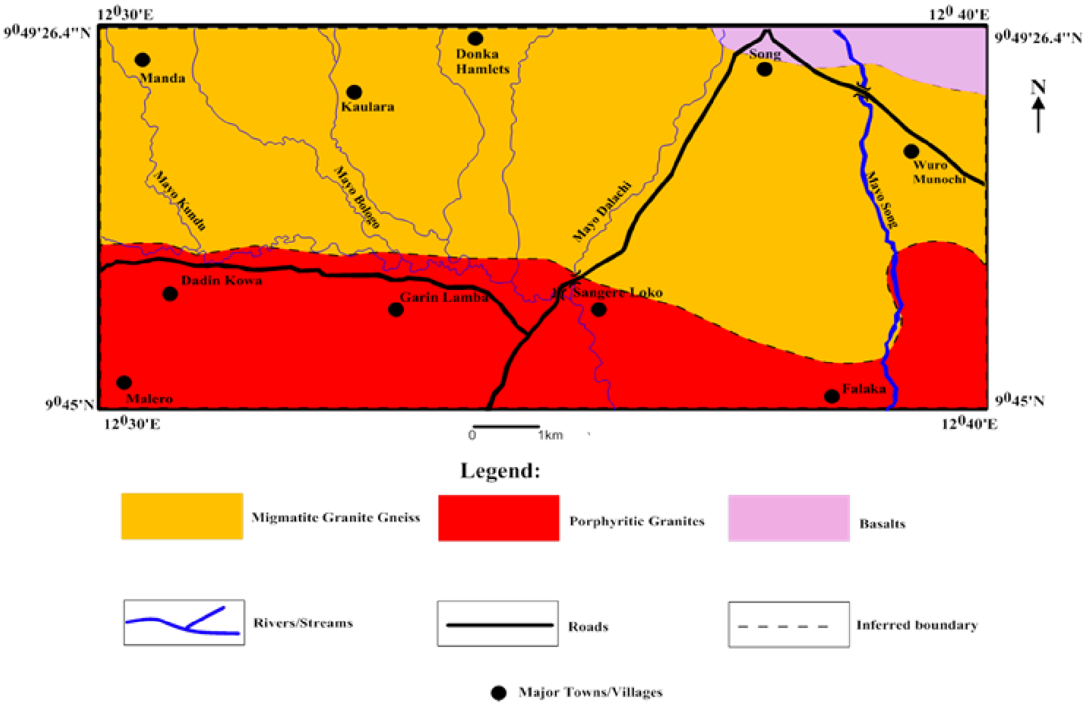

Figure 2: Geologic Map of the Study Area .

IV. Materials and Methods:

4.1 Instrumentation

The instrument used during the survey was the G-856 proton precession magnetometer. The proton precession magnetometer is a versatile tool for locating buried ferromagnetic targets and measuring the intensity of magnetic field. The proton precession magnetometer's sensitivity is high and it is essentially free from drift.

G-856 is a portable magnetometer. As a hand carried instrument, it features simple, push button operation and a built in digital memory which shares over 5000 readings. This relieves the user of the need to physically write down the data in the field. The sensing element consists of a bottle containing low freezing point hydrocarbon fluid about which is wound a coil of copper wire. A strong magnetic field (polarizing field), oriented at a large angle to the earth's field direction, is applied by sending a direct current in the coil to displace the protons out of the earth's field. When the polarizing field is switched off, the protons while returning to their original alignment precess (to re-align themselves with the normal magnetic flux density) for a short time around the direction of the earth's ambient field ([16]).

4.2 Magnetic Data Acquisition

The research work was carried out in stages, viz: Preliminary work in the survey area took the form of a reconnaissance geological mapping, which was followed by geophysical data acquisition, data processing and interpretation. The magnetic field mapping exercise was conducted along traverses at intersections of grid lines across the study area. About 171 stations were covered as in Figure 1. Station positioning was done with the aid of GPS .The magnetometer readings were recorded at a station interval of 950m per station throughout the survey area.

4.3 Magnetic Data Reduction

The magnetic field data were corrected for diurnal variation which is due to electric current within the earth's ionosphere ([16]). These currents are mainly caused by interactions with plasmas connected with solar winds. These diurnal variations fluctuate rapidly, but smoothly with time (minutes to hours). The magnetic field readings were corrected for diurnal effects by establishing a base station in the study area. The differences observed in base readings are then distributed among the readings at stations occupied during the day according to the time of observation. Base station re-occupation was done within two hours, thirty minutes. The base stations were adequately described and, where possible, permanently marked so that extensions can be linked to previous work by exact re-occupation. It should be remembered that magnetometers do not drift and base readings are taken solely to correct for temporal variation in the measured field.

4.4 Magnetic Data Processing

The magnetic processing involves the use of various filters on the magnetic data that will reveal certain features which will aid in the interpretation. The magnetic data of the study area was imported into the computer using the software WINGLINK (version 1.62.08) to produce the total magnetic intensity map as shown in Figure 3. This was further subjected to a high resolution filtering techniques such as; polynomial fitting, upward continuation, vertical derivatives and 2 D depth modeling. Data processing was done in order to enhance the data. It suppresses noise and enhances signal ratio.

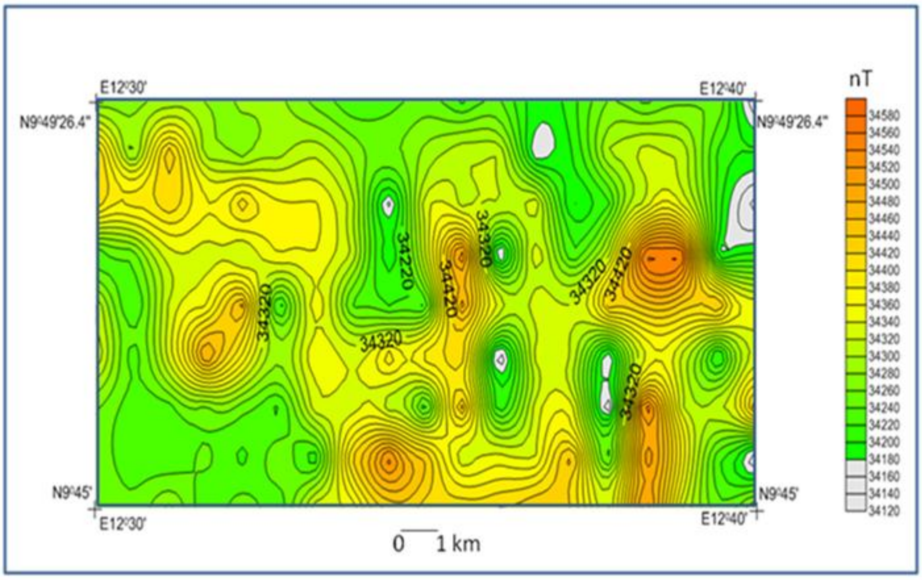

Figure 3: Total Magnetic Intensity Contour Map of the Study Area. (Cont. Int. 20 nT).

4.4.1 Regional magnetic field:

The earth's main magnetic field changes with time due to variation in the motion of the convection currents within the outer core. These changes (called west-ward drift or secular variations) cause the magnitude, F, inclination, I, and declination, D to change with time. These values are collectively known as the International Geomagnetic Reference Field (*IGRF*). As a consequence the *IGRF* is updated every ten or five years and is revised to give the definitive geomagnetic reference field (*DGRF*), which is the current reference model of the earth's magnetic field. The *IGRF* model (2015) was used to estimate the non-crustal effects from the data as shown in Figure 4.

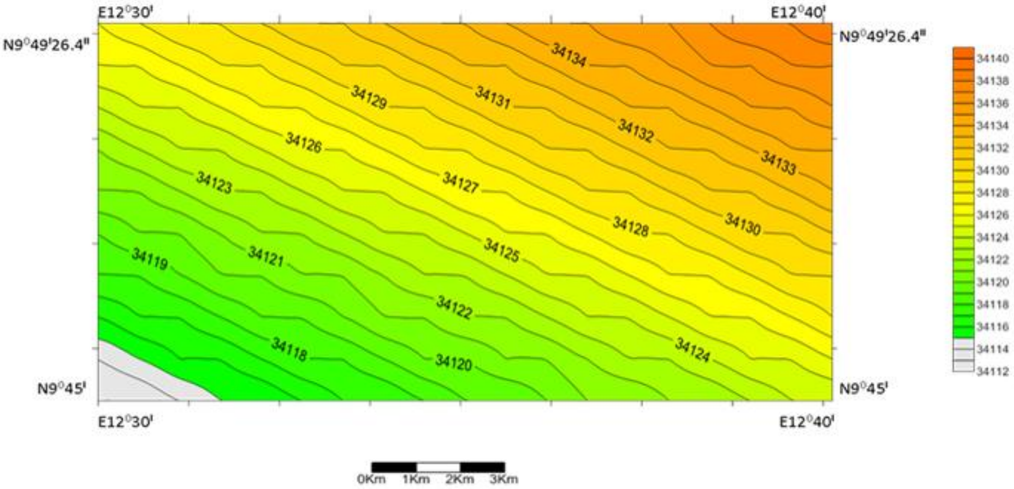

Figure 4: IGRF Model for the Study Area. (Cont. Int. 1 nT).

The regional magnetic field (*IGRF*) is due to deep seated structures underlying the study area, these structures do not originate and/or terminate in the area and as such correcting effects due to their magnetic field is necessary for effective interpretation. It can also be expressed as: *Total Field = Regional Field + Residual Field, and therefore leads to Regional Field = Total Field – Residual Field.*

The value of, the Earth's main field (regional) at each point were estimated using program *IGRFGRID* (predictive values for 2015), with basic input of latitude and longitude values delimiting the study area, and an epoch date of 1st April, 2013. The computed values were contoured as shown in Figure 4. The magnetic pattern consists of lines plunging NW-SE increasing in value from 34114nT in the SW to 34138nT to the NE. Over this area, the removal of the *IGRF* from original total magnetic field value leaves residual values that ranges from -20nT to +440nT.

The difference between the TMI value and the computed *IGRF* value, represent the residual magnetic field over the study area. The residual value was used together with their corresponding geographic coordinates to produce the contoured maps of the residual magnetic field. Thus, correct removal of the *IGRF* from the observed field is a first step in the processing of magnetic data.

4.4.2 Residual magnetic field

The residual magnetic field is due to localized structures within the study area and has a direct correlation with mineralization pattern and magnetic mineral occurrence in the area. To acquire the residual magnetic field over the area, the magnetic data was corrected for the time variations of the earth's magnetic field. In addition, a model such as the International Geomagnetic Reference Field (*IGRF*) was used to remove the non-crustal effects from the data; the Definitive Geomagnetic Reference Field (*DGRF*) is sometimes used in place of the *IGRF*. In this interpretation, the *IGRF* was used to generate the residual field. The residual data were contoured using computer software (SURFER 11.0) to produce residual map of magnetic anomalies. The Residual Magnetic Field can be expressed thus: *Residual Field = Observed Field – IGRF.*

4.4.3 Derivative Techniques (Vertical and Horizontal)

The second vertical derivative enhances near-surface effects at the expense of deeper anomalies. Second derivatives are a measure of curvature, and large curvatures are associated with shallow anomalies, while small curvatures are for gentle sources. The second vertical derivatives can be obtained from the horizontal derivatives because the magnetic field satisfies Laplaces equation.The equations were adopted from Telford *et al*. (1990) and modified for magnetic field.

$\partial^2 H / \partial z^2 = -(\partial^2 H/ \partial x^2 + \partial^2 H/ \partial y^2)$ .... (1)

$\partial H / \partial x^2 + \partial^2 H/ \partial y^2 + \partial^2 H/ \partial z^2$ .... (2)

$\partial^2 H / \partial x^2 + \partial^2 H/ \partial y^2 + \partial^2 H/ \partial z^2$ .... (3)

For the one dimensional case, the first derivative can be estimated by dividing the difference between readings at two nearby locations x_1 and x_2, separated by the distance Δ ×.

$$\partial H(x_{1.5}) / \partial x = [H(x_2) - H(x_1)]/\Delta x \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The second derivative is obtained from the difference between nearby first derivatives:

$$\partial^2 H(x_2)/\partial x^2 = \left[\frac{\partial H(x_{1.5})}{\partial x} - \frac{\partial H(x_{1.5})}{\partial x}\right]/\partial x \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$[H(x_3)-H(x_2)]/\partial x - [H(x_2)-H(x_1)]/\partial x \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$[H(x_3)-2H(x_2)+H(x_1)]/(\partial x)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

4.5 Two - DimentionalModeling

Interpretation of magnetic field data generally involves the construction of a model, simulating the distribution of magnetization in the subsurface material. Such models are commonly assemblages of magnetic bodies, whose location, geometrical shapes, and magnetic properties determine their contribution to anomalous magnetic field. All potential field methods suffer from the fact that an infinite number of models can produce any given response. Successful modeling depends on the ability of the interpreter to impose such initial constrictions to the geometry and magnetic properties, that the ambiguity of the solution is minimal.

V. Results and Discussion

5.1 Qualitative Interpretation of the Magnetic Data

The residual magnetic map is characterized by high and low amplitude anomalies as shown in Figure 5. The magnetic anomalies are trending in the N-S, E-W and NE-SW directions. Visual inspection of the residual magnetic map shows that the dominant trends in the study area are N-S and E-W directions. The observed magnetic anomalies in thestudy area have a width of 1-3 km with steep gradients indicating shallow sources.

The residual magnetic anomaly map of the study area shows four major areas of positive residual magnetic anomalies resulting from volcanic basic rocks. The magnetic highs are labeled (A, B, C, and D) and coincide with the sub-volcanic basic rocks. Anomaly A occurs to the south of the study area. Anomaly B occurs to the east of Chochowo, while anomaly C and D occurs to the southeast of the study area. Anomalies B and D trends in N-S direction, while anomalies C and A are oriented in the E-W direction. Anomaly C has a wavelength of about 2.5 km and is due to deeper sources. The northern portion of the map is dominated by high amplitude negative anomalies. The high amplitude anomalies are due to shallow sources. West of anomaly B is a prominent low magnetic anomaly that extends from Chochowo to Donka Hamlets and is about 1.7 km in amplitude. Two prominent and high amplitude negative anomalies occur to the west and east of anomaly C and are about 1.8 km in amplitude.

From the residual magnetic map of the study area, areas of occurrence of zero or negative magnetic anomalies interpreted in terms of the presence of granites, and gneiss. They may also be due to susceptibility variations in the lithologies or a combination of both.

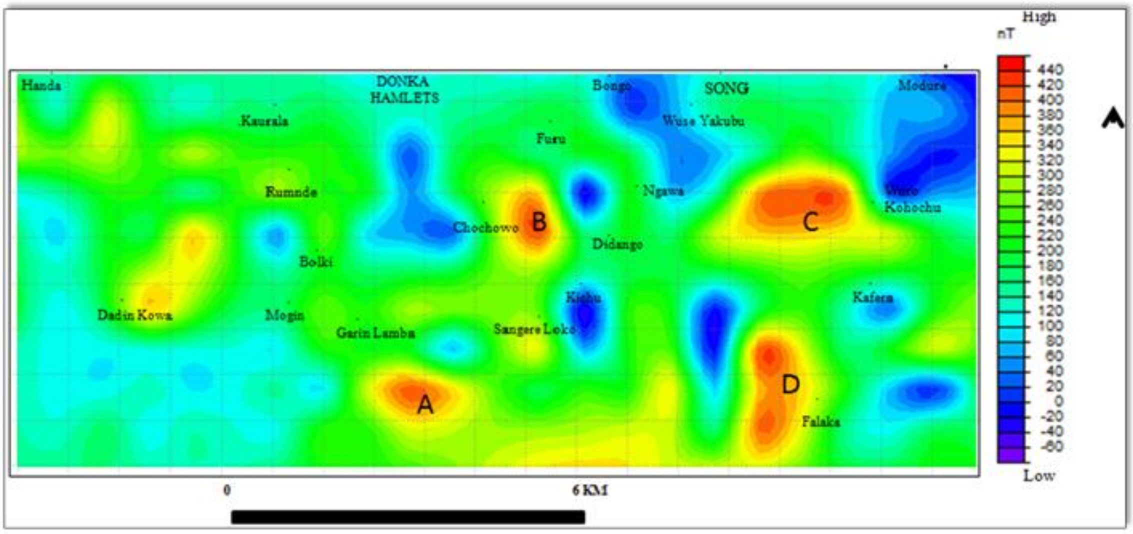

Figure 5: Residual Magnetic Map of the Study Area. (Cont. Int. 20nT)

5.2 Second vertical derivative

The second vertical derivative map as shown in Figure 6 narrows the width of the anomalies and showed areas of positive and negative anomalies that ranges from 188.8354 nT to 188.8394 nT. The magnetic highs coincide with the volcanic basic rocks that were actually exposed at the surface. The intermediate anomalies are probably the sub-volcanic basic rocks that lie at shallow depth due to slow cooling of the magma. The negative anomalies could be interpreted in terms of granites and / or gneiss.

A total of fourty five prominent trends were observed as shown in Table 2, and the major alignment of the second vertical derivative is the N-S anomalies. Minor alignments observed are NW-SE, E-W, and NE-SW. This is however congruent with the work of [11]. The Author concluded that the tectonic trends are NW-SE, NE-SW, N-S, and E-W and these have produced faults, shear zones, joints and folds.

5.3 Structural Analysis

The satellite image shows that most streams have straight channels and flow N-S, NW-SE, and NE-SW as shown in Figure 7. The drainage pattern is dendritic. The lineaments on the satellite imagery as shown in Figure 8 are more varied and concentrated over the granite and migmatite–gneiss complex than on the basaltic/basic rocks. The lineaments on the satellite map vary in lengths from 0.5 – 1.7 km and are oriented in NW-SE, NE-SW, NNW-SSE, ENE-WSW and NNE-SSW directions. Minor trends of lineaments are along E-W and N-S. The dominant and oldest trend in the study area as shown in Figure 9 is the NW-SE direction which is in the direction of Pan-African major direction for lineaments. The NW-SE lineaments are among the longest and invariably are of deep crustal origin ([17]). The E-W trend correlates with the axis of the Yola Arm, while the ENE-WSW trends correlates with the Adamawa trend which is also one of the Pan-African foliation trend. The northeastern portions are characterized by high lineaments intersection and are areas of basement intrusions.

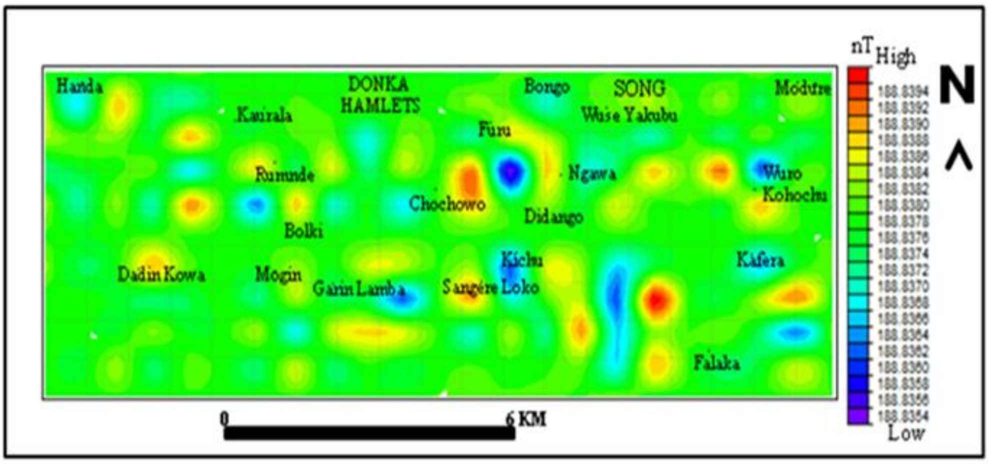

Figure 6: Second Vertical Derivative Map of the Study Area

Table 2: Magnetic Anomaly Trends obtained from Second Vertical Derivative Map

Trends	Number
N-S	28
E-W	13
NE-SW	2
NW-SE	2
TOTAL	45

N: North W: West S: South E: East

Figure 7: Satellite Image of the Study Area Showing the Drainage Network.([5]).

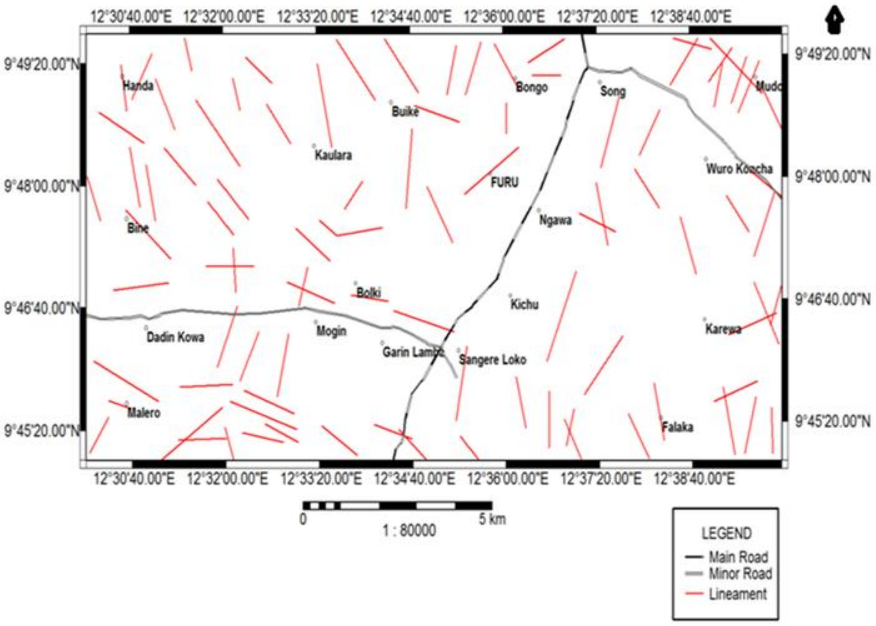

Figure 8*:* Satellite Lineament Map of the Study Area (Source:[5])

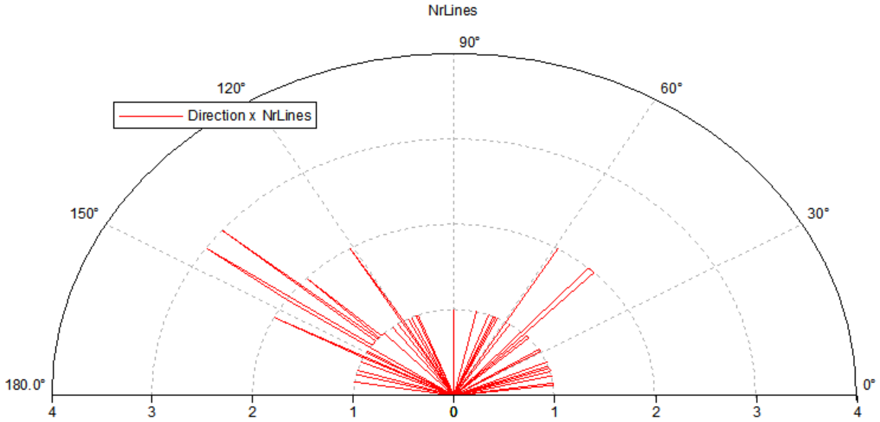

Figure 9: Rose plot of the structures within the area of interest showing major structures in the NW - SE direction, followed by NE-.SW direction.

5.5 2-D Model of Magnetic Profiles

The magnetic models and depth estimates were based on three profiles as shown in Figure 10, and involve the estimation of the overburden thickness to the top of the magnetic basement. The depth estimation of the basement in the area and identification of the rock boundaries was carried out using Winglink modeling method. The depth estimates indicates varied basement topography with depth ranging from 10 m to 400 m. The topography of the study area revealed that the basement consist of consolidated rocks. Profiles AA' and BB' trends in W-E direction and shows areas of magnetic highs. Profile CC' trends in SW-NE direction. The magnetic highs are suspected to be due to near surface magnetic minerals such as sub-volcanic basalt/basic rocks.

5.5.1 Profile AA'

Profile AA' was drawn perpendicular to the anomalies from W - E and cover a distance of 14000 m. The geological section model is shown in Figure 11. The magnetic strength plotted along this profile shows significant high maximum amplitude of up to 34400 nT with a minimum amplitude value of between 34050 – 34200 nT. The minimum amplitude of the graph coincides with gneiss of susceptibility of 0.1×10^3 S.I. units and the maximum amplitude matched the basalt/basic rocks with susceptibility of 25×10^3 S.I. units, while porphyritic granite has susceptibility of 2.5×10^3 S.I. units as seen in Table 1. Depth to sub-volcanic (basic) rocks from Winglink modeling range from about 270 m - 400 m..

5.5.2 Profile BB'

This profile passes through two areas of prominent magnetic anomalies. The profile was drawn perpendicular to the anomalies from W - E and cover a distance of 9000 m. The geological section model is shown in Figure 12. The magnetic strength plotted along this profile shows significant high maximum amplitude of up to 34500 nT with a minimum amplitude value of 34000 nT. The minimum amplitude of the graph coincides with gneiss of susceptibility of 0.1×10^3 S.I. units and the maximum amplitude matched the basalt/basic rocks with susceptibility of 25×10^3 S.I. units, while porphyritic granite with susceptibility of 2.5×10^3 S.I. units as seen in Table 1. Depth to sub-volcanic (basic) rocks from Winglink modeling range from about 10 m - 300 m.

5.5.3 Profile CC'

Profile CC' was drawn from SW - NE and cover a distance of 7000 m. The geological section model is shown in Figure 13. The magnetic strength plotted along this profile shows significant high maximum amplitude of up to 34400nT with a minimum amplitude value of about 34000nT. The minimum amplitude of the graph coincides with granites of susceptibility of 2.5×10^3 S.I. units and the maximum amplitude matched the basalt/basic rocks with susceptibility of 25×10^3 S.I. units. Depth to sub-volcanic (basic) rocks from Winglink modeling range from about 180 m - 350 m.

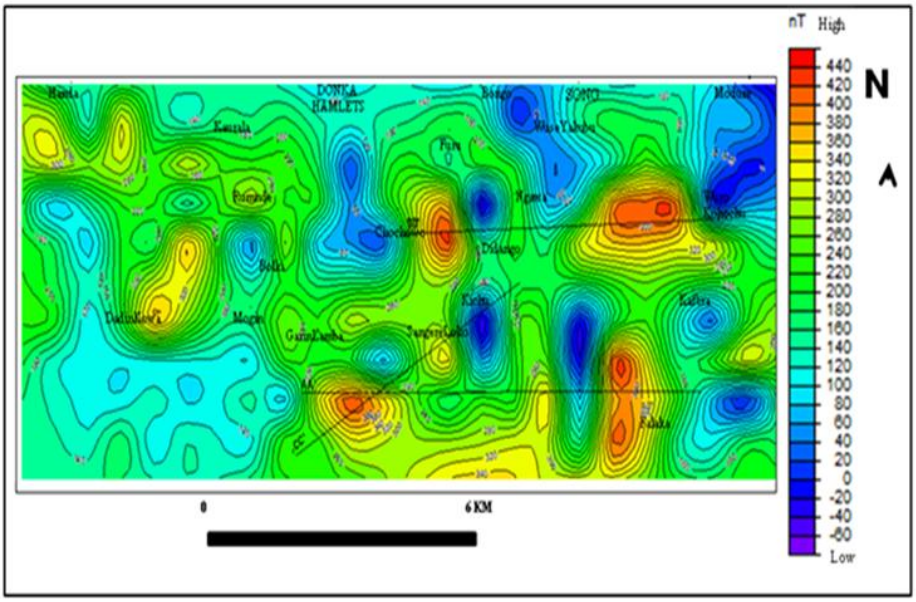

Figure10: Residual Magnetic Map showing profiles along (AA', BB' and CC'). (Cont. Int.20nT).

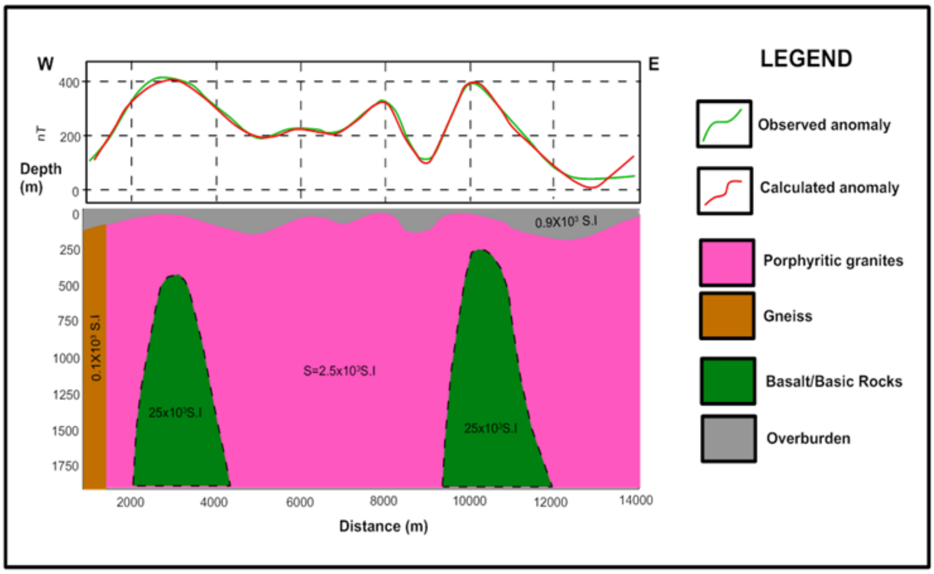

Figure11:2-D Residual Magnetic Anomaly Model for Profile AA'.

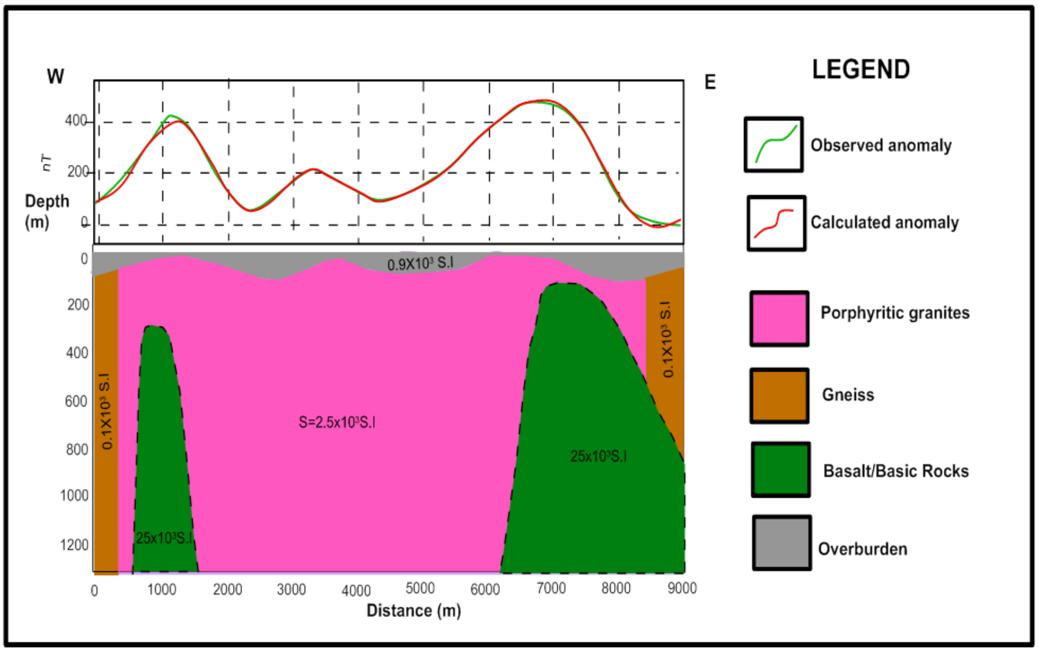

Figure12: 2-D Residual Magnetic Anomaly Model for Profile BB

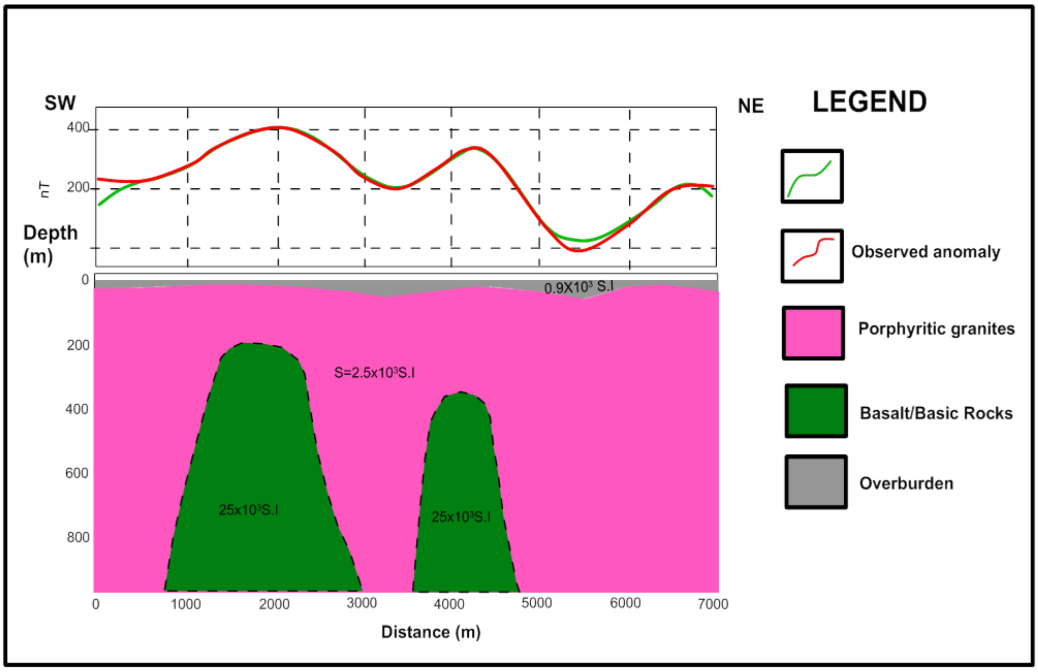

Figure 13:2-D Residual Magnetic Anomaly Model for Profile CC'.

VI. Summary and Conclusion:

The residual magnetic anomaly map, the 2-D model and field studies provides valuable information on the geology and structure of this part of Nigeria's basement complex that has been relatively understudied. Based on the results obtained from the qualitative and quantitative interpretation of ground magnetic data of SangereLoko and environs, Northeastern Nigeria, the main findings can be summarized as follows:

The residual magnetic anomaly map is characterized by high and low amplitude anomalies. The magnetic anomaly ranges from 34120nT to 34580nT. From the residual magnetic map of the study area, there are four major areas of positive residual magnetic anomalies resulting from sub-volcanic basic rocks these are found central to the study area. Areas of zero or low magnetic anomalies are interpreted in terms of the presence of granites and gneiss. They may also be due to susceptibility variations in lithology or both. The magnetic anomalies trend in the N-S, E-W and NW-SE directions which are consistent with the major structural trends in the basement. The E-W trending anomaly (south of the study area) is consistent with the structural orientation of the E-W Yola Trough.

The 2-D modeling results shows varied basement topography with depth to magnetic basement that ranges from 10 m to 400 m. The magnetic profiles show significant high maximum amplitude of up to 34500nT with a minimum amplitude value of about 34000nT. The major drainage channels in the study area are structurally controlled. Most streams (Mayo Dadachi, Mayo Borongo, and Mayo Kundu) have straight channels and flow N-S and NW-SE. By implication the emplacement trends of sub-volcanic rocks is closely related to the flow direction (N-S, NW-SE) of major streams of the area..The dominant and oldest trend in the study area is the NW-SE direction which is in the direction of Pre-Pan-African deformations in the area. The NW-SE lineaments are among the longest and invariably are of deep crustal origin.

The research work has been able to map and identify locations of sub-volcanic basic rocks for the first time in the area. The residual magnetic map is characterized by high and low amplitude anomalies. The lineaments in the study area are principally oriented in NW-SE, NE-SW, NNW-SSE, ENE-WSW and NNE-SSW directions. Minor trends of lineaments are along E-W and N-S. The E-W trending anomaly is consistent with the structural orientation of the E-W Yola arm while ENE-WSW trends correlates with the Adamawa trend which is also one of the Pan–African foliation trend. The dominant and oldest trend in the study area is the NW-SE direction which is in the direction of Pan-African major direction for lineaments. The northeastern portions of the study area are characterized by high lineaments intersection and are areas of basement intrusions. The depth estimates of the overburden thickness to the top of the magnetic rocks shows varied basement topography. The study confirms the presence of subterranean or subvolcanic basic rocks in the area, whose depths range from <1 m below the surface to about 100 m. The research work has provided a better understanding of the geology of the study area.

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