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ORIGINAL RESEARCH

Mapping of Lineament Structures for Groundwater Study using Aeromagnetic Data: Case Study of a part of Ilorin and its Adjoining Areas, Central Nigeria

Olawuyi[1*], A. K. and Oddiah[2], O. A.

[1]Department of Applied Geophysics, University of Ilorin, Ilorin. Nigeria
[2]Department of Geology and Mineral Sciences, University of Ilorin, Nigeria
[*]Corresponding Author: E-mail address: olawuyi.ak@unilorin.edu.ng

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ABSTRACT

Lineaments mapping over the Basement Complex rocks of southwestern Nigeria at Ilorin, Central Nigeria 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 data using Oasis Montaj^{TM} and the geological information obtained from the area. The analyses made on the IGRF corrected aeromagnetic data acquired was used to estimate depth to anomalous sources using 3-D Euler deconvolution. The 3D Euler Deconvolution was used to estimate and examine the shape, type of magnetic field within a window and calculate 3-D source locations based on its structural index. The results obtained from aeromagnetic data analysis augmented with geological information obtained from literature 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 maps which indicate a structural control of the drainage system in the study area. The orientation of the extracted faults and lineament features showed a preponderance of NE-SW trend followed by NW-SE trend, which corroborate 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.

Keywords/phrases: 3D Euler Deconvolution, Lineaments, Qualitative, Quantitative, anomalies

Introduction

Airborne magnetic techniques have taken a major character in studies of regional Precambrian basement geology. The technique is principally complementary for structural and lithological differentiations revealed by lateral variations in the physical properties of the crystalline rocks (Okpoli, 2019).

Several methods of faults/ lineaments analysis have evolved over the years. For example, (2D Forward modeling and inversion (Talwani *et al*., 1959); Euler deconvolution (Reid *et al*., 1990, FitzGerald *et al*. 2004).

The use of potential field methods (Gravity and Magnetic) for surface geophysical studies have a long history of applications in exploring the earth for structural targets, especially in search for energy sources (coal, oil and gas) and economic mineral sources such as gold, diamonds etc. They also have applications in hydrogeologic, environmental and engineering related problems, but are more often used as reconnaissance tools in exploration (Kearey *et al.*, 2004). The interpretation of large volumes of data aided by "automatic" interpretation techniques such as Spectral or Euler deconvolution can provide considerable information about local anomalies. The use of these techniques is based on the concept that the anomalies can be caused by many relatively simple sources, such as monopole, dipoles or lines of dipoles, and produce positions and depths of these sources. The results obtained may then serve as input for a more detailed interpretation.

In recent years, the interpretation of magnetic anomalies data collected over large regions of the world is facilitated by the development of special techniques for the statistical analysis of magnetic anomalies (Dods *et al*., 1985). The wealth of new interpretation methods and refinements of existing geophysical methods to map subsurface geological structures from aeromagnetic data along with more sophisticated acquisition systems and GPS navigation have dramatically improved the resolution of total magnetic field data and their gradients. This improvement in data resolution has allowed the application of more powerful computational methods to interpret these surveys often using higher (2nd and 3rd) order derivatives (Nabighian *et al*., 2005).

Several methods have been developed that provide the depth to magnetic sources, the magnetization of the source material, and/or the geometry of the causative bodies. Semi-automatic methods for analyzing profile data have been outlined by Nabighian (1972, 1974), Atchuta Rao *et al.* (1981) and Thompson (1982). Other authors give a three -dimensional (3-D) treatment of the problem, suitable for use on gridded data sets (Nabighian, 1984; Blakely and Simpson, 1986; Reid *et al.*, 1990; Wang and Hansen,1990).

The Euler deconvolution method has proved a popular interpretation method which has evolved in significant theoretical ways following the original two-dimensional (2D) (profile) work of Thompson (1982) and the three-dimensional (3D) (grid) implementation by Reid *et al*, (1990). Euler deconvolution provides automatic estimates of source location and depth. Euler de-convolution has been implemented by many organizations and individuals (e.g. Ravat, 1996 and Reid *et al*, 1990). Applications to gravity are fewer.

Several articles have been published on the Nigerian basement complex's structural and tectonic framework, based on analysis of aeromagnetic data (Ajakaiye *et al.,* 1986, Osagie et al., 2021, Balogun, 2019 etc).

In this paper is presented the 3D Euler deconvolution of the acquired aero-magnetic data over a part of Ilorin and its adjoining areas, 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.

Location and Geologic Setting

The study area covers a part of Ilorin (Sheet 223) in the Nigerian topographical map. A Sheet comprises of ½ degree by ½ degree contour map on a scale of 1:100,000. The area lies within latitude 08° 27'N to 08° 30'N and longitude 04° 31'E to 04° 38'E, occupying an area of about 70.45 km^2, in Ilorin the capital of Kwara State in Nigeria (Fig. 1).

Balogun (2019), recorded that, Migmatite–Gneiss–Quartzite complex rocks constitute about 75% of the rocks occurring in the area and include Migmatite Gneiss, Banded Gneiss, Granite Gneiss and Quartzite. The Younger Metasediment rocks in the area include the schist and flaggy quartzite, which constitute about 20% of the rocks found in the study area (Fig. 1). While the Younger Metasediments, as shown on the geologic map (Fig. 1), only occurred at the south-eastern region, the Migmatite–Gneiss–Quartzite complex rocks continued to the east of the study area to areas like Ajegunle, Oko-Baba, Ilofa, Eruku, etc. which were not covered in the study area.

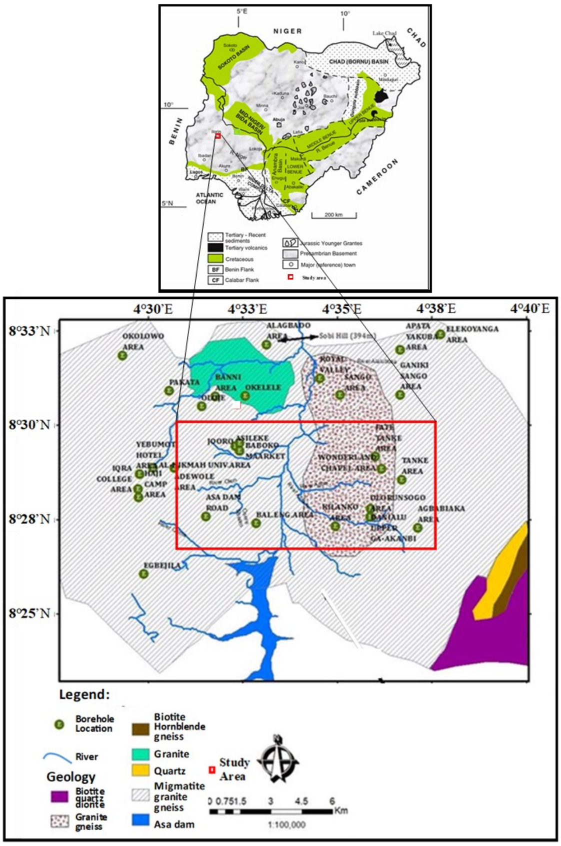

Figure 1: The geologic map of Ilorin and its adjoining areas (After Ashaolu, 2016, Inset is the geological sketch map of Nigeria, After Obaje, 2009)

Materials and Methods

Aeromagnetic Data

The data used for the study is the high-resolution 100 m × 100 m grid aeromagnetic (Total Magnetic Field Intensity (TMI)) map, (Fig. 2) having a mean terrain clearance of 80m, acquired by the Nigerian Geological Survey Agency (NGSA) in 2006. For this study, the data was reduced to the magnetic equator (REDE) to remove asymmetries associated with low magnetic latitude anomalies (Fig. 3). The aeromagnetic data (i.e. Ilorin aeromagnetic grid map, Sheet 223), was procured from the 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.

Since the data collection for this area was done in 2006, then 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.

The TMI and REDE map emphasize 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.

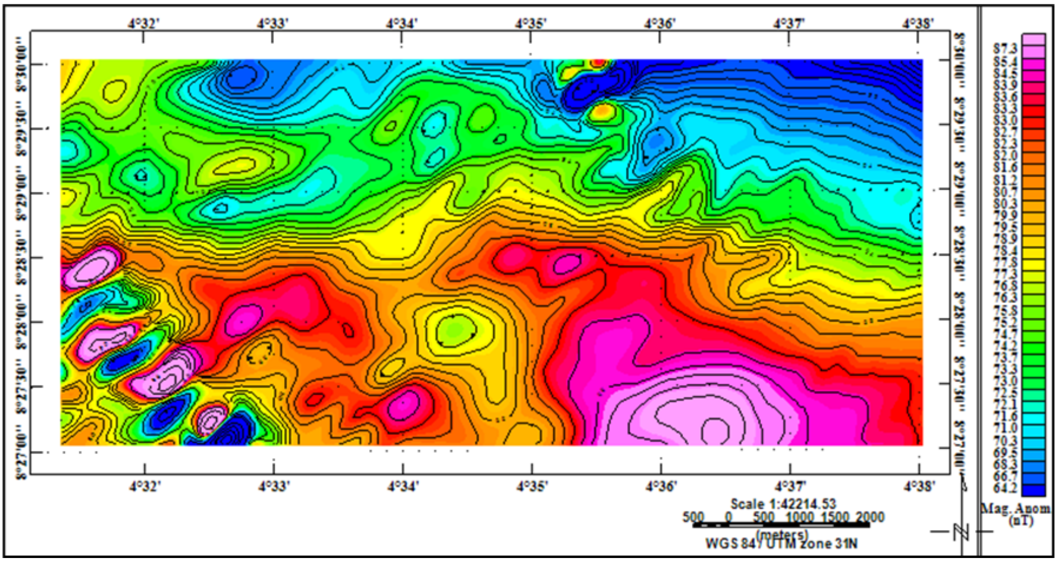

Figure 2: TMI map of the Study area

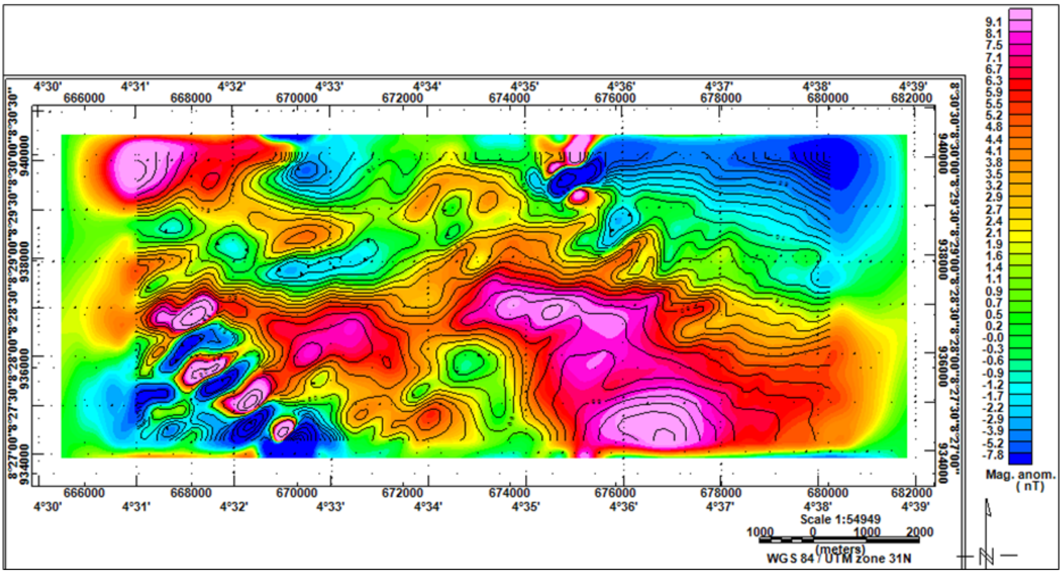

Figure 3: The Reduced to Equator (REDE) map of the Study area

Methodology

Euler Deconvolution

The 3D Euler deconvolution technique was used on the aeromagnetic data to provide estimates of depths to anomalies sources and determine the source location (x_o,y_o,z_o) through the inversion of the Euler's homogeneity equation over a window of data. 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 function of the source coordinate and, therefore, satisfies 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 *apriori* knowledge about the magnetic source geometry and information about the magnetization vector (Barbosa *et al*., 2000). The 3-D Euler Deconvolution processing routine is an automatic location and depth determination software package for gridded magnetic and gravity data (Oasis montaj^{TM}). The depths are displayed as a grid and are based on source parameters of the following source models: contacts (faults), thin sheets (dykes) or horizontal cylinders. The relationship between structural index (n), type of magnetic/gravity model and position of the calculated depth as described by Hsu (2002) is presented in the Table 1. The structural index for gravity model is one less than that of magnetic and the maximum for gravity is 2.

Table 1. The Relationship Between Structural Index (n), Type of Magnetic/Gravity Model and Position of the Calculated Depth (After Hsu, 2002).

Structural index (n)	Types of magnetic model	Types of gravity model	Position of Euler depth
0.0	Contact with large depth extent	Sill/Dyke/Step	At top and edge
0.5	Contact with small depth extent	Ribbon	
1.1	Thin prism with large depth	Pipe	At top and centre or at edge and half throw
2.0	Vertical or horizontal cylinder	Sphere	At centre
3.0	Sphere		

Theory of Euler Deconvolution Method:

According to Whitehead and Musselman, 2005). 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:

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

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). 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 (Whitehead and Musselman, 2005):

$$\mathrm{A} = (\mathrm{x} \quad \mathrm{x}_0)\frac{\partial T}{\partial x} + (\mathrm{y} \quad \mathrm{y}_0)\frac{\partial T}{\partial y} + (\mathrm{z} \quad \mathrm{z}_0)\frac{\partial T}{\partial z} \qquad (3)$$

Given a set of observed total field data, we can determine an optimum source location by $(\mathrm{x}_0, \mathrm{y}_0, \mathrm{z}_0)$ solving Euler's equations for a given index n by least-squares inversion of the data.

Results and Discussion

Depth Estimation

3-D standard Euler deconvolution

Zone Coloured Euler Solutions for Different Geologic Structures

The structural indices 0.0 to 3.0 (i.e. faults with large depth to sphere model; magnetic), represent the different geologic structures. In the Ilorin study area, Figs. 4a and b show the results obtained for structural indices of 0.0 (i.e. faults/steps, dykes and sills model (near surface); magnetic) and 0.5 (i.e. faults/steps, dykes and sills model (deep seated); magnetic).

In Oasis montaj^{TM}, window size determination is either by default (i.e. 20 x 20) or through iterations, as the correct SI for a given feature will give the tightest clustering of solutions or sharpest focus of results. The structural index 0.0 and 0.5 (magnetic) of 3D Euler Deconvolution has been used worldwide to detect the near surface and deep seated faults/ steps, dykes and sills model (Kearey *et al.*, 2004 and Olawuyi *et al.,* 2016). Also, Figs. 5a and b show the superimposition of faults and lineaments obtained from 3D Euler solutions on the drainage map of the study area. Many of these channels coincided with the Euler solutions clusters, confirming that the drainage in the study area is structurally controlled. The fact that both features are oriented mostly in the NE-SW followed by NW-SE directions corroborate 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).

The abundance of lineament structures in Ilorin and its adjoining areas is an indication that the area is potentially viable for groundwater exploration. ‘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).

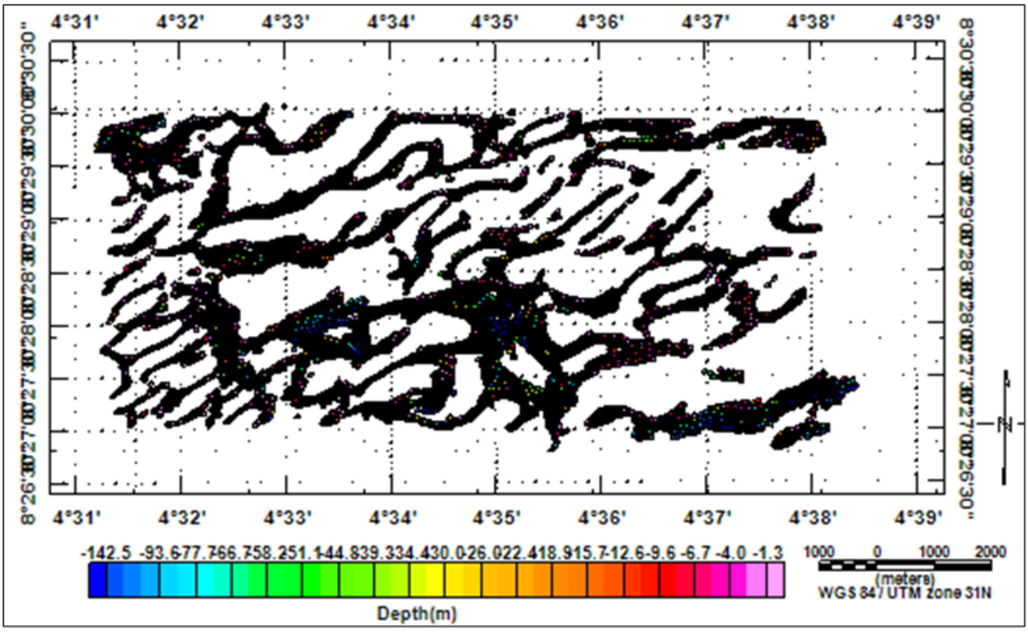

Figure 4a: Result of Euler Deconvolution of Aeromagnetic Data of Ilorin and its adjoining areas (SI=0.0).

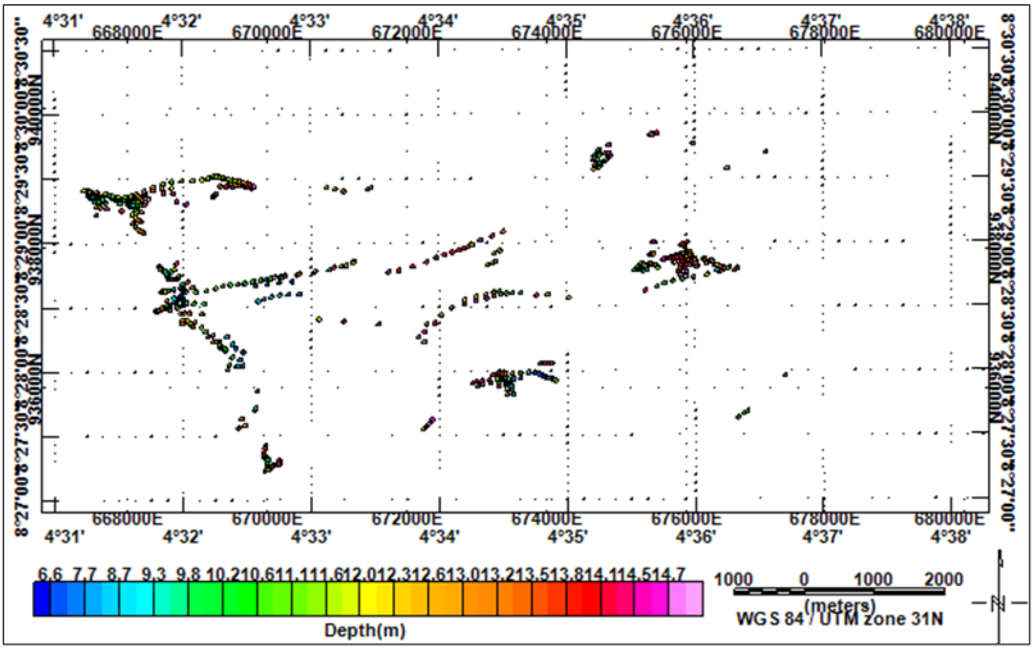

Figure 4b: Result of Euler Deconvolution of Aeromagnetic Data of Ilorin and its adjoining areas (SI: 0.5)

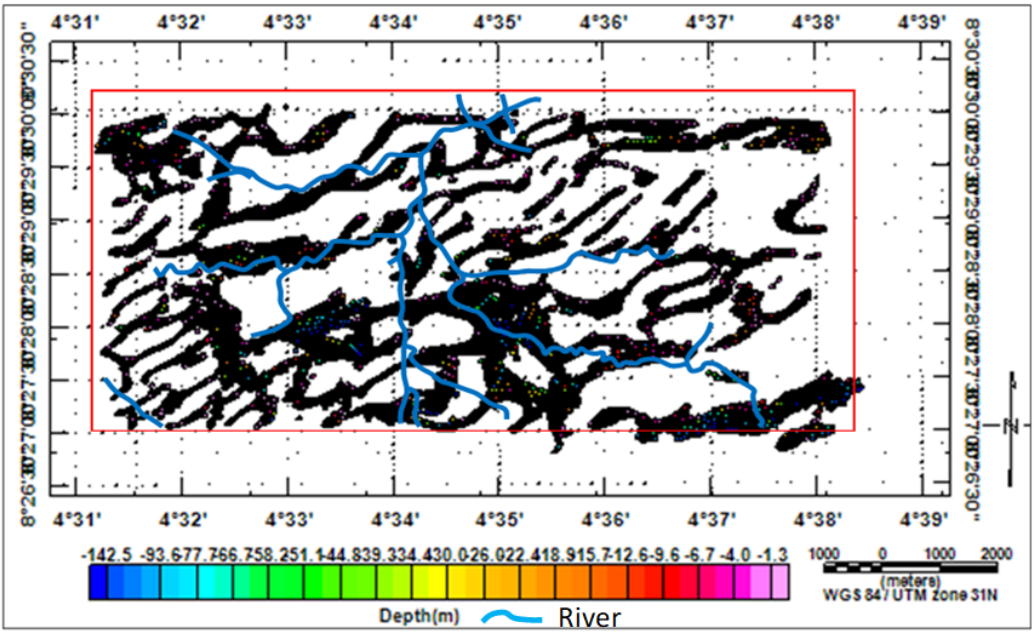

Figure 5a: Superimposition of Result of Euler Deconvolution of Aeromagnetic Data of Ilorin and its adjoining areas (SI=0.0) over the drainage map.

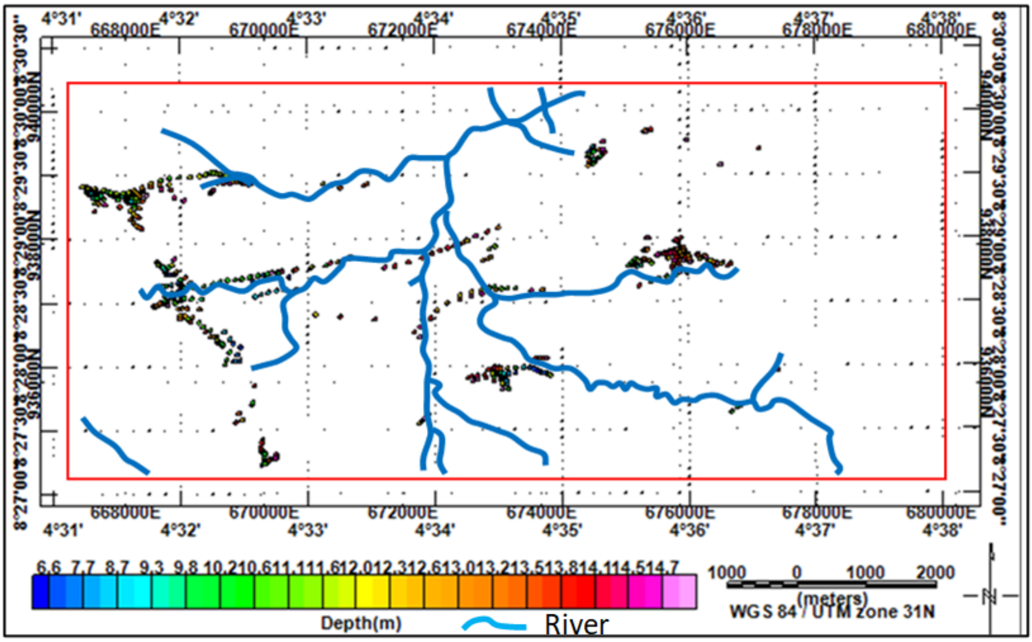

Figure 5b: Superimposition of Result of Euler Deconvolution of Aeromagnetic Data of Ilorin and its adjoining areas (SI: 0.5) over the drainage map.

Conclusions

Airborne magnetic datasets over Ilorin and its environs, in Central Nigeria were collected and processed. The IGRF corrected TMI map was reduced to the equator and processed with 3D Euler deconvolution subroutine of Oasis montaj^{TM}. Using the appropriate structural indices, the lineament structures within the Ilorin and its adjoining areas were identified and correlated with the drainage map. The lineaments structures did not only coincide with the river channels but were both aligned mostly in the NE-SW followed by the NW-SE directions, showing that the drainage is not only structurally controlled but corroborates 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). The abundance of lineament structures in Ilorin and its adjoining areas could also imply that the area under study is potentially viable for groundwater exploration.

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