APPLICATION OF EULER AND WERNER DECONVOLUTION TECHNIQUES FOR THE INTERPRETATION OF AEROMAGNETIC DATA AROUND BANKE RING COMPLEX, NIGERIA

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Abstract: Werner and Euler deconvolution techniques have been applied on aeromagnetic data to characterize geologic structures/lineaments around Banke ring complex, Nigeria. The aeromgnetic data were obtained from the newly acquired high resolution aeromagnetic data by Nigerian Geological Survey Agency. Four profiles were laid on the aeromagnetic data around the Banke complex for Werner deconvolution analysis. Magnetic susceptibility values range from $1.8926x10^{-3}$ – $5.8118x10^{-3}$ SI units, which suggests that the rocks/minerals include biotite, garnet, fayalite, olivine, phyllite, quartzite, dolomite, igneous rocks while dip angle have values from 5.6^0 – 81.2^0, and could be attributed to Pan-African shallow structures (contact model). The trend of the lineaments/ fractures is dominant in the NW-SE direction, conforms with the trends obtained for basement structures in previous studies. The trends of the lineaments/ fractures were likely established during the Pan-African orogeny. Depth range produced by 3D Euler deconvolution is from 500 - 2500 m for all the lineaments. This gives an insight of approximate depth range of all the lineaments/ fractures across the whole map in the study areaunlike, Werner deconvolution which is profile biased.

Keywords: Aeromagnetic, Euler deconvolution, Werner deconvolution, Banke complex, lineaments

Introduction

The continued expansion in the demand for minerals of all kinds since the turn of the century have led to the development of many geophysical techniques of ever increasing sensitivity for the detection and mapping of the unseen deposits and structures (Telford *et al*., 1990).

The Earth's magnetic field of an area is directly influenced by geological structures, geological composition and magnetic minerals, most often due to changes in the percentage of magnetite in the rock. Objects that are underground can warp the simple patterns of the Earth's magnetic field into complex shapes (Grant and Martin, 1966). The magnetic map allows a visualization of the geological structure of the upper crust of the Earth, the presence of faults and folds (Atchuta and Badu, 1981). In exploration geophysics, aeromagnetic maps are important tools for mapping geology (Smith and O'Connell, 2007). A study of these shapes on a magnetic map can reveal much information about the features that are underground. This information can include the location, size and shape, volume or mass, and depth of the features; in some cases, the age of a feature and its material (stone, soil, metal) may be estimated (Telford *et al*., 1990).

Many airborne geophysical surveys have been conducted in Nigeria including airborne magnetic, gravity and radiometric to identify the various geological features over the country. The study area and its environs have been surveyed and studied by several geoscientists, particularly for the surface geological mapping and geochemical studies (Bennett *et al.*, 1984). The subsurface geological mapping has less been performed in the study area by integrating geological records and geophysical studies. Irrespective of this, only a little attempt has been made so far to understand the detailed relationship between structural features observed on the ground and those extending into the subsurface. This research is aimed at mapping geological structures (lineaments) and estimating the depth to top of magnetic bodies within the study area using Euler and Werner deconvolutions.

Materials and Methods

Location of the study area

The study area is situated in Kubau local government area of Kaduna State, Nigeria. The area lies within the Northern Nigerian Basement complex between longitudes $08^0 33'$E - $08^0 35'$E and latitudes $10^0 50'$ N – $10^0 52'$ N. The Banke Younger Granite ring complex lies about 20 km northwest of the Riruwai complex, 15 km north of the Kudaru complex and 42 km east of the Dutsenwai complex. It is accessible via the Jos – Saminaka – Kano, Pambeguwa – Ikara and Zaria – Dutsenwai – Anchau tarred roads (Magaji and Ike, 2008).

Geology of the study area

The Banke complex covers an area about 227.2 km^2, of which a third consists of basement rocks enclosed within the ring fault. It has approximate dimensions of 17.5 by 15 km. The Banke complex is located in the north western part of the Nigerian Younger Granite Province (Fig. 1). They are related suites of shallow anorogenic ring complexes emplaced into precambrain basement gneisses, meta-sediments and granites (Older granites) and have been dated at 175±5 Ma (Van Breemen *et al*., 1977).

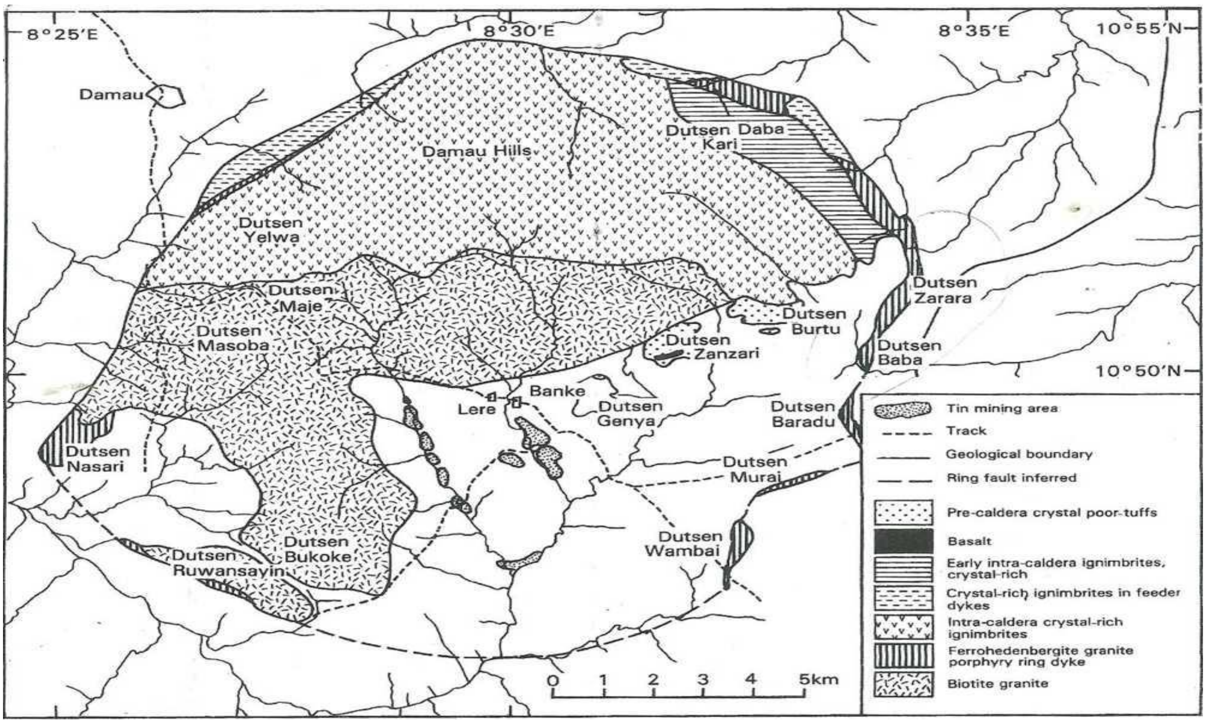

Fig. 1: Geological map of the Banke complex (Bennett *et al*., 1984)

Data acquisition

Four high resolution aeromagnetic maps (HRAM) were acquired from the Nigerian Geological Survey Agency (NGSA), Abuja. These sheets include; sheets 103 (Ikara), 104 (Lere), 125 (Dutsenwai) and 126 (Ririwai). The aeromagnetic data were obtained as part of a nationwide aeromagnetic survey sponsored by the Geological Survey of Nigeria. The data were acquired at a flight altitude of 80 m along a series of NE – SW flight lines with a spacing of 500 m. The data were made available in the form of contoured maps on a scale of 1:100,000 and in half degree sheets. The sheets then put together extend from 10^0 30' N - 11^0 30' N and from 8^0 00' E - 9^0 00' E covering the study area and its environs. The magnetic field intensity ranges from 31800 to 33600 nT. Most of the anomalies trend NW – SE, NE – SW directions with some trending in the E – W direction (Fig. 2).

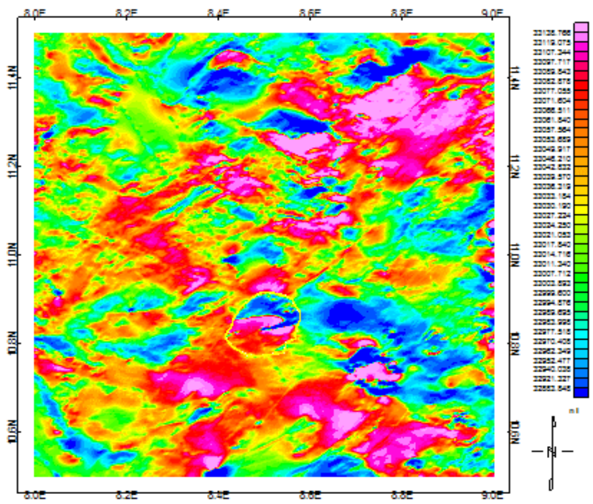

Fig. 2: Total Magnetic Intensity (TMI) Map of the study area gridded on the oasis montaj software using a grid cell size of 0.00225 degrees (250 m) with the yellow line indicating the outline of the Banke Complex

Data processing

Data processing is the series of steps taken to remove both signal and spurious noise from the data that are not related to the geology of the Earth's crust. This process thereby prepares the dataset for the interpretation by reducing the data to only contain signal relevant to the area of interest. The processing of airborne data for this research involved verifying and editing raw data, the application of a gridding routine, regional-residual separation and the application of enhancement technique. Some corrections like removing diurnal variation of the Earth's magnetic field, aircraft heading, instrument variation, lag error between aircraft and the sensor and inconsistencies between flight lines and tie lines were done by FUGRO (the contractors). The geophysical data set for the study area was co-registered to Universal Transverse Mercator (UTM) Coordinate System, zone 32 of North hemisphere.

The main software used for the processing and enhancement of the airborne geophysical data were the Geosoft® (Oasis Montaj) and Golden software (Surfer).

Regional-residual separation

The Total Field Aeromagnetic Anomaly Map (Fig. 2) consists of two components, regional and residual fields. The regional–residual separation technique is carried out to filter the regional component, which originates due to deep seated sources from the residual component, which is related to local, shallow structures. The Regional Fields Aeromagnetic Anomaly Map (Fig. 3) are large features presented as trends and continue smoothly over very considerable areas, and are caused by deeper homogeneity of the earth's crust (Nettleton, 1976). Residual Field Aeromagnetic Anomaly Map (Fig. 4) was extracted from the Total Field Aeromagnetic Anomaly Map (Fig. 2) by a best-fit polynomial of first degree fitted to the aeromagnetic data set, using the least square technique. The least squares criterion regional-residual separation is such that the residual is the square of the deviation of the regional from the observed (measured). The regional uses a polynomial surface to expose the residual features as deviation from the observed field. The separation of a data into two component is done by fitting a trend (plane) surface, which may be defined

as a linear function of the geographic coordinates of a set of observations (in this case, total magnetic field data) so constructed that the squared deviations from the trend are minimized. Residual magnetic field data set was obtained as the deviations of the fitted plane surface from the total magnetic field intensity (Megwara and Udensi, 2014) using Surfer software and gridded method with a grid cell size of 0.00225 degrees (Fig. 4). The regional field values (Fig. 3) for the aeromagnetic data, ranges from 33021.5 nT- 33029 nT with the NE-SW trend in the study area.
Four profiles (AA', BB', CC' and DD') were chosen across the residual aeromagnetic map of the study area (Fig. 5) to estimate the depth to magnetic bodies, dip (orientation) and susceptibility (intensity) of the causative body (faults) using the Werner deconvolution technique when the sources are assumed to be dike and contact. The data were generated automatically along the profiles on the aeromagnetic map with Surfer software.

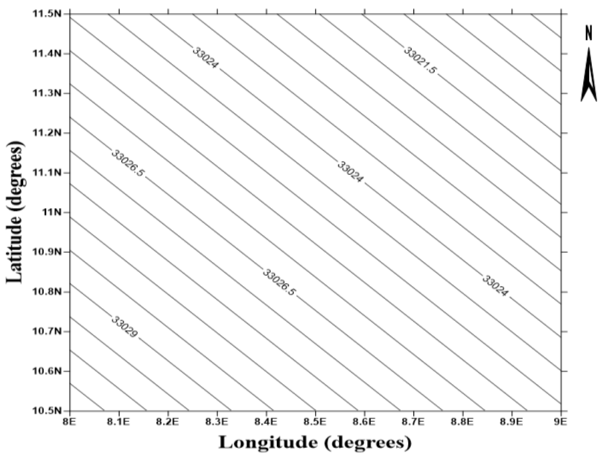

Fig. 3: Regional contour map of aeromagnetic data (contour interval 0.5 nT)

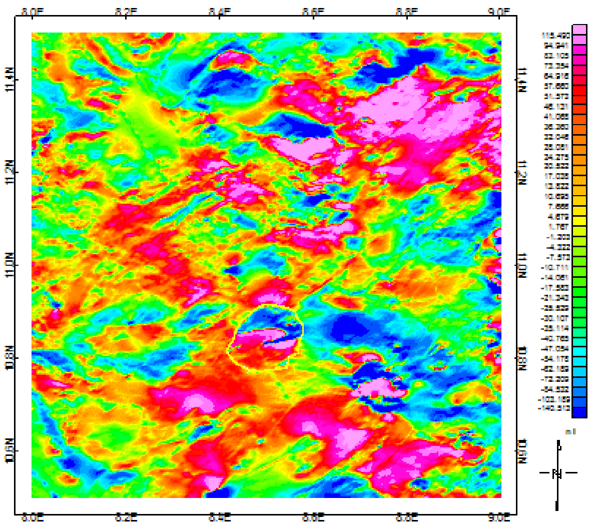

Fig. 4: Residual magnetic intensity grid map of the study area gridded on oasis montaj using the minimum curvature method on a cell size of 0.00225 degrees (250 m) with the yellow line indicating the outline of the complex

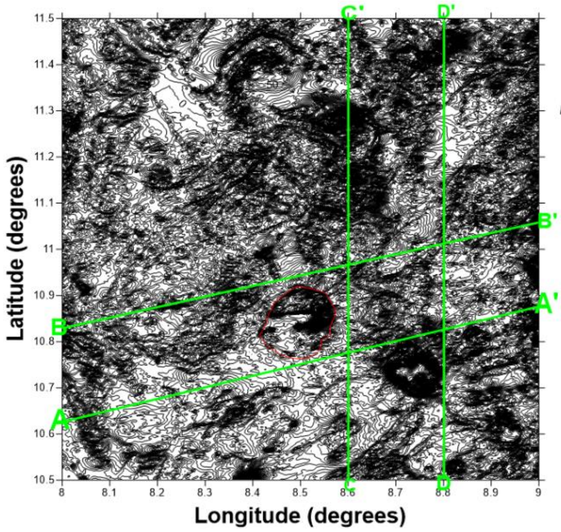

Fig. 5: Residual aeromagnetic anomaly map with selected profiles; AA', BB', CC' and DD' (contour interval = 10 nT)

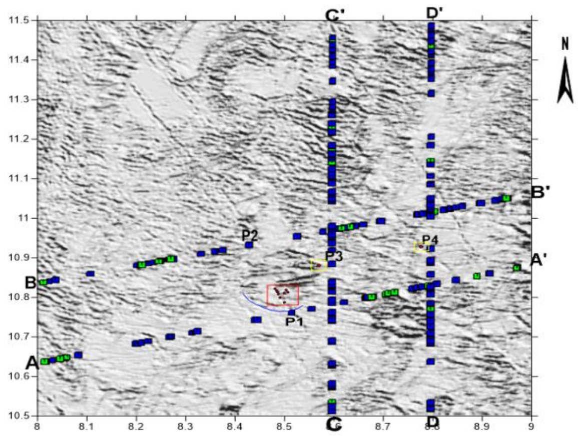

Fig. 6: Plot of the locations of Werner solutions of the profiles on the shaded relief map of the FVD; the blue symbols represent the contact solutions while the green symbols represent the dyke solutions. The red points indicates mineralization points in the complex and the light blue line indicates the inferred ring fault

First vertical derivative

Computing the first vertical derivative (FVD) is an important step in the interpretation of aeromagnetic data, particularly in studies dealing with narrow and shallow anomalies. It reduces the effect of long-wavelength regional anomalies (which are usually deeper) and enhances the higher frequency shallow anomalies (Grauch *et al*., 2009; Milligan and Gunn, 1997). The vertical derivative map is much more responsive to local influences than to broad or regional effects and therefore tends to give sharper picture than the map of total field intensity. The FVD shaded relief map (Fig. 6) give enhanced linear features within the study area

Werner deconvolution technique

The equations for the total field due to thin sheets and edges of a thick body are used in this method to compute the depth to the top, susceptibility contrast, and the dip of these features from a given total magnetic field profile. The term "Werner deconvolution" refers to a set of algorithms whose feature is the linearization of a two-dimensional (2-D) inverse problem for the parameters of a magnetic dike or contact by clearing the denominators of the rational functions that describe their anomalies (Hansen and Simonds, 1993).

Basic theoretical equations of the Werner deconvolution technique.

The equation of a dike can be expressed in the form:

$$F(x) = \frac{A(x-x_o)+Bz}{(x-x_o)^2+z^2}$$

where F is the total magnetic field intensity at x, and x represents the distance along a profile which passes over dike for which the depth to the top is z and its horizontal distance along the profile to the point immediately above the top of the dike is x_o. A and B are constants which depend on the orientation and magnetization of the dike. There are four unknown quantities: A, B, x_o, z.

Werner points out that in the simple case where observations are made in a level plane over the level bounded bodies whose length and depth are infinite and whose strike is perpendicular to the direction of the profile, equation can be rearranged into the form:

$$x^2F(x) = a_0 + a_1x + b_0F(x) + b_1xF(x)$$

Where: $a_0 = -Ax_0 + Bz$, $a_1 = A$, $b_0 = -x_0^2 - z^2$, and $b_1 = 2x_0$

This may be evaluated at four field points to obtain a system of equations the simultaneous solution of which would yield values for $a_0, a_1, b_0,$ and b_1. In turn, $x_0, z, A,$ and B may then be evaluated from equation.

Conversely, the depth and horizontal position of the top of the dike are functions of the parameters of the equation:

$$x_0 = \frac{1}{2}b_1 \quad \text{and} \quad z = \pm\sqrt{-4b_0 - b_1^2}$$

Since there are four unknowns, simultaneous solution of equation at four *x* values and their corresponding *F* values will yield solutions for a_0, a_1, b_0, b_1, and from equation, for x_0 and z. In the simple case, the geometric solution is complete. The depth to the top of the dike (thin sheet) has been determined.

If we now admit the possibility of interference and assume that the interference can be represented by a polynomial of some degree. The addition of an interference term in the form of a polynomial $C_0 + C_1x + C_2x^2 + \cdots + C_nx^n$ to the total magnetic anomaly, equation, leads to an improvement in the estimates of the determining physical quantities $x_0, z, A,$ and B.

$$F(x) = \frac{A(x-x_o)+BZ}{(x-x_o)^2+Z^2} + C_0 + C_1x + C_2x^2 + \cdots + C_nx^n$$

where n is the order of the interference polynomial and C's are the coefficients. We now have a total of (n + 5) unknowns and therefore (n + 5) points are required to solve for the unknowns.

For the purpose of direct interpretation, the source bodies can be divided into types:

- The bodies whose width is comparable to their depth from the plane of observation. These can be called thin bodies, because the edges of these bodies cannot be located easily, with reasonable accuracy.
- The bodies of considerable lateral extent, whose bounding edges can be separately identified. The expression for the total magnetic field due to thin dikes of any arbitrary dip was given by Werner (1953). Werner's interpretation equations were reproduced by Hartmann *et al.* (1971):

But in this research Geosoft was used for Werner deconvolution analysis which involves Werner deconvolution operator as a sliding window that moves along a profile and continually solves for the four unknowns. The parameterization of that operator consists of (1) the size of the window, which will influence the estimated depth of the anomaly; (2) how it moves on a profile, which controls the number of generated solutions; and (3) parameters that exclude the spurious solutions (caused by noise) (Megwara & Udensi, 2014).

Basement rocks generally have strong magnetic susceptibilities compared to values for sedimentary rocks. Variations of the magnetic intensities over basement complexes are therefore considered to originate in: the sedimentary structure, intrusive and extrusive volcanic bodies either within the basin or basement itself, or occasionally in variation of susceptibilities in materials within the basement (Behrendt and Klitgord, 1980). Therefore, calculation of depth-to-magnetic source is one of the useful applications of magnetic data over basement complexes.

Euler deconvolution technique

The objective of the 3D Euler deconvolution process is to produce a map showing the locationsand the corresponding depth estimations of geologic sources of magnetic or gravimetric anomalies in a two-dimensional grid (Reid *et al*., 1990). The Standard 3D Euler method is based on Euler's homogeneity equation, which relates the potential field (magnetic or gravity) and its gradient components to the location of the sources, by the degree of homogeneity N, which can be interpreted as a structural index (Thompson, 1982). The method makes use of a structural index in addition to producing depth estimates. In combination, the structural index and the depth estimates have the potential to identify and calculate depth estimates for a variety of geologic structures such as faults, magnetic contacts, dykes, sills, etc. The algorithm uses a least squares method to solve Euler's equation simultaneously for each grid position within a sub-grid (window). A square window of predefined dimensions (number of grid cells) is moved over the grid along each row. At each grid point a system of equations is solved, from which the four unknowns (x, y as location in the grid, z as depth estimation and the background value) and their uncertainties (standard deviation) are obtained for a given structural index (Whitehead and Musselman, 2008).

Thompson (1982) showed that Euler's homogeneity relation could be written in the form

$$(x - x_0)\frac{\partial T}{\partial x} + (y - y_0)\frac{\partial T}{\partial y} + (z - z_0)\frac{\partial T}{\partial z} = N(B - T),$$

where (x_0, y_0, z_0) is the position of a magnetic source whose total field T is detected at (x, y, z). The total field has a regional value of B.

For example, the best results for a contact are obtained by structural indices of 0 to 0:5, while for thin two-dimensional dyke structures a structural index of 1 yields the best estimates. The significance of the location and depth estimates obtained by 3D Euler Deconvolution is given by the specificity of the chosen parameters like the grid cell size, window size, structural index, chosen depth uncertainty tolerance, etc. The selection of the grid cell size should be based on the grid spacing and the wavelength of the anomalies to be analyzed, as the software Geosoft Oasis montaj allows a square window size of up to 20 grid cell units.

Results and Discussion

Werner deconvolution

The computed depth estimates associated with magnetic basement dikes or faults/contacts of the four aeromagnetic profiles are presented (Figs. 7a-c) and generated more contacts (circles) compared to dikes (diamond shape) for the horizontal gradient for the field. Since variations in magnetic fields observed at the points of intersection along all the four profiles give contact solutions rather than dike solutions. This could be likely a confirmation that the contact-like solutions are fractures within the basement structures of the study area. These geologic structures could serve as the conduits through

which the minerals flow during formation. Variations of magnetic field intensity associated with the lineaments vary from profile to profile and runs in SW – NE direction, at a depth of 200 m, susceptibility value of 0.0022462SI units, dip angle of 5.6^0 and horizontal distance of 58.23 km (Fig. 7a).The profile (Fig. 7b) runs SW – NE and a distance of 48.18 km along the profile. The depth to the source anomaly is 352.9 m, angle of dip values of 81.2^0 and magnetic susceptibility 0.0029160SI units respectively. It was observed that lineament which follows an S – N direction, intersects the point where copper mineralization has been observed and this magnetic anomaly occur at a depth of about 592.0 m, susceptibility value of 0.0018926SI, angle of dip of 20.9^0 and horizontal distance of 42.01 km (Fig. 7c).In Fig. 7d, the depth occur at 672.2 m, susceptibility value of 0.0058118SI, angle of dip of $34.4^0$and horizontal distance of about 46.18 km.
Magnetic susceptibility values range from $1.8926x10^{-3}$ – $5.8118x10^{-3}$ SI units, suggests that they are biotite, garnet, fayalite, olivine, phyllite, quartzite, dolomite, igneous rocks (Clarke and Emerson, 1991; Telford *et al*., 1976) while dip angle have values from 5.6^0 –81.2^0, could be attributed to Pan-African shallow structures (contact model). Dike model anomaly occurs at a greater depth than the contact model (Mushayandebvu *et al*., 2001) and the trend of the lineaments/ fractures is in the NW-SE direction, in conformity with the trends obtained for basement structures in previous studies (Oluyide, 1973). The trends of the lineaments/ fractures were likely established during the Pan-African orogeny (McCurry, 1971).

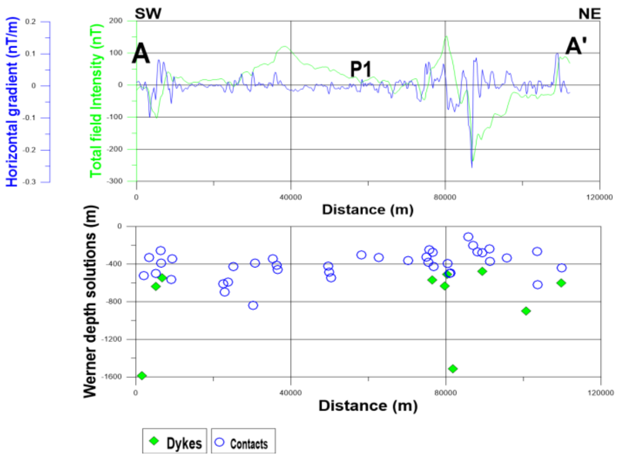

Fig. 7a: Werner depth solution for profile AA' with point "P1" indicating where the profile intersects the geological structure in that direction

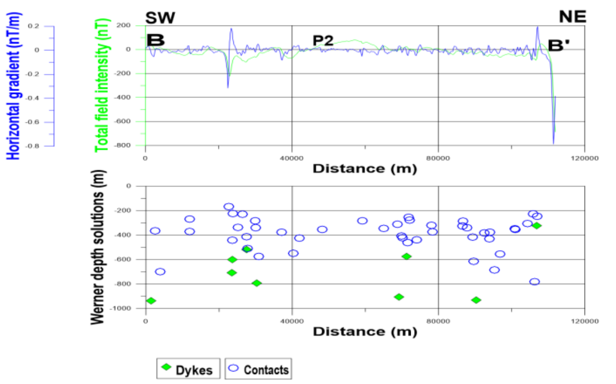

Fig. 7b: Werner depth solution for profile BB' with point "P2" indicating the point where the profile intersects the geological structure in that direction

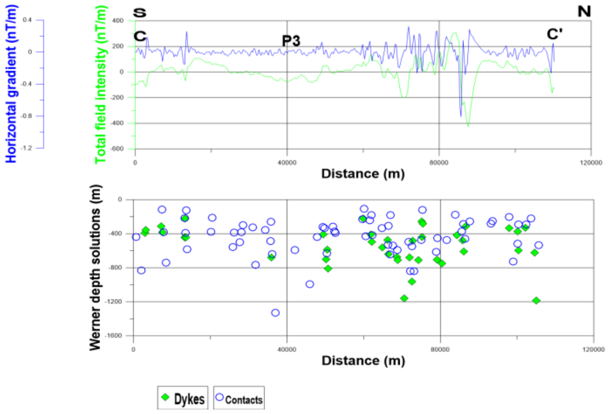

Fig. 7c: Werner depth solution for profile CC' with point "P3" indicating the point where the profile intersects the geological structure in that direction

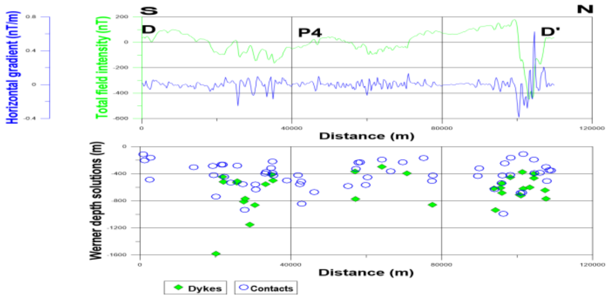

Fig. 7d: Werner depth solution for profile DD' with point "P4" indicating the point where the profile intersects the geological structure in that direction

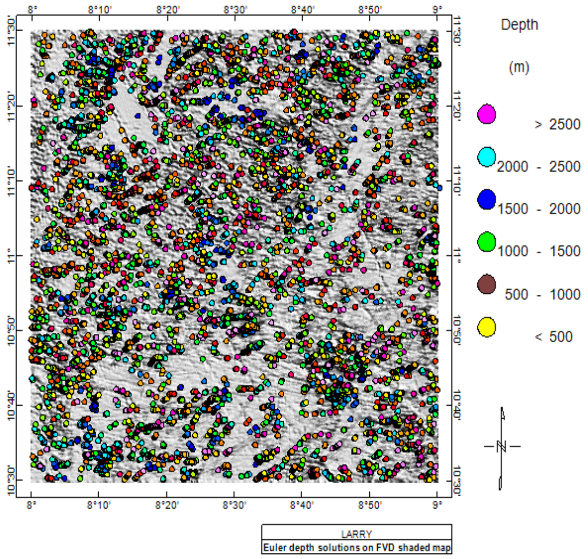

Fig. 8: Plot of Euler depth solution on the first vertical derivative shaded relief map

Figure 8 shows 3D Euler deconvolution solutions of the study area with depth ranging between 500 and 2500 m for all the lineaments. This gives an insight of approximate depth range of all the lineaments/ fractures across the whole map unlike Werner deconvolution which is profile biased.

Conclusion

The Werner and Euler deconvolution methods have proved effective in the estimation of depths to source of magnetic anomalous bodies using aeromagnetic data set.The depth and dip values obtained in this study, indicated that the lineaments/ fractures are relatively shallow structures and of similar trend to the Nigerian basement complex structures. The magnetic susceptibility values range from $1.8926x10^{-3}$ – $5.8118x10^{-3}$ SI units in the area, represent a variation in the mineral composition. This wide represents biotite, garnet, fayalite, olivine, phyllite, quartzite, dolomite, igneous rocks in the study area.

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