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Lineaments Mapping for Hydrogeological Study Using Aeromagnetic and Pseudogravity Data: A Case Study of Lafiagi, Southwestern Nigeria.

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Abstract

Lineaments mapping over a part of the transition environment between the Basement Complex rocks of the southwestern Nigeria and the Sedimentary rocks of the Nupe Basin was carried out. It was aimed at identification of the structural features responsible for the hydrogeology of the area. This work involved the qualitative and quantitative analysis of aeromagnetic and pseudo-gravity data using Oasis Montaj^{TM} and the geological data using Rockwork15^{TM} software. The 2-D Forward modeling and inversion of the acquired aero-magnetic and pseudo-gravity data augmented with geological information obtained from reliable sources were employed in the lineaments extraction and interpretation works. The results have shown that the identified faults and lineament features obtained from geophysical data generally coincide with the river channels on the geologic and drainage maps which indicate a structural control of the drainage system in the study area. The rose diagram of the extracted faults and lineament features showed a preponderance of NE/SW trend followed by NW-SE and N-S trends.

Key words: Basement, Sedimentary, Faults, Lineaments, Forward Modeling and Inversion.

1.0 INTRODUCTION

The dynamic and hidden nature of groundwater often impedes the understanding and management of this vital resource. An initial step toward sustainable groundwater-resource management involves understanding the hydrogeologic nature and mechanics of the resource (Denny *et al.,* 2007). Since the past few decades, several methods of faults/ lineaments analysis have evolved. For example, (Euler deconvolution [Reid *et al*. 1990, FitzGerald *et al*. 2004]; 2D Forward modeling and inversion [Talwani *et al*. 1959 and Talwani and Heirtzler 1964] amongst others).

In this paper is presented the 2-D Forward modeling and inversion of the acquired aero-magnetic and pseudo-gravity data in a part of Lafiagi, Southwestern Nigeria. The hydrogeological implication of the mapped fault/ lineaments and their correlation with structurally controlled drainage and aquifers within the study area are discussed. It is anticipated that the simplicity of this approach will support the application of this methodology in other study areas with similar characteristics.

1.1 Study Area

The study area covers a part of Lafiagi (Sheet 203) in the Nigerian topographical map. A Sheet comprises of ½ degree by ½ degree contour map on a scale of 1:100,000. It is situated at the transition environment between the Nupe Basin and the Southwestern Nigerian Basement Complex (Fig. 1). It is bounded by latitudes $8^{\circ}40'$ and $8^{\circ}51'$ N and longitude $5^{\circ}00'$ and $5^{\circ}23'$ E, covering an area of 896.6 km^2. Guinea savannah type vegetation with two distinct seasons (rainy and dry) is found in the study area. A mean annual temperature of $29^{\circ}\mathrm{C}$ and mean annual rainfall of 300mm has been reported by Udo (1982).

The Nupe Basin is a NW-SE trending embayment perpendicular to the main axis of the Benue Trough and the Niger Delta Basin of Nigeria. The sedimentary rock is flanked by both the Basement Complex rocks of Southwestern and Northcentral Nigeria.

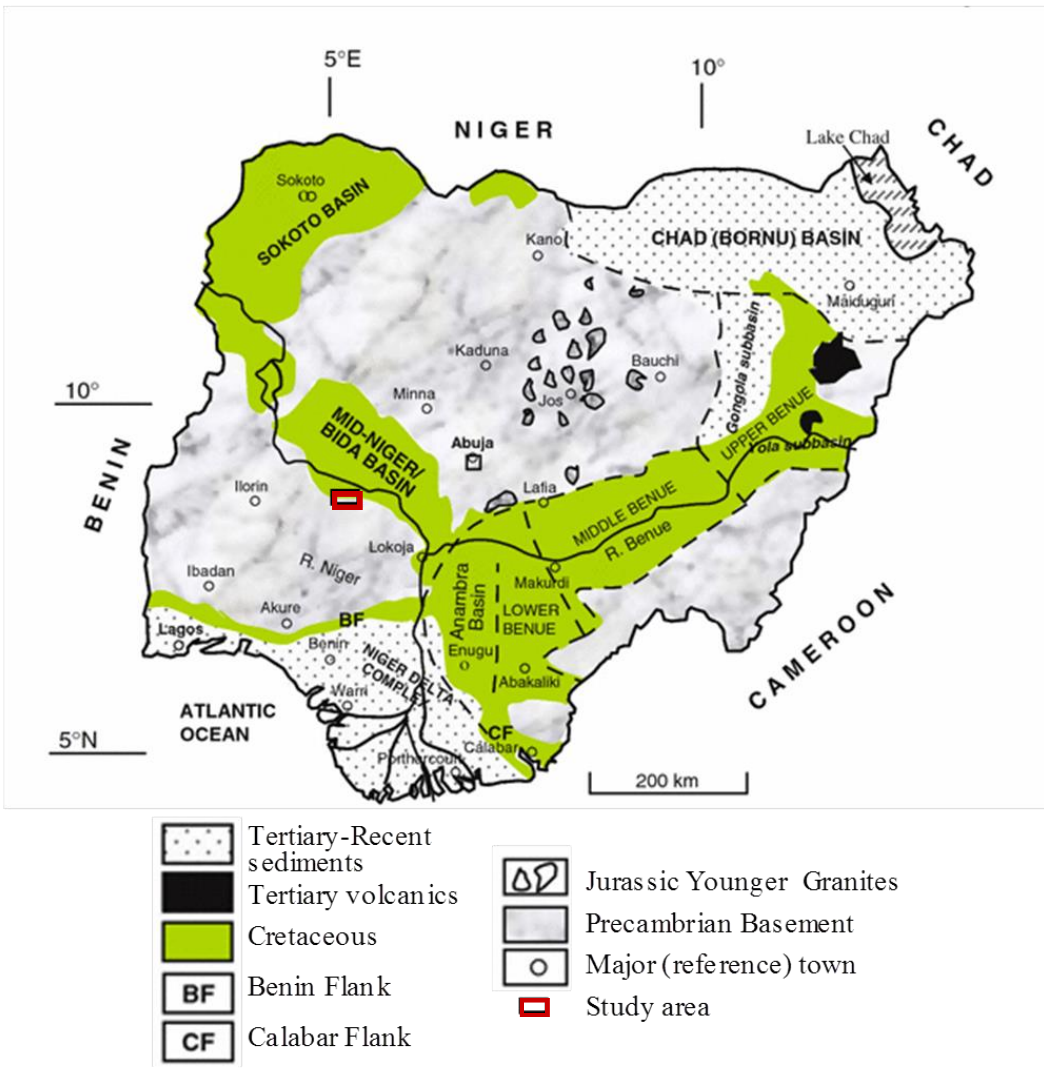


Fig. 1: Geological Sketch Map of Nigeria Showing the Major Geological Components (Basement, Younger Granites and Sedimentary Basins) and the Study Area (Adapted from Obaje, 2009).

The Nigerian Basement Complex lies at the reactivated part (i.e. internal region) of the Pan-African belt following the plate tectonic processes which involved the collision between the passive continental margins of the West African craton and the active continental margin (Pharusian belt) of the Tuareg shield about 600 Ma ago (Leblanc, 1981 and Black *et al*., 1979). The Pan African in Nigeria was followed by conjugate strike slip fault systems which average in the NE-SW and NW-SE direction and which show dextral and sinistral sense of displacement which cut across the earlier Pan African structures (Ball, 1980). The Basement Complex rocks in the study area (Fig. 2) include granites, biotite gneiss, amphibolite, pegmatite, quartz schist and mica schist while the Sedimentary rocks consist of Upper Cretaceous sediments (sandstone, ironstone and siltstone) which are believed to be between 300 to 1000 m thick (Adeleye, 1973).

1.2 Structural Geology and Hydrogeology

Lineaments are major topographic features or geologic structures that could be of regional extent usually in linear or curvilinear continuous or discontinuous over an entire length (Megwara and Udensi, 2013). The Nupe basin has been confirmed to be bounded by a system of linear faults trending NW-SE, using geophysical data (Kogbe *et al*., 1983). Udensi *et al*. (2003) has revealed the presence of lineaments within the Bida basin. In the Crystalline Basement Complex rocks of Nigeria, groundwater occurs either in the weathered mantle or in the joint and fracture systems in the un-weathered rocks (Ako and Olorunfemi, 1989 and Olayinka and Olorunfemi 1992). The highest groundwater yield in the basement terrains is found in areas where thick overburden overlies fractured zones (Olorunfemi and Fasuyi, 1993). However, the aquiferous zones in the sedimentary environments are primarily found within the Nupe Sandstone Group in the Northern and Central parts of the Edu and Pategi LGA (Bello and Makinde, 2007).

2.0 MATERIALS AND METHODS

2.1 Data Source and Analysis

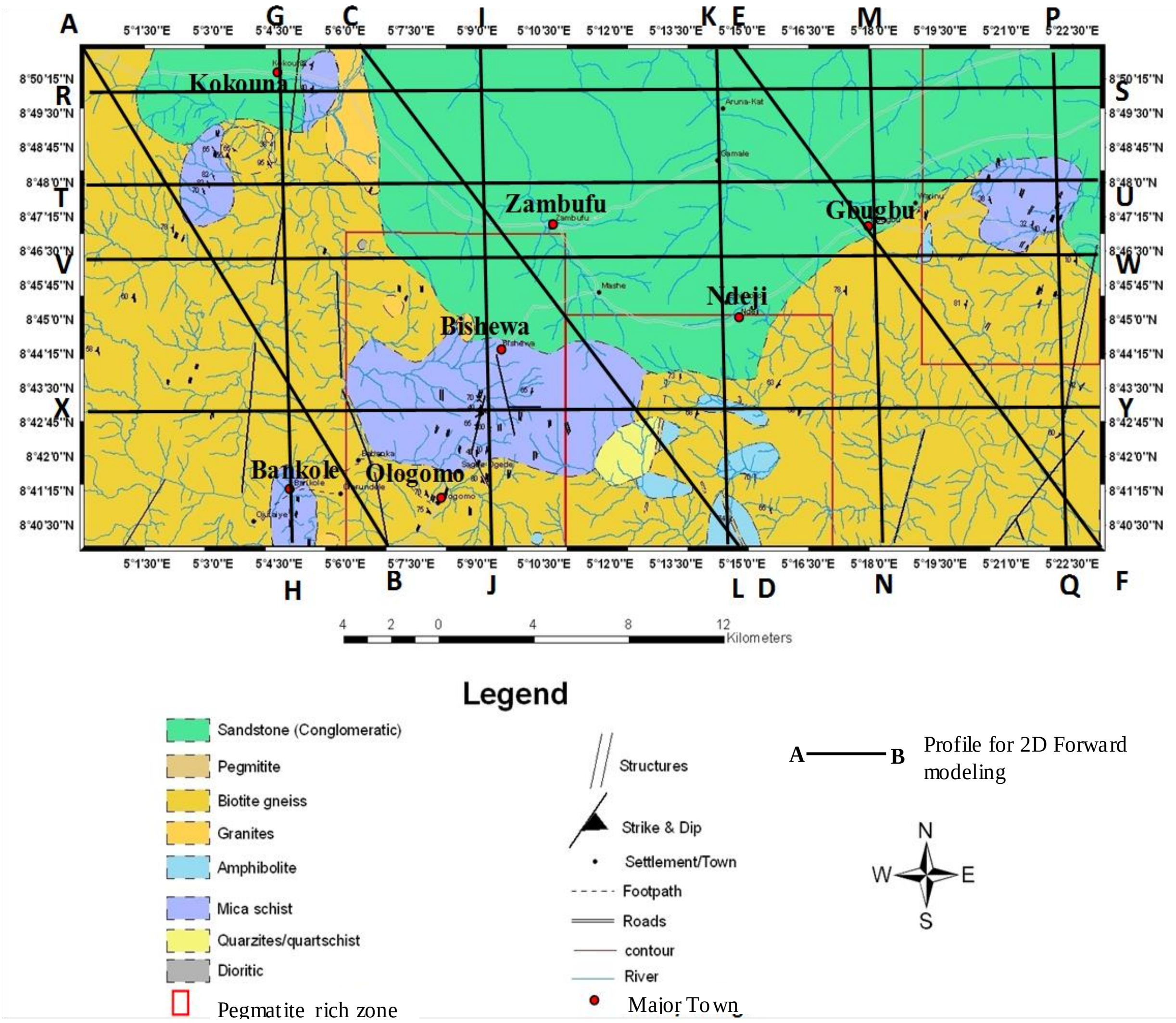
A digitized aeromagnetic data (i.e. Lafiagi aeromagnetic grid map, Sheet 203), was procured from the Nigeria Geological Survey Agency (NGSA), Abuja, Nigeria. The survey which was aimed at mineral and ground water development through improved geological mapping was collected at Flight Height of 80 m, Flight line spacing of 500 m, and Tie line spacing of 2000 m. The Flight Line direction was NW - SE whereas the Tie Lines were NE - SW. For ease of processing, the data was stripped of a common value of 32,000 nT. This value may therefore be added to every data point to get the exact regional field. However, doing this will not change the Grid in any way since the value is common to all the data points.

Data collection for this area was done in 2006, so a 2005 epoch International Geomagnetic Reference Field (IGRF) was used to calculate Inclination and Declination as follows:

Field Strength = 33129.9632nT; Inclination = -6.87339275; Declination = -2.51357917.

Figure 3 is the Total Magnetic Intensity (TMI) map of the study area. The map emphasizes the intensities and the wavelengths of the local anomalies that reveal information on the geometry, strike, contacts between rocks and intensities of magnetization within the study area. Several anomalies can be referred to distinct magnetic zones.

The fact that ground gravity data could not be acquired at the same grid spacing as the aeromagnetic data (100 m) supplied by the Nigerian Geological Survey Agency (NGSA), especially the accuracy and precision demanded in the contract for this particular data which was aimed at mineral



Fig, 2: Geological Map of the Study Area (Adapted from Garba, 2011).

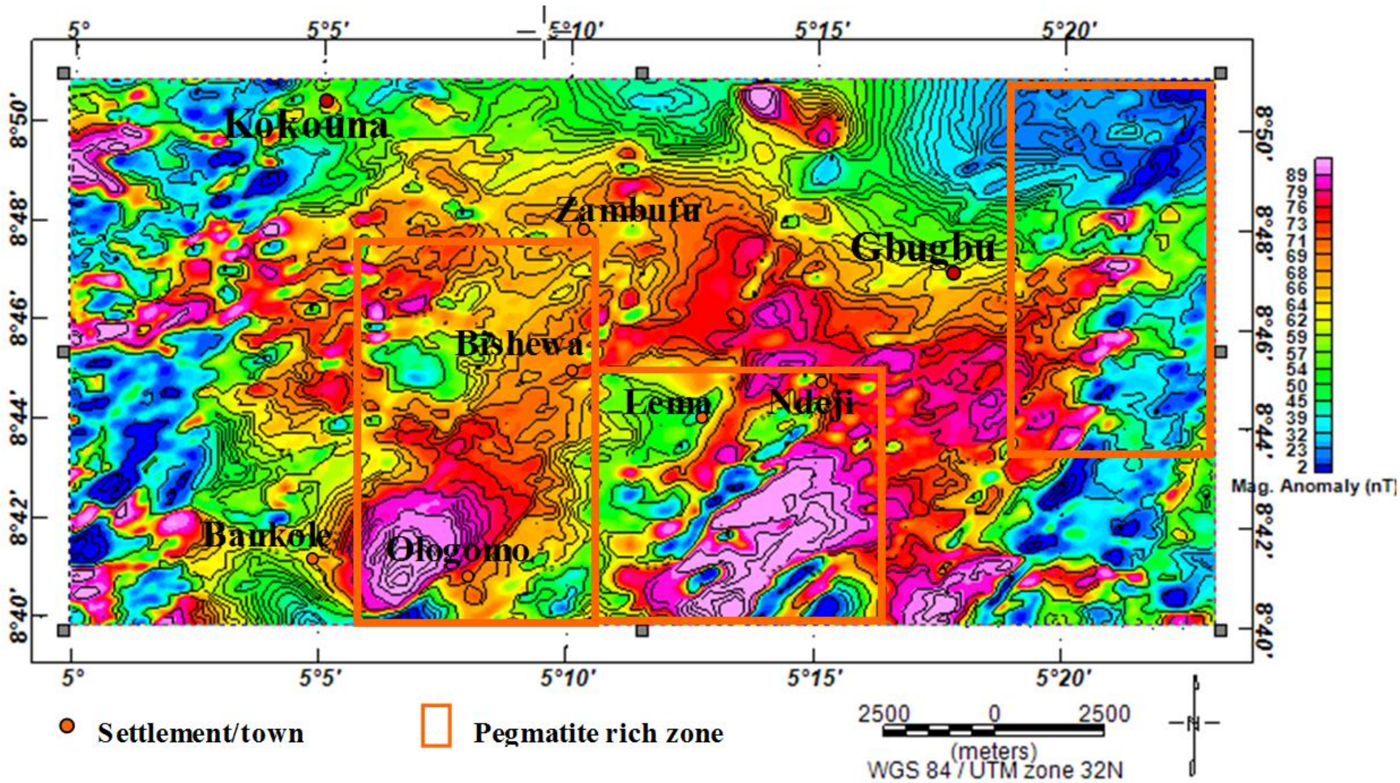


Fig. 3: Superimposition of Total Field Aeromagnetic Map (TMI) and its Contour

exploration in Nigeria and the issue of aliasing which normally arise as a result of large data spacing, the best alternative for gravity map in this work was the pseudogravity map generated properly from the aeromagnetic data using the MAGMAP subroutine programme of Oasis montaj^{TM} software. The transformation of magnetic field anomalies (Fig. 4a) into pseudogravity anomalies (Fig. 4b) is made possible by the Poisson's relationship between gravity and magnetic fields, assuming a common source (Schnestler and Taylor, 1984; Roest and Pilkington, 1993).

2.2 2D Forward Modeling and Inversion of the Aeromagnetic and Gravity Data

To quantitatively interpret the magnetic and pseudo-gravity data (Figs. 4a and b), the GM-SYS profile of Oasis montaj software was used. The GM-SYS profile is a program for calculating the gravity and magnetic response from a geologic cross-section model. Forward modeling involves creating a hypothetical geologic model and calculating the geophysical response to that earth model while inversion, optimization or inverse modeling involves the reverse procedure. Starting with the observed geophysical response, an earth model that will provide the best fit to that data is calculated. Because gravity and magnetic calculations are non-linear, the calculations use an iterative process. Two-Dimensional (2-D) models assume the earth is two-dimensional; i.e. it changes with depth (the Z direction) and in the direction of the profile (X direction; perpendicular to strike). 2-D models do not change in the strike direction

(Y direction). The a priori information obtained from geologic map, and the magnetic and pseudo-gravity data were used in GM-SYS profile of Oasis montaj software for the 2D forward modeling and inversion of the aeromagnetic and pseudo-gravity data (Fig. 4). The profiles in Fig. 2 (AB - XY) were also chosen on the magnetic and pseudo-gravity maps and were subsequently interactively employed in the 2-D forward and inversion, optimization, or inverse modeling.

The aeromagnetic and gravity anomalies are trending mainly in the NE-SW and N-S directions with occasional NW-SE (e.g. around Bankole) direction. The first three profiles in Fig. 2 (AB, CD and EF) were therefore chosen perpendicular to the strike for maximum information on the causative structures and the geology of the area while other profiles (GH – XY) were chosen to cut across the two main lithologies (i.e. Basement and Sedimentary) and suspected structures.

2.3 Theoretical Basis for 2D Forward Modeling and Inversion of the Aeromagnetic and Gravity Data

The 2D Forward modeling and inversion methods used to calculate the gravity and magnetic model response are based on the methods of Talwani *et al*. (1959) and Talwani and Heirtzler (1964), and make use of the algorithms described by Won and Bevis (1987). Two-and-a-half dimensional calculations are based on Rasmussen and Pedersen (1979). The GM-SYS inversion routine utilizes a Marguardt inversion algorithm (Marguardt, 1963) and the USGS computer program, SAKI (Webring, 1985) to linearize and invert the calculations (Tom *et al.,* 2009).

3.0 RESULTS AND DISCUSSIONS

3.1 Pattern Interpretation of the Aeromagnetic and Gravity Data

The aeromagnetic and pseudogravity anomalies maps (Figs. 4a and b) have been divided into four distinct zones and subzones of various magnetic and gravimetric characteristics. These include:

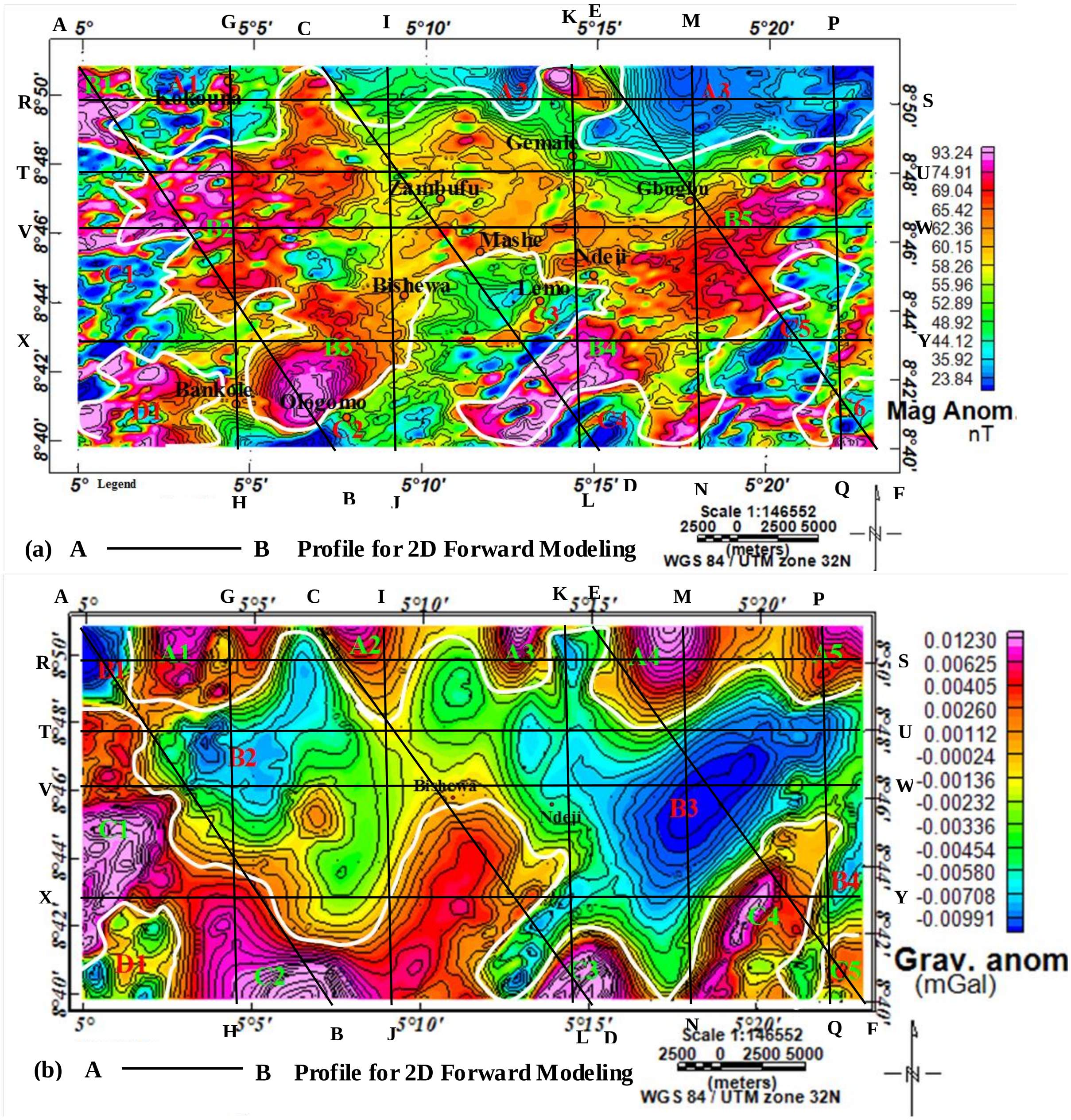


Fig. 4: (a) Total Field Aeromagnetic Map (REDE) and its Contour

(b) Pseudogravity Map and its Contour

(i) Zone A which is characterized by low to intermediate magnetic relieves (i.e. subzones A1`to A3; Fig. 4a) with corresponding high density relieves (i.e. subzones A1 to A5; Fig. 4b) in the Northern part of the study area. The anomalies in this zone have amplitudes varying mostly from < 23 nT to 58 nT and -00136 to 0.01230 mGal for magnetic and gravity data respectively.

(ii) Zone B is characterized by anomalies with broad and wide extent having moderately high to very high and occasional low magnetic relieves (i.e. subzones B1 - B5; Fig. 4a) with corresponding low density relieves (i.e. subzones B1 – B4; Fig. 4b) in the central part of the study area. The NW-SE and NE-SW shown by these anomalies are characteristic of lineament features. These anomalies have amplitudes that vary mostly from < 52 to > 93 nT and from < -0.00991 mGal to approx. 0.00112 mGal for magnetic and gravity data respectively. The rocks here include: Cretaceous sediments, Biotite gneiss, Mica schist, Quartzite/Quartz schist and Amphibolite.

(iii) Zone C is characterized by ring strake and speckled mixture of high and low magnetic relieves (i.e. subzones C1- C6; Fig. 4a) with corresponding moderately high to very high gravity relieves with mostly concentric patterns (i.e. subzones C1- C5; Fig. 4b). These anomalies have amplitudes of < 23 to > 93 nT and approx. -0.00336 to > 0.01230 mGal for the magnetic and gravity data respectively. This zone is associated on the geological map with Biotite gneiss, Mica schist and Amphibolite.

(iv) Zone D is characterized by a relatively low to intermediate magnetic (Fig. 4a) and gravity (Fig. 4b) relieves that are wedged to

the extreme corner of the south-western part of the study area (D1). The amplitudes range from approximately 35 to 52 nT (magnetic) and -00136 to -00580 mGal (gravity).

3.2 Superimposition of Inferred Fault/Lineaments Obtained from 2D Forward Modeling on Drainage Map

Figures 5 and 6 show typical aeromagnetic and pseudogravity anomalies profiles and their corresponding earth models generated from the GM-SYS profile of Oasis montaj™ software used. The inferred fault/lineaments occur at the inflection points (e.g. I, S2 and W2 in Fig. 5) which correlate with the change in density of the rock formations, weak points associated with reworking or reactivation of the earlier Pan African structures, the boundary between sedimentary and Basement Complex rocks etc. These fault/lineaments were picked along the various profiles and posted on the drainage map, and the direction of the corresponding river channel was inferred as the lineament direction (Fig. 7). The inferred fault/lineaments obtained from 2D Forward Modeling coincide with the river channels, confirming the fact that the drainage in the study area is structurally controlled (Garba, 2011). The groundwater flow in fractured bedrock aquifers is predominantly through fractures, with large-scale fracture zones and faults acting as conduits for flow at the regional scale (Denny *et al.,* 2007). Figure 8 is the rose plot of fault/lineaments features showing the preponderance of the NE-SW trend, followed by the NW-SE and N-S trends thereby confirming the fact that the Pan African in Nigeria was followed by conjugate strike slip fault systems which averaged in the NE-SW and NW-SE directions and showed dextral (e.g. Q in Fig. 7) and sinistral sense of displacement which cut across the earlier Pan African structures (Ball, 1980).

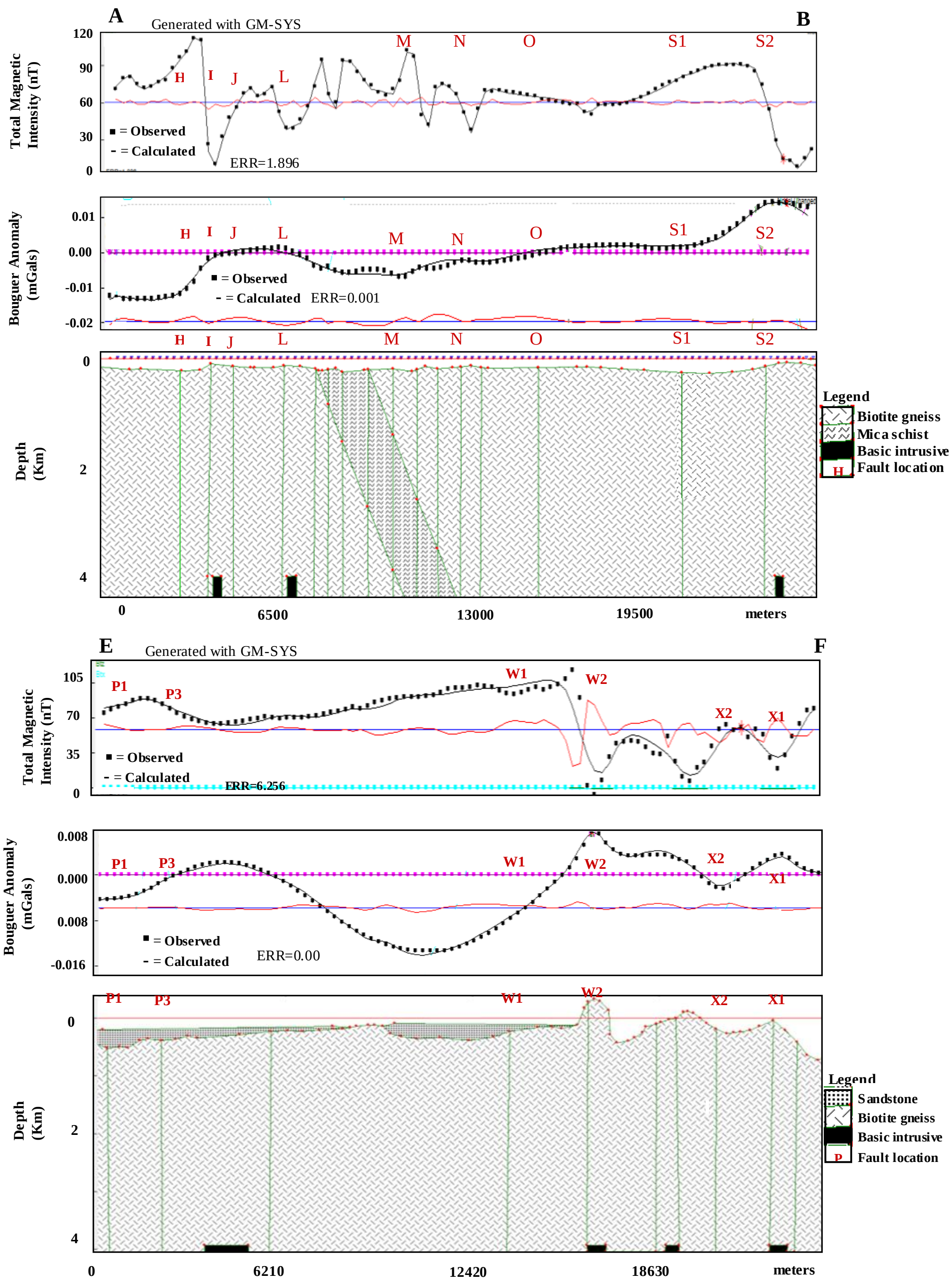


Fig. 5: A Typical Aero-Magnetic, Pseudo-Gravity Anomalies and their Corresponding Earth Model along Profiles AB (top) and EF (bottom).

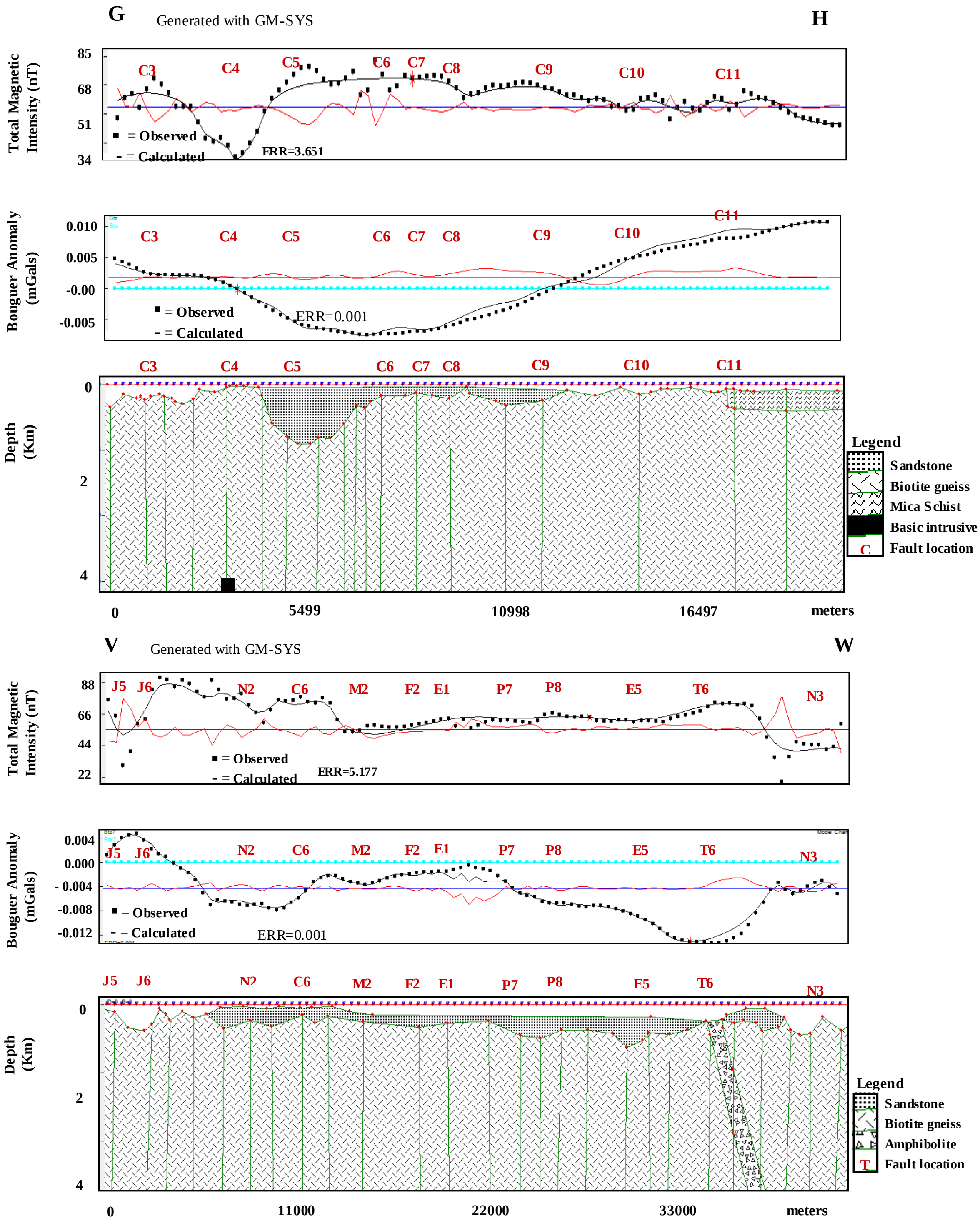


Fig. 6: A Typical Aero-Magnetic, Pseudo-Gravity Anomalies and their Corresponding Earth Model along Profiles GH (top) and VW (bottom).

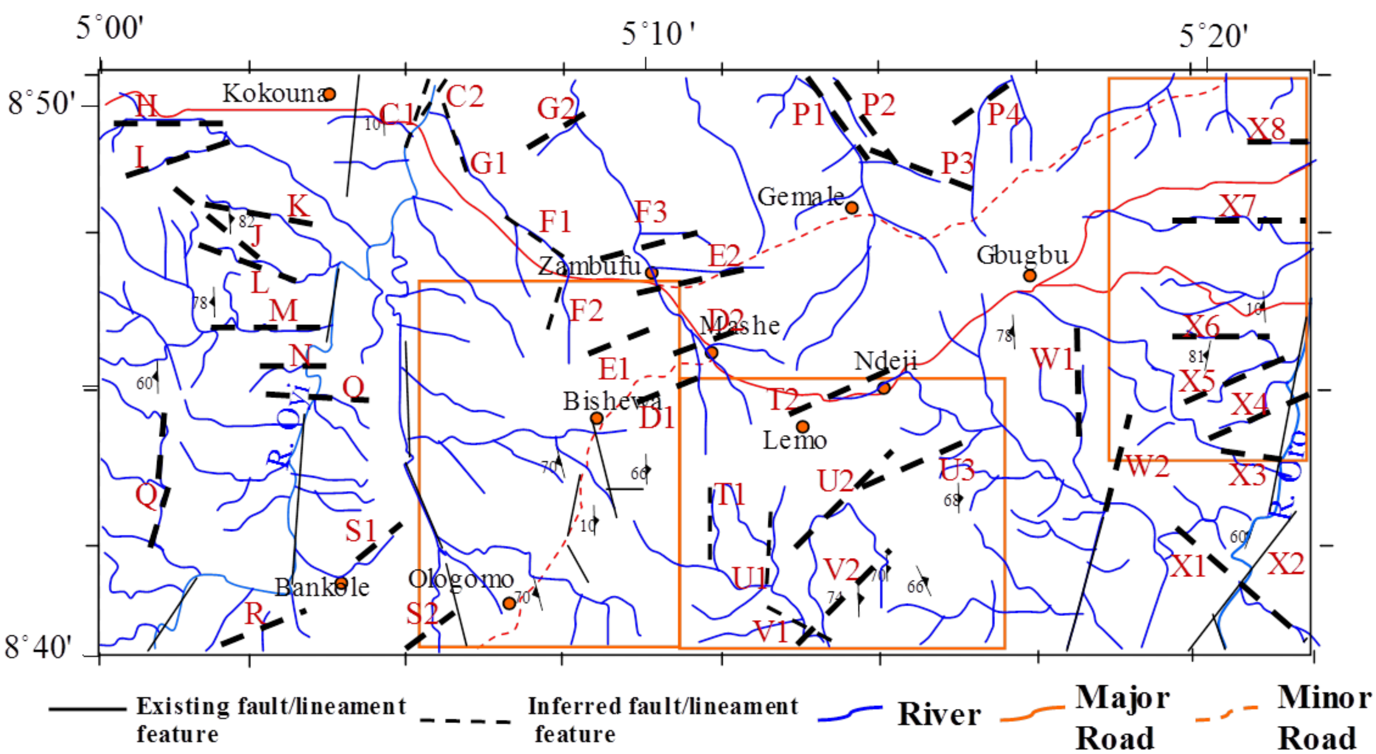


Fig. 7: Superimposition of Inferred Fault/Lineaments Obtained from 2D Forward Modeling on Drainage Map.

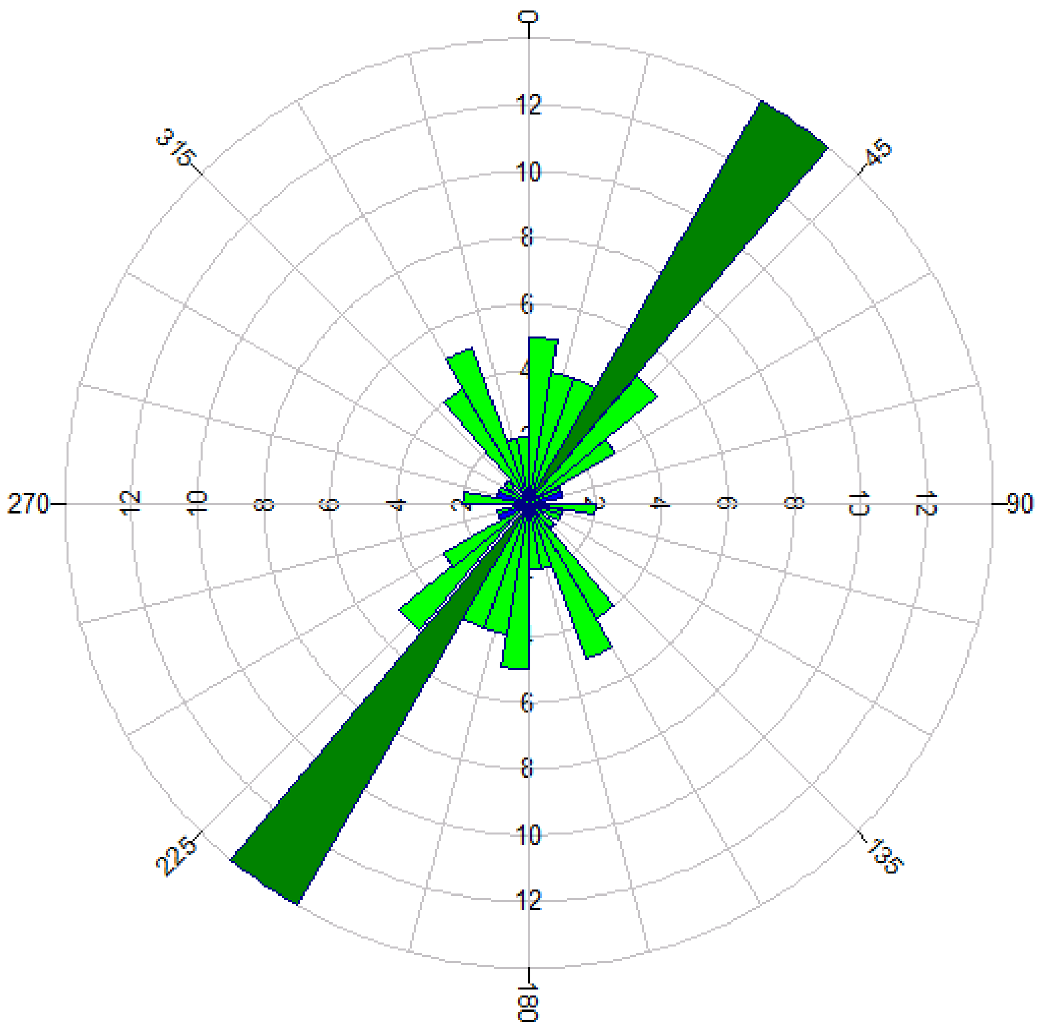


Fig. 8: Rose Plot of Faults/ Lineaments Features in the Study Area.

4.0 CONCLUSIONS

This research has evaluated the lineament structures within the Lafiagi Study area using geological, aeromagnetic and gravity data. The newly mapped lineament features from geophysical data as well as the existing ones from geologic map (e.g. Figs. 2 and 7) generally coincide with the river channels on the drainage map which indicate a structural control of the drainage system in the study area. These set of structures which might have resulted from the reactivation or reworking of the crystalline basement complex region of West- African craton after the Pan-African orogeny (Black *et al*., 1979 and Leblanc, 1981) are generally oriented in the NE-SW or NW-SE directions (Fig. 7) and correlate with the general geologic strike, corroborating the fact that the Pan African in Nigeria was followed by conjugate strike slip fault systems which averaged in the NE-SW and NW-SE directions and showed dextral and sinistral sense of displacement which cut across the earlier Pan African structures (Ball, 1980).

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