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Mapping of Lineament Structures using Potential Fields Data in Lafiagi Area, Central Nigeria.

Olawuyi*, A. K.

Department of Geophysics, University of Ilorin, Nigeria.

Abstract

An evaluation of the lineament features 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 tectonics and hydrogeology of the area. The work involved the qualitative and quantitative analysis of aeromagnetic data and pseudogravity transforms using Oasis Montaj^{TM}. The 3-D Euler Deconvolution results from acquired potential fields data, augmented with geologic information were employed in the lineaments extraction and interpretation work. The results have shown that the mapped lineament features 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 Euler solutions'-based lineament features and that of the local geology showed a predominance of NE-SW and N-S trends respectively, typical of the post-Pan African lineaments.

Key words: Faults, Lineaments, Basement, Sedimentary, hydrogeology and Euler Deconvolution.

1. Introduction

In the last few decades, several methods of Faults/ lineaments study have evolved. For example, Euler deconvolution [Reid *et al.*, 1990]; 2-D Forward modeling and inversion [Talwani *et al*. 1959, Talwani and Heirtzler 1964] amongst others. The use of Euler Deconvolution as an interpretation tool to determine source location of potential field anomalies is well established (Mushayandebvu *et al.*, 2004). An automated method to eliminate poorly constrained solutions (Fairhead *et al.*, 1994); the estimation of the structural index (Barbosa, *et al.*, 1999) amongst others, represent recent improvements in the technique. The geology of the Nupe Basin around Lafiagi study area is characterized by the mainly Santonian to Maestrichtian sediments of sandstones, siltstones and superficial alluvial deposits (Adeleye, 1976).

*Corresponding Author: Olawuyi, A. K.
Email: gideonola2001@yahoo.com

Borehole log reports show that primary porous and permeable formations of the Nupe Sandstones Group predominate the northern and central parts of the study area. The lithology of these formations, according to Mallam and Ajayi (2000), are alluvium, weathered laterite, sandy clay and clayey sand. The southern part of this Basin is characterized by formations with secondary permeabilities with the following lithologies: weathered laterite, sandy clay/ clayey sand, fractured basement and fresh basement rocks. Generally the rock units in this region are known to be highly characterized by intercalations of claystone, siltstone, silt, clay and weathered bedrock. These geological materials are usually liable to act as an aquitard or aquifer zone in the sedimentary terrain and the crystalline basement complex existing in this area.

In areas underlain by crystalline rocks, presence of structures like fractures, fissures, veins, joints and such other structural deformations of the basement complex control the flow of groundwater and also influence the rate of recharge and discharge of the main aquiferous units. There is the existence of minor fractures with approximately NW-SE trends which intrude the basement complex rock in the southern part of the study area and create relatively thick highly weathered overburdens (Bello and Makinde, 2009).

According to Argialas *et al.* (2003), 'Geologic lineaments mapping is considered as a very important issue for problem solving in engineering, especially, in site selection for construction (dams, bridges, roads, etc), mineral exploration, hot spring detection, hydrogeological research, etc'. Clark (1985) opinned that, 'The occurrence of groundwater in fissure systems or weathered zones means that the resources at any one site are finite and relatively small. Well yields similarly are limited, rarely exceeding 500 m^3 per day. In this situation the groundwater is strucurally controlled and, therefore, susceptible to investigation by a variety of techniques including photogeology and geophysics'. Other workers who have mapped lineaments using geophysical approaches include: Opara *et al.*, 2015 and Owona Angue *et al.,* 2016.

Africa has high rainfall variability, with highest variability occuring in the wettest months. The relationship between climate and shallow groundwater resources in Africa remains poorly defined (Taylor *et al*, 2009); however, it is obvious that in areas where the drainage is structurally controlled, the faults and fracture zones will act as conduits for flow and groundwater sustainability is more likely endangered.

This paper presents the 3-D Euler Deconvolution of the acquired aeromagnetic and pseudogravity data in a part of Lafiagi, central Nigeria. The emphasis is on the trends and hydrogeological implication of the mapped lineaments (faults) and their correlation with structurally controlled drainage and aquifers within the study area.

1.1 Study Area

The study area covers a part of Lafiagi (Sheet 203) in the Nigerian topographical map. It is situated at the transition environment between the Nupe Basin and the Southwestern Nigerian Basement Complex (Figure 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. 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 basin is flanked by the Basement Complex rocks of Southwestern and Northcentral Nigeria (Olawuyi, 2015 and Olawuyi *et al.*, 2015).

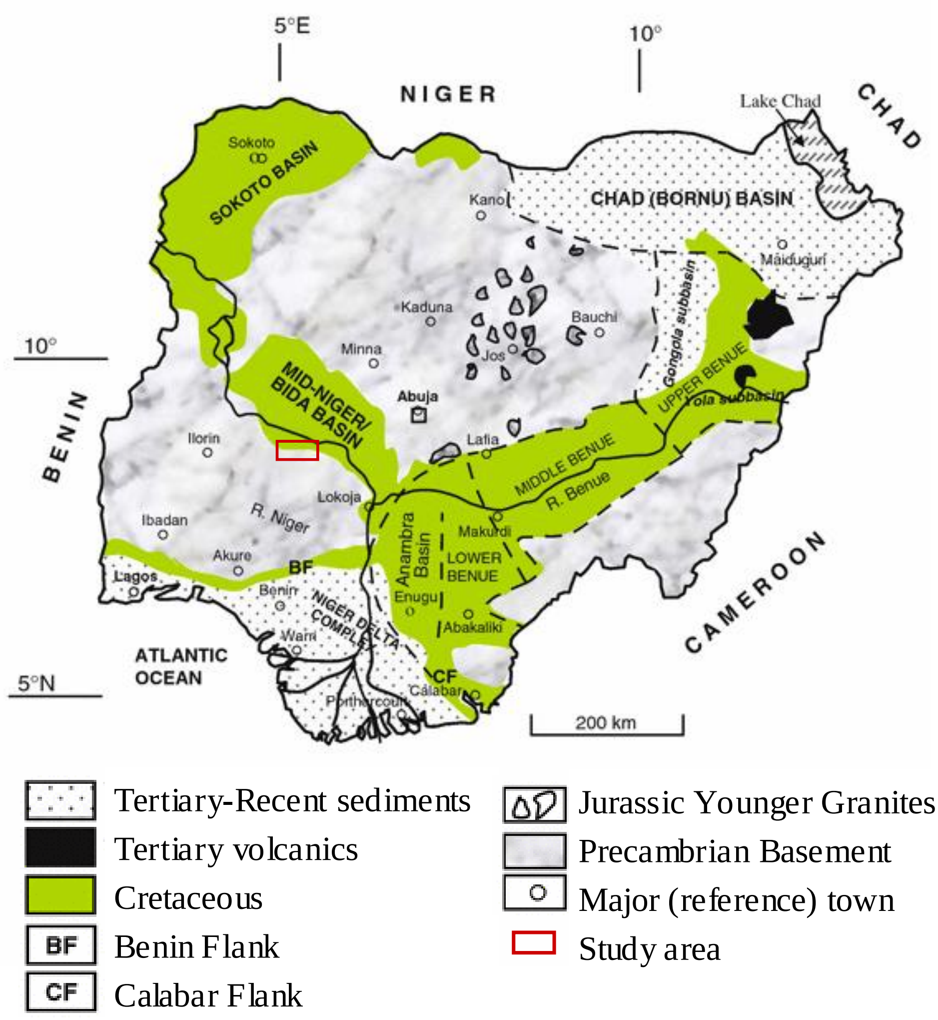


Figure 1: The Geological Sketch Map of Nigeria Showing the Major Geological Components (Basement, Younger Granites and Sedimentary Basins) and the Study Area (Adapted from Obaje, 2009).

The Nigerian Basement (Figure 1) was affected by 600Ma Pan-African orogeny and it occupies the reactivated regions which resulted from plate collision between the passive continental margins of the West African craton and the active Pharusian continental margin. The effects of Pan African orogeny in Nigeria include the conjugate strike slip fault systems which trend in the NE-SW and NW-SE directions, which show dextral and sinistral sense of displacement, and which cut across the earlier Pan African structures (Ball, 1980). The Basement Complex rocks in the study area (Figure 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). The known pegmatite-rich zones are demarcated with red rectangles within the study area (Olawuyi, 2015).

1.2 Structural Geology and Hydrogeology

Lineaments may result from faults, joints, folds, contacts or other geological reasons, and are found in igneous, sedimentary and metamorphic rocks. Lineament-mineral association is possible through the process of mineralization (Megwara and Udensi, 2014). The bedrock at the southcentral part of Nupe Basin is highly faulted: two sets of faults trending in a northwest – southeast and northeast – southwest direction (Idornighie and Olorunfemi, 1992). In the Crystalline Basement Complex rocks of Nigeria, groundwater occurs either in the weathered zone or in the joint and fracture systems in the un-weathered rocks (Ako and Olorunfemi, 1989).

2. Materials and Methods

2.1 Data Source and Analysis

The 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 reduced 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 (Olawuyi, 2015 and Olawuyi *et al.*, 2015).

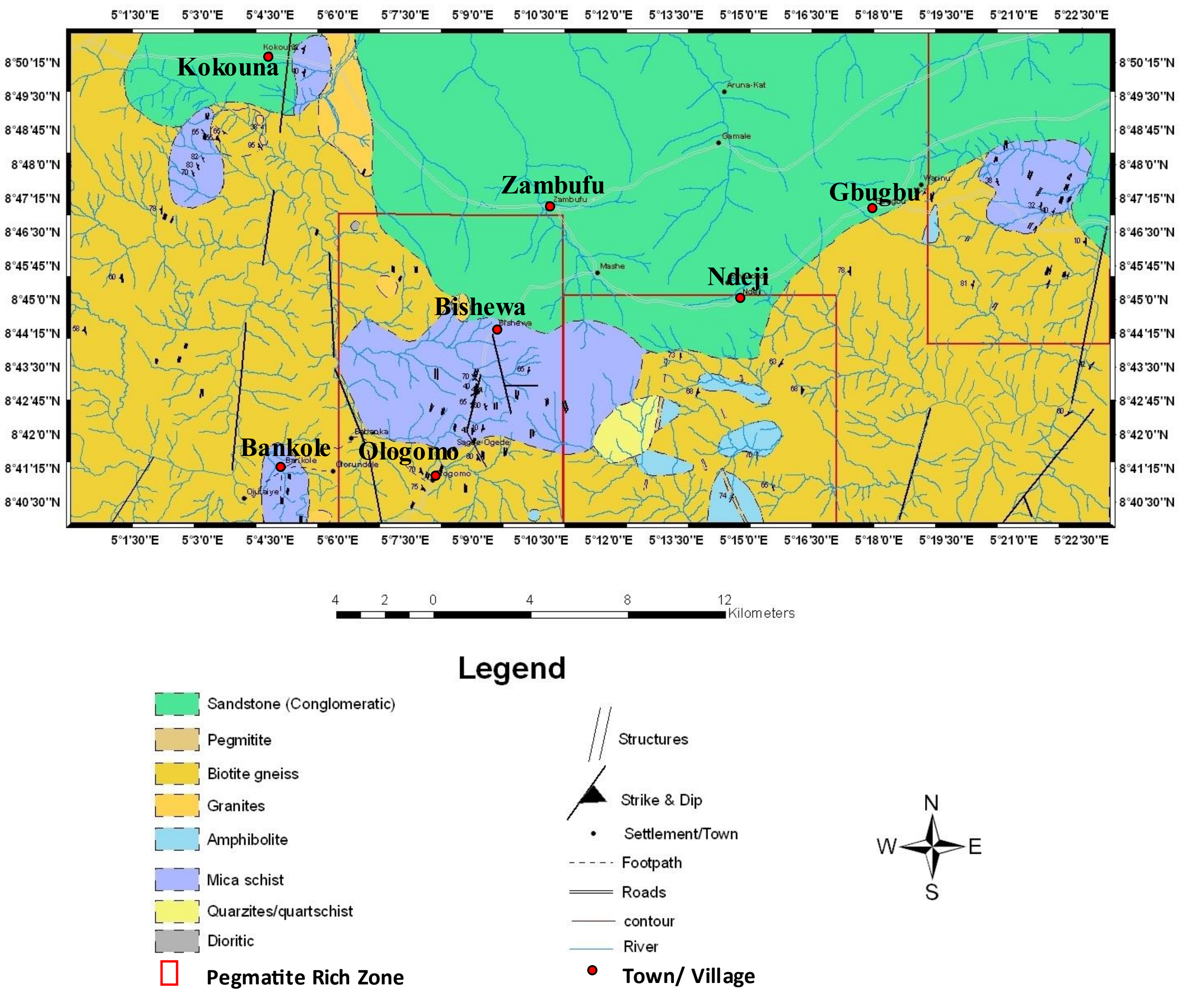


Figure 2: Geological Map of the Study Area (Adapted from Garba, 2011).

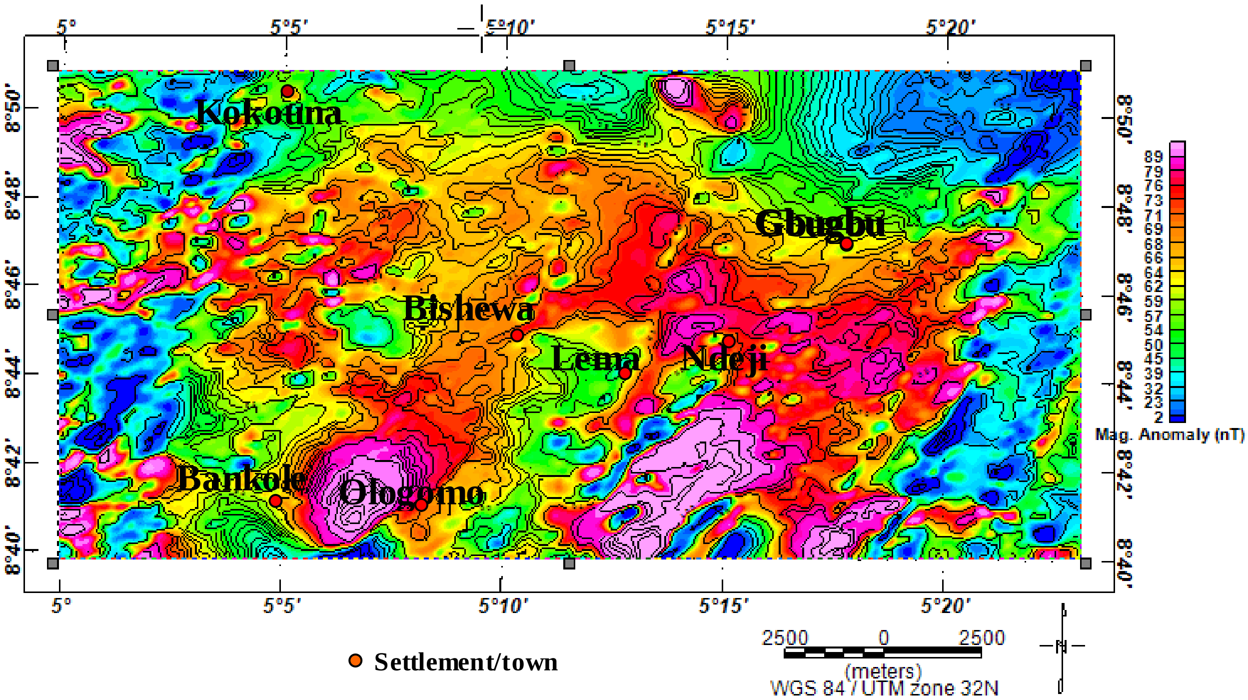


Figure 3: Superimposition of Total Field Aeromagnetic Map (TMI) on its Contour Map (Adapted from Olawuyi, 2015).

2.2 The 3D Euler Deconvolution Method:

The 3D Euler deconvolution technique is an equivalent method based on the Euler's homogeneity equation as developed by Reid *et al.* (1990) following Thompson's (1973) suggestion and operating on gridded magnetic data. The method is based on the concept that anomalous magnetic fields of localized structures are homogeneous and, therefore, satisfy Euler's homogeneity equation. The method operates on the data directly and provides a mathematical solution without recourse to any geological constraints. The application of Euler deconvolution has emerged as a powerful tool for direct determination of depth and probable source geometry in magnetic data interpretation (Barbosa *et al*., 1999). The Euler derived interpretation requires only a little a priori knowledge about the magnetic source geometry and information about the magnetization vector (Barbosa *et al*., 2000).

The 3D Euler Deconvolution processing routine of Oasis Montaj™ is a semiautomatic location and depth determination software package for gridded magnetic and gravity data. The depths are displayed as a grid and are based on source parameters of the following source models (e.g. Hsu, 2002): contacts (faults), thin sheets (dykes) or horizontal cylinders.

Theory of Euler Deconvolution Method:

Any three-dimensional function *f (x,y,z)* is said to be *homogeneous* of degree *n* if the function obeys the expression:

$$f\ (tx, ty, tz) = t^{n}\ f\ (x, y, z) \qquad (1)$$

From this it can be shown that the following (known as *Euler's equation*) is also satisfied:

$$x\frac{\partial f}{\partial x} + y\frac{\partial f}{\partial y} + z\frac{\partial f}{\partial z} = nf \qquad (2)$$

Thompson (1982) has shown that simple magnetic and gravity models conform to Euler's equation. The degree of homogeneity, *n*, can be interpreted as a *structural index* (SI), which is a measure of the rate of change with distance of a potential field. A magnetic point dipole corresponds to n = 3, while a gravity point mass, a magnetic pole (theoretical) and a line of magnetic dipoles corresponds to n = 1. Reid *et al.* (1990) have shown that a magnetic contact will yield an index of 0.5 provided that an offset A is introduced to incorporate an anomaly amplitude, strike and dip factors (e.g. Whitehead and Musselman, 2005 and Megwara and Udensi, 2014):

$$A = (x \quad x_0)\frac{\partial T}{\partial x} + (y \quad y_0)\frac{\partial T}{\partial y} + (z \quad z_0)\frac{\partial T}{\partial z} \qquad (3)$$

Given a set of observed total field data, we can determine an optimum source location (x_0, y_0, z_0) by solving Euler's equations for a given index n by least-squares inversion of the data.

3.0 Results and Discussions

3.1 Pattern Interpretation of the Aeromagnetic Data and Pseudogravity Transforms

The Reduced - to - Equator (REDE) aeromagnetic and Pseudogravity maps (Figures 4a and b) have been divided into four distinct zones and subzones of various magnetic and pseudogravity characteristics. These include (Olawuyi, 2015 and Olawuyi *et al.*, 2015):

(i) Zone A with low to intermediate magnetic relief (i.e. subzones A1`to A3, Figure 4a) that correlates with high pseudogravity relief (i.e. subzones A1 to A5, Figure 4b) in the Northern part of the study area. The anomalies have amplitudes varying mostly from < 23 nT to 58 nT and -00136 to 0.01230 mGal for magnetic data and pseudogravity transforms respectively.

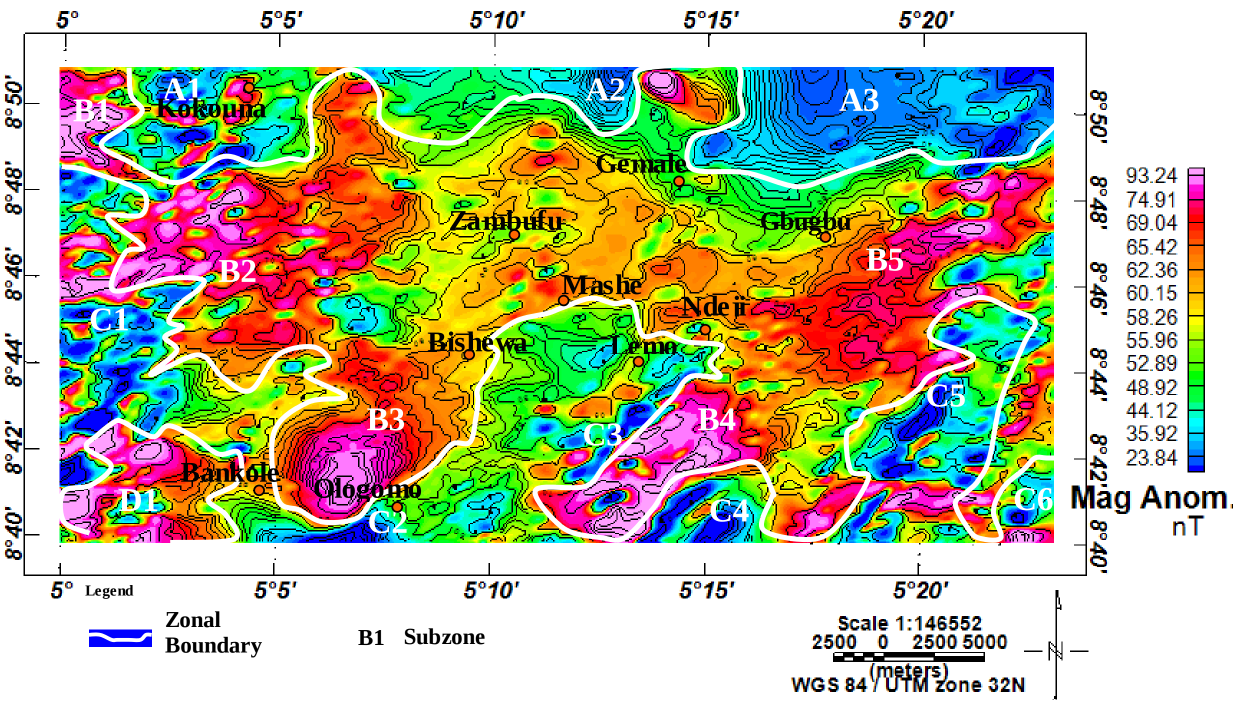
(ii) Zone B with broad and wide extent having moderately high to very high and occasional low magnetic relief (i.e. subzones B1 - B5, Figure 4a) that correlates with low pseudogravity relief (i.e. subzones B1 – B4, Figure 4b) in the central part of the study area. The NW-SE and NE-SW trends shown by these anomalies are characteristic of lineament features. Their amplitudes vary mostly from < 52 to > 93 nT and from < -0.00991 mGal to approx. 0.00112 mGal for magnetic data and pseudogravity transforms respectively. The rocks here are composed mainly of Cretaceous sediments and a few other rocks like Biotite gneiss, Mica schist, Quartzite/Quartz schist and Amphibolite.

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

(iv) Zone D with relatively low to intermediate magnetic (Figure 4a) and pseudogravity (Figure 4b) relief that are wedged to the extreme corner of the southwestern part of the study area (D1). The amplitudes range from approximately 35 to 52 nT (magnetic) and -00136 to -00580 mGal (pseudogravity).

3.2 Superimposition of Zone Colored Euler Solutions for Lineaments on Drainage Map

Figures 5 and 6 show the superimposition of zone colored Euler solutions for near surface lineaments (i.e. magnetic S.I = 0.5 and pseudogravity S.I = 0.0 respectively, see Hsu (2002)) on the drainage map of the study area. The Euler solutions are the colored circles. The colors show their corresponding depth while the clustering in a linear manner shows that they are lineament features. Both maps show the preponderance of the NE-SW, followed by NW-SE and N-S trends and coincidence of the fault/lineament features with the river channels at many areas thereby confirming the fact that the drainage in the study area is structurally controlled (Garba, 2011).



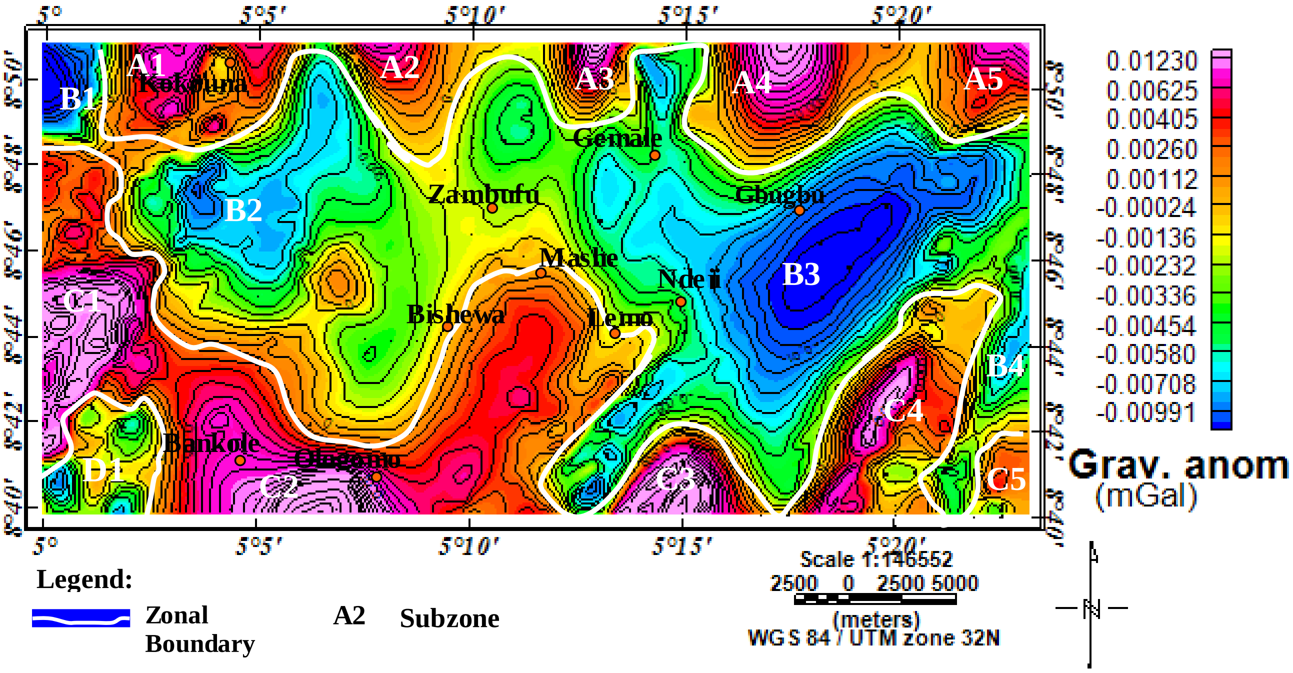


Figure 4: (a) Total Field Aeromagnetic Map (REDE) and its Contour (Top)

(b) Pseudogravity Map and its Contour (Bottom) (Adapted from Olawuyi, 2015).

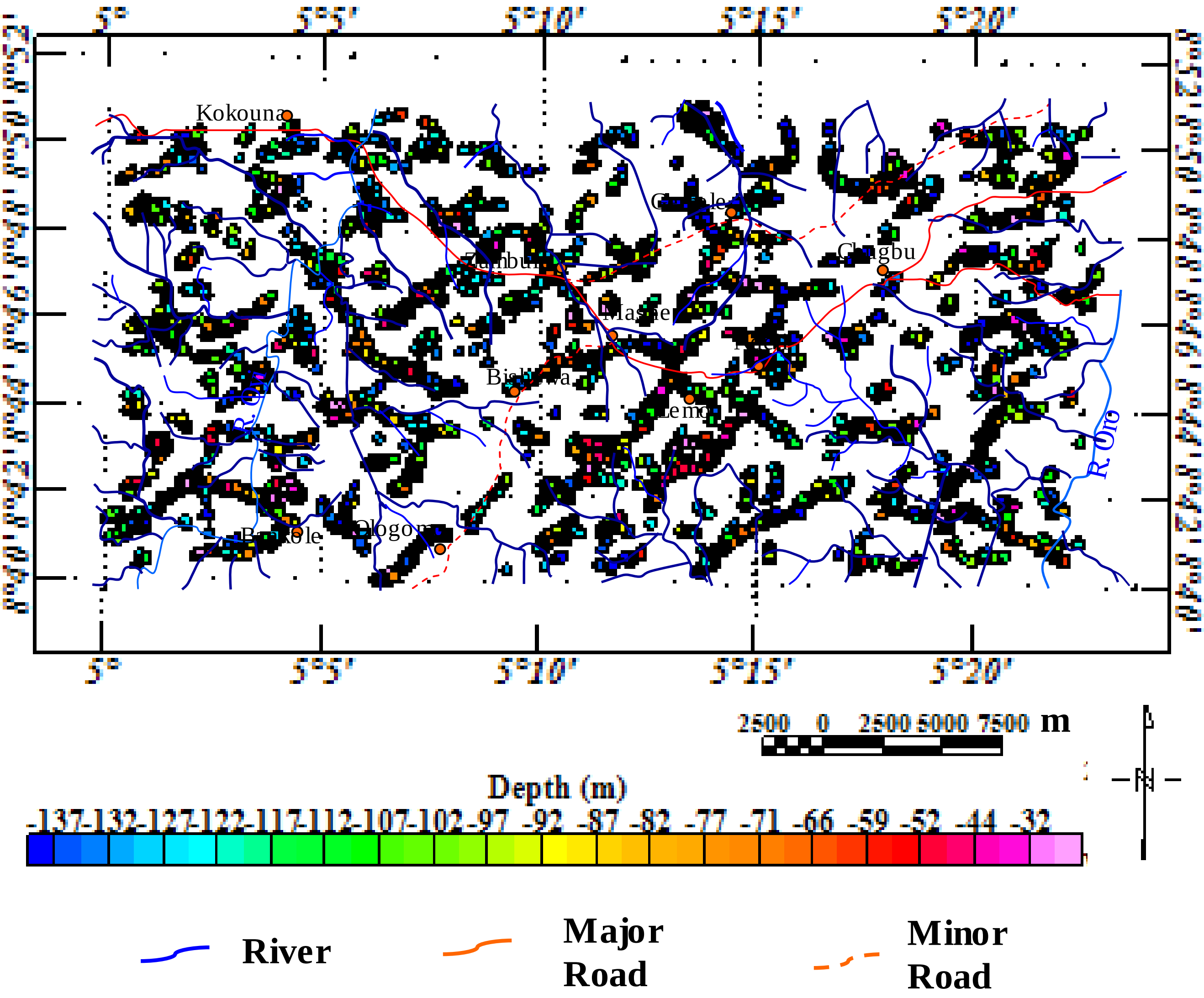


Figure 5: Superimposition of Euler Solutions'-based Lineaments Obtained from Aeromagnetic Data on Drainage Map of the Study Area (Adapted from Olawuyi *et al.*, 2015).

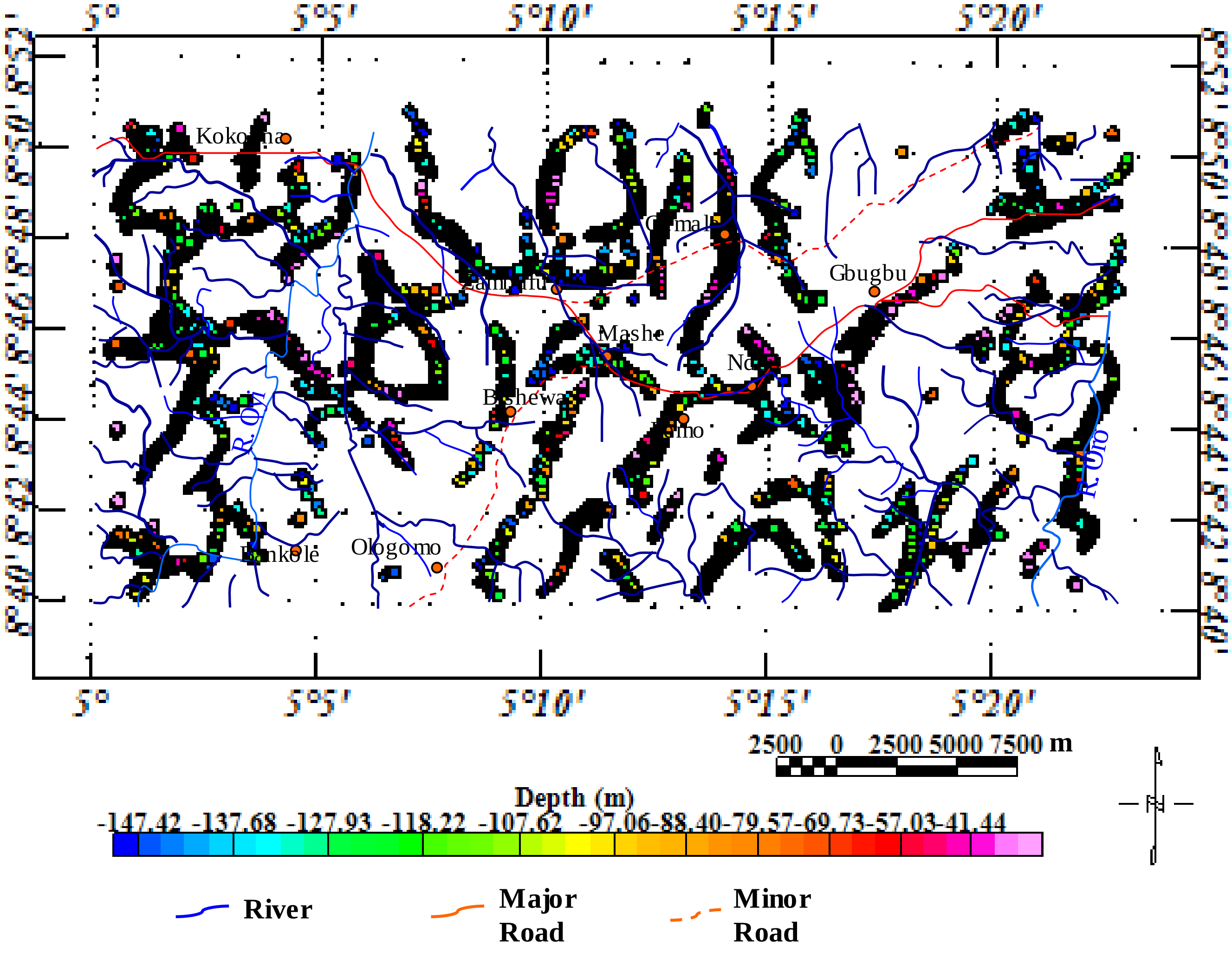


Figure 6: Superimposition of Euler Solutions'-based Lineaments Obtained from Pseudogravity Transforms on Drainage Map of the Study Area (Adapted from Olawuyi *et al*., 2015).

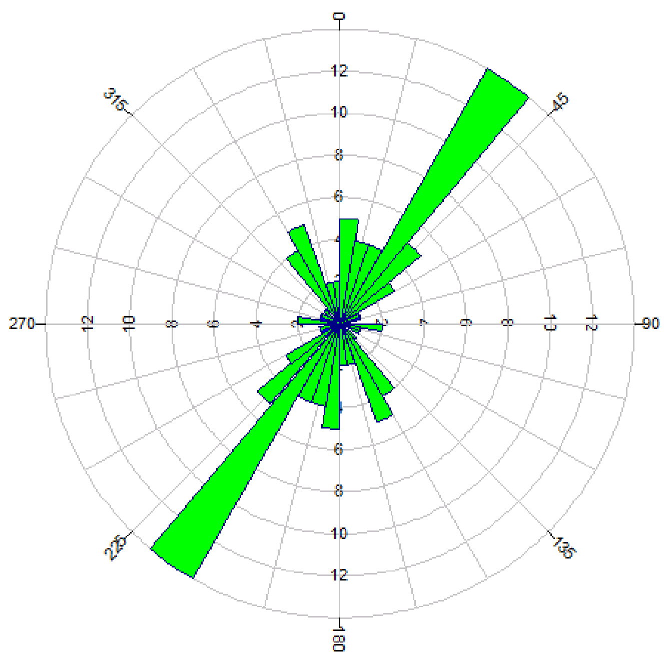
3.3 Rose Diagram

Figure 7 is the rose plot of Euler solutions'-based lineaments in the study area (top), showing the preponderance of the NE-SW trend, while the geologically mapped lineaments in the study area (bottom), show the preponderance of the N-S trend followed by the NE-SW trend thereby confirming the fact that the effects of Pan African in Nigeria include conjugate strike slip fault systems which trend 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, see also Olawuyi, 2015 and Olawuyi *et al*., 2015).

4.0 Conclusions

The research has evaluated the faults/lineament structures within the Lafiagi Study area using aeromagnetic data and pseudogravity transforms. The newly mapped faults and lineament features from geophysical data as well as the existing ones from geologic map (e.g. Figures 2, 5 and 6) 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 which are generally oriented in the NE-SW, NW-SE and N-S directions correlate with the general geologic strike and corroborate the fact that the effects of the Pan African orogeny in Nigeria include the conjugate strike slip fault systems which trend in the NE-SW and NW-SE directions and show dextral and sinistral sense of displacement which cut across the earlier Pan African structures (Ball, 1980).

According to Clark (1985), 'The occurrence of groundwater in fissure systems or weathered zones means that the resources at any one site are finite and relatively small. Well yields similarly are limited, rarely exceeding 500 m^3 per day. In this situation the groundwater is strucurally controlled and, therefore, susceptible to investigation by a variety of techniques including photogeology and geophysics'. The relationship between climate and shallow groundwater resources in Africa remains poorly defined (Taylor *et al*, 2009), however, it is obvious that in areas where the drainage is structurally controlled, the faults and fracture zones will act as conduits for flow and groundwater sustainability is more likely endangered.



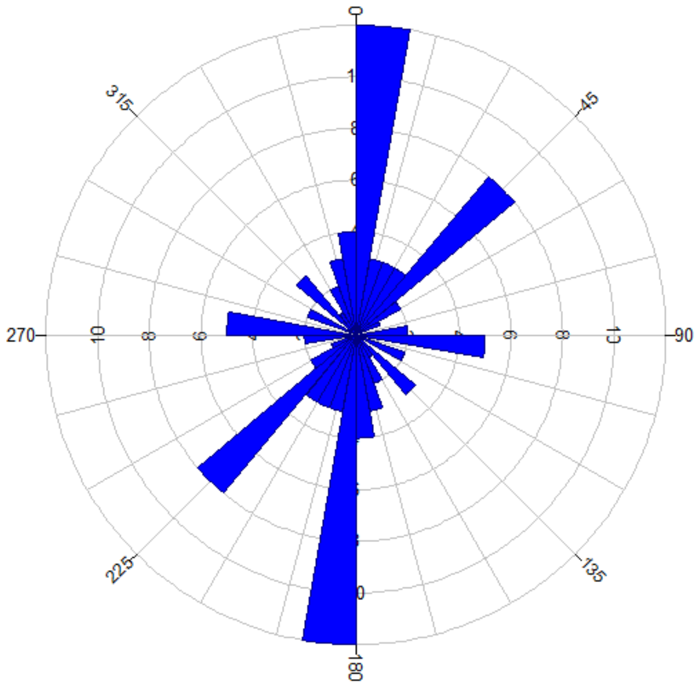


Figure 7: Rose Plot of Euler Solutions'-based Lineaments from the Study Area (Top) and Geologically Mapped Lineaments from the Study Area (Bottom) (Adapted from Olawuyi, 2015 and Olawuyi *et al*., 2015).

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