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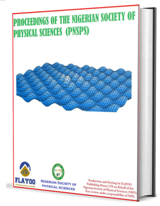

Application of Euler and Werner deconvolution techniques in delineating tin deposit in Okeso area, Southwestern, Nigeria

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ABSTRACT

The Okeso pegmatites field was evaluated using magnetic method within abandoned mining site close to the southeastern region of Ojoku area. The study aims to delineate, identify geological boundaries and determine depth of tin deposits in the area. The acquired magnetic data was enhanced with the combination of 3D Euler and Werner deconvolution methods. Five magnetic profiles were selected and carried out on the residual anomalies around the abandoned mine site at Okeso with three of the profile lines were in the NW-SE direction and two in the NE-SW direction. The residual magnetic anomalies showed the magnetic susceptibilities of $\leq 4.5118 \times 10^{-3}$ nT in the ore bearing pegmatite within the basement rocks. Results from profiles of Werner deconvolution identified some shallow tectonic structures like fractures, pegmatites and faults which are capable of hosting metallic tin deposits. The depth to the magnetic source varies from a minimum to a maximum of 300 m to 1200 m below the subsurface in all selected profiles, suggesting the shallow nature of the magnetic source in the area. Additionally, the dip angle ranges from 5.60 to 81.20, potentially attributed to Pan-African shallow structures according to the contact model. Solutions obtained from the structural index of contact and dyke reveals the presence of dyke formation and boundaries which separate rocks from one another. The trend of the lineaments/ fractures which were likely established during the Pan-African orogeny is dominant in the NE-SW direction, conforms with the trends obtained for basement structures in previous studies. Depth range produced by 3D Euler deconvolution is from 50 - 1000 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 area unlike, Werner deconvolution which is profile biased. The identical signature from all profiles implies that the tin deposit is relatively uniform, extending to a great depth in the area. This represents economically viable quantity and makes it a worthy target for investors.

Keywords: Okeso pegmatite, Aeromagnetic, Euler deconvolution, Werner deconvolution, Fractures

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1. INTRODUCTION

In order to investigate internal geological structures, especially in the search for ore deposits, it is essential to measure the Earth's magnetic field extensively [1]. Ore is deposited through dykes, folds, joints, and faults as a result of tectonic activity and the pas-

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sage of hydrothermal fluids. Magnetic prospecting techniques are a useful way to map these hidden structures. Ref. [2] claimed that identifying periodic discontinuities and pattern breaks in the magnetic fabric as well as figuring out the structural makeup of basement rocks are the two most important and accurate uses of magnetic data. The Werner deconvolution method is an appropriate methodology for determining depth because the total field from a thin dike created is comparable to the horizontal gradient of the total field induced by the edge of a thick interface body. Additional techniques for determining depth include the wavelet approach, local wave number methods, Werner deconvolution, Euler deconvolution, and spectral analysis. In general, the Werner deconvolution method performs better when it comes to dike depth estimate and contact delineation. This method falls under the category of automatic depth estimate techniques since it estimates the depth to the magnetic anomalies using vertical derivatives. According to Ref. [3], the Werner deconvolution function requires that the source bodies are contacts or dykes with unlimited depth extent. According to Ref. [4], airborne magnetic surveys are a highly successful method of defining the local geology and structure of basement terrains. Furthermore, as noted by Refs. [5–7], it is a quick, affordable, and adaptable geophysical technique for defining subsurface geological structures and rocks, especially in areas with restricted exposure.

In Nigeria, numerous aircraft geophysical surveys have been carried out to locate various geological features throughout the country using gravity, magnetic, and radiometric techniques. There has not been much subsurface geological mapping done in the same area. Despite this, not much research has been done to completely understand the intricate interaction between structural elements that are visible above ground and those that extend below it. The objective of this research is to locate the lineaments, or geological structures, in the southwest of (sheet 223). Using Euler and Werner deconvolutions, this entails characterizing their trends, aerial extents, and the depth to the top of magnetic bodies.

2. MATERIALS AND METHODS

2.1. LOCATION OF THE STUDY AREA

The study area (Figure 1) lies between 4°32′00" to 4°42′00"N and 8°00′00" to 8°30′00"E. Expressed in Universal Traverse Mercator (UTM) coordinates, it is located between 890,500-940,000 m N and 665,000-720,000 m E within Zone 31N of Minna Datum. It covers part of an adjacent half degree sheet of Ilorin (i.e. sheet 223) in the Nigerian topographical map with land area covered of 55 km × 55 km and elevation ranged between 162 and 659 m. The area falls within Asa Local Government Area located at the northwestern and southwestern part of Kwara State. It is surrounded by Moro local government to the north, Oyun and Offa local government to the South and Ilorin west local government to the East. Some towns within the study area include Ilorin, Igbaja, Oro, Ajese-Ipo, Offa and Erin-Ile [8].

2.2. GEOLOGICAL SETTING

Okeso is topographically situated in the northwest region of Nigeria, Ilorin Sheet 223, and the rocks there are part of southwest basement complex of the country. The geology of the crystalline basement rocks of the Ilorin Sheet, which constitute a component of the West African Craton, is roughly similar to that of the other basement rocks of southwest Nigeria, which have been extensively studied [9–12]. They consist of an Eburnean (2000-200 Ma) migmatite complex. The region's extensive magmatic activity caused the Older Granite series of Pan African age to be deposited. Basement rocks with crystals that range in age from fresh to weathered make up the lithologies beneath. Pegmatite, biotite, hornblende gneiss with intercalated amphibolites, porphyritic granites, and granite gneiss are the main crystalline rocks.

2.3. DATA ACQUISITION

The Nigerian Geological Survey Agency (NGSA), located in Abuja, provided high resolution aeromagnetic map (HRAM) sheet 223 (Ilorin) used for this paper. The geological survey of Nigeria funded a nationwide aeromagnetic survey, which is how the aeromagnetic data were collected. At a height of 80 meters, the data were collected along a sequence of NE-SW flight lines that were 500 meters apart. Half degree sheets and contoured maps with a 1:100,000 scale were the formats in which the data were released. Regional and residual fields make up the two components of the total magnetic field intensity (Figure 2).

2.4. DATA PROCESSING

The practice of removing spurious noise and signal from data that has nothing to do with the Earth's crust's geology is known as data processing. By narrowing down the data to only include signals pertinent to the area of interest, this procedure consequently gets the dataset ready for analysis. Verifying and modifying raw data, using a gridding routine, separating regional residuals, and applying enhancement techniques were all part of the processing of the aerial data used in this study. FUGRO (the contractors) made some corrections, such as eliminating the Earth's magnetic field's daily variations, aircraft heading, instrument variation, lag inaccuracy between the aircraft and the sensor, and inconsistent flight lines and tie lines. Zone 32 of the North Hemisphere's Universal Transverse Mercator (UTM) Coordinate System was coregistered with the geophysical data collection for the research area. Esri ArcGIS, Golden software (Grapher and Surfer) and Geosoft (Oasis Montaj) were the primary programs utilized for processing and improving the aerial geophysical data.

2.5. REGIONAL-RESIDUAL SEPARATION

Regional and residual fields make up the two halves of the total field aeromagnetic anomaly map (Figure 2). The regional component, which comes from deep-seated sources, is separated from the residual component, which is connected to local, shallow structures, using the regional-residual separation technique. Deeper homogeneity of the earth's crust is the cause of the huge characteristics shown as trends and flowing smoothly across extremely vast areas in the Regional Fields Aeromagnetic Anomaly Map (Figure 3) [13]. A best-fit first-degree polynomial fitted to the aeromagnetic data set using the least squares method was used to derive the residual field aeromagnetic anomaly map (Figure 3) from the RTE-TMI anomaly map (Figure 2).

Regional-residual separation according to the least squares criterion is defined as follows: the residual is equal to the square of the regional variation from the observed (measured). The resid-

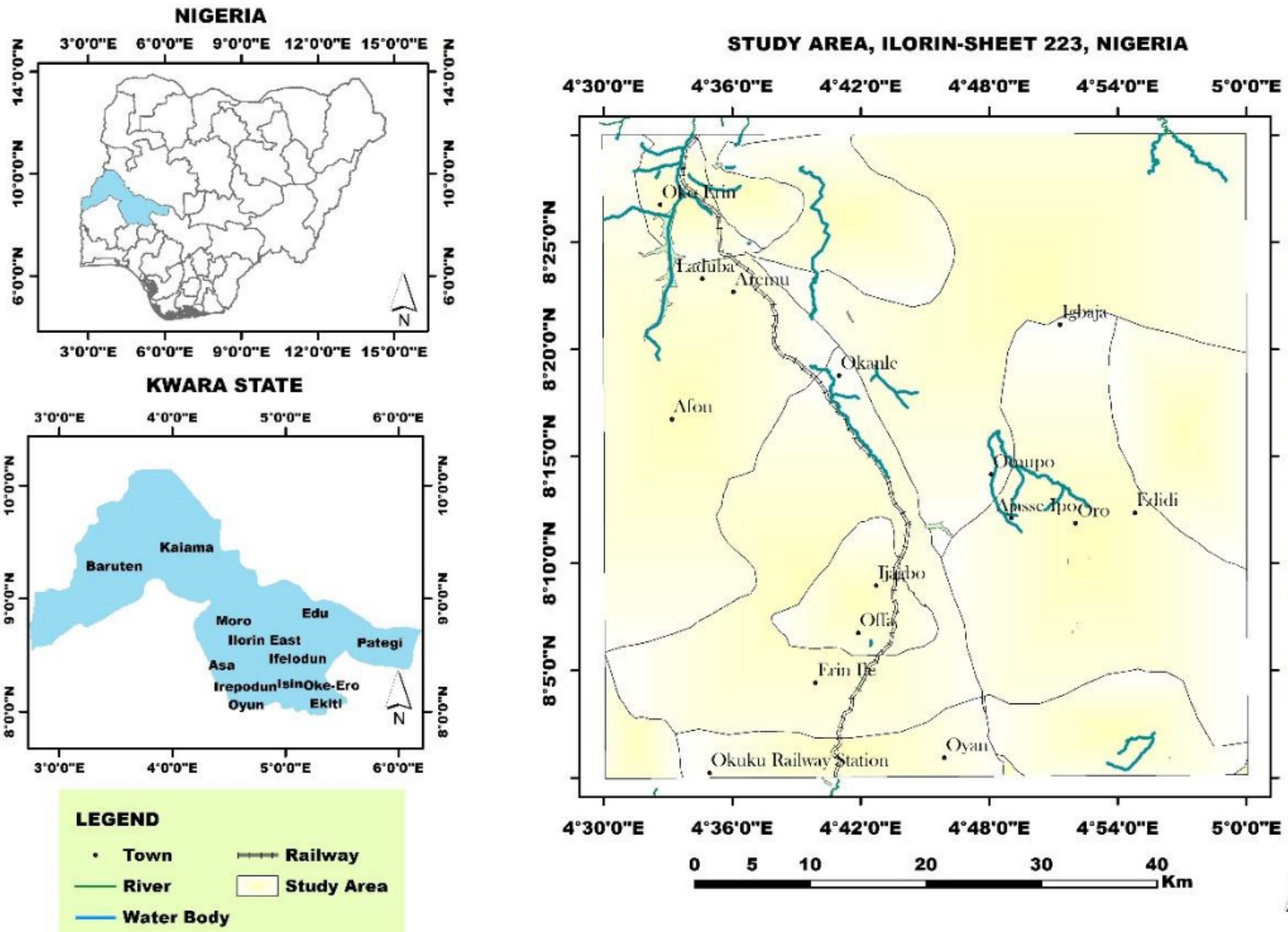

Figure 1. Location of the study area.

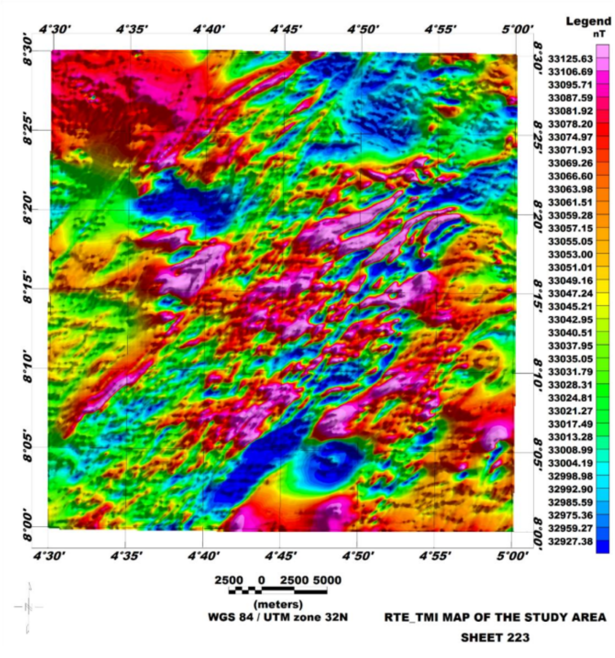

Figure 2. Total magnetic intensity map.

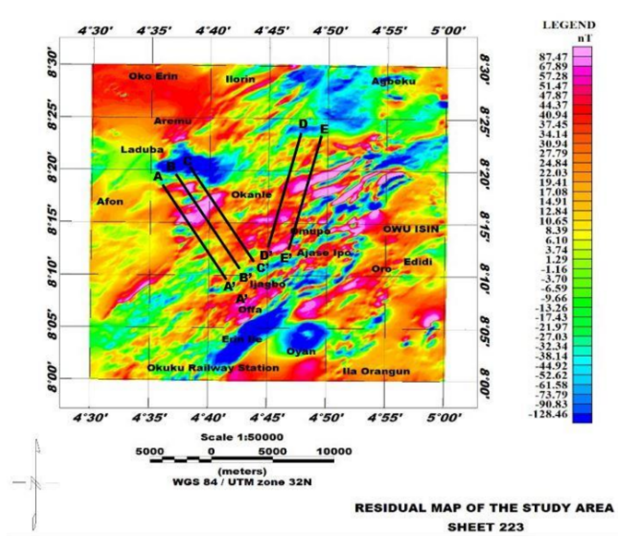

Figure 3. The residual intensity map.

ual features are exposed by the regional as a departure from the observed field using a polynomial surface. Fitting a trend (plane) surface, which can be described as a linear function of the geo-

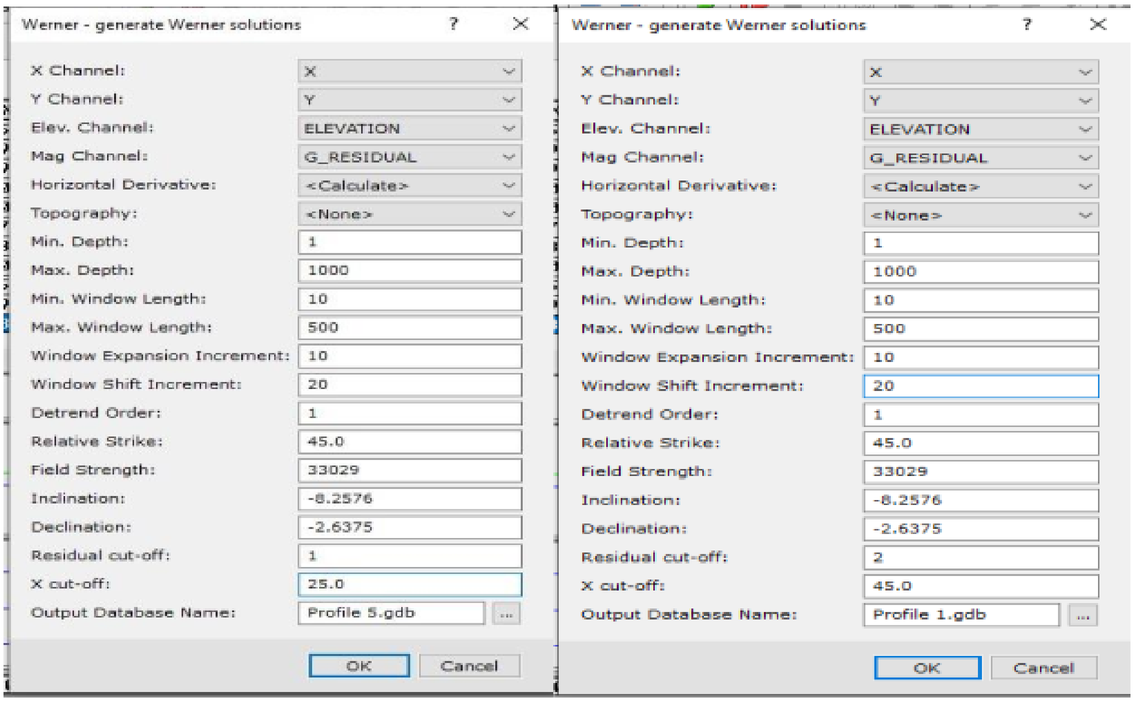

Figure 4. Werner deconvolution parameters used in aeromagnetic data processing.

graphic coordinates of a set of observations (in this example, the total magnetic field data), so constructed that the squared deviations from the trend are minimized, is the method used to split a data set into two halves.

Using Oasis software and a gridded approach with a grid cell size of 125 m, the residual magnetic field data set was derived as the deviations of the fitted plane surface from the overall magnetic field intensity. In order 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, four profiles (AA', BB', CC', and DD') were selected across the residual aeromagnetic map of the study area (Figure 3). Along the profiles, the data were automatically created.

2.6. WERNER DECONVOLUTION TECHNIQUE

This approach computes the depth to the top, susceptibility contrast, and dip of these features from a given total magnetic field profile by using the equations for the total field owing to thin sheets and edges of a thick body. The term "Werner deconvolution" is characterized by the linearization of a two-dimensional (2-D) inverse problem for the parameters of a magnetic dike or contact through the removal of rational functions that characterize the anomalies in the denominators [14].

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 [14].

The Werner deconvolution method is a fundamental theoretical formula, which can be expressed as a dike's equation.

$$F(x) = \frac{A(x - x_0) + Bz}{(x - x_0)^2 + x^2}, \quad (1)$$

where x is the distance along a profile that crosses a dike, the depth to the top of which is z, and the horizontal distance along the profile to the point directly above the top of the dike is x_0. F is the total magnetic field intensity at x. The constants A and B are contingent on the dike's magnetization and orientation. A, B, x_0, and z are the four unknown quantities.

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

$$x^2 F(x) = a_0 + a_1 x + b_0 F(x) + b_1 F(x), \quad (2)$$

where $a_0 = -A_1 x_0 + Bz$, $a_1 = A$, $b_0 = -x_0^2 - z^2$, 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 the equation.

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

$$x_0 = \tfrac{1}{2} b_1, \quad z = \pm\sqrt{-4b_0 - b_i^2}. \quad (3)$$

Since there are four unknowns, the equation can be solved simultaneously at four x values and the matching F values to find the answers for $y0$, z, and $y1$, as well as for y_0, y_1, and y_2. The geometric solution is finished in the simple situation. It is known how deep the thin sheet (dike) is at the top. Now that interference is a possibility, let's assume that it can be represented by a polynomial of some degree. Enhancement of the estimates of determining physical quantities x_0, z, A, and B is achieved by adding an interference term to the total magnetic anomaly equation in the form of a polynomial $C_0 + C_1x + C_2x^2 + \cdots + C_nx^n$.

$$F(x) = \frac{A(x - x_0) + Bz}{(x - x_0)^2 + x^2} C_0 + C_1x + C_2x^2 + \cdots + C_nx^n, \quad (4)$$

where the C's are the coefficients and n is the interference polynomial's order. There are now $(n + 5)$ unknowns in all, hence in order to solve for the unknowns, $(n + 5)$ points are needed. The source bodies can be separated into the following categories for direct interpretation.

Thin bodies, defined by their width equal to depth, are difficult to determine accurately. These bodies have distinct bounding edges and were used to calculate the total magnetic field. Ref. [15] provided the equation for the total magnetic field owing to thin dikes of any arbitrary dip.

However, Werner deconvolution analysis, which employs the Werner deconvolution operator as a sliding window that moves along a profile and continuously solves for the four unknowns, was done in this study using Geosoft. The operator's parameterization comprises three elements: (1) the size of the window of the anomaly, which will influence the estimated depth; (2) its movement on a profile, which regulates the quantity of solutions produced; and (3) parameters that eliminate noise-induced spurious solutions [16]. Compared to sedimentary rocks, basement rocks often have stronger magnetic susceptibilities. Therefore, the sedimentary structure, intrusive and extrusive volcanic bodies inside the basin or basement itself, or rarely variations in susceptibilities in materials within the basement are thought to be the origins of variations in the magnetic intensities over basement complexes. Five profiles which ran across the fault were selected, the parameters used in generating the solutions are shown in the Figure 4.

2.7. EULER DECONVOLUTION TECHNIQUE

The goal of the three-dimensional Euler deconvolution procedure is to create a two-dimensional grid map that displays the locations and accompanying depth estimates of geologic sources of magnetic or gravimetric anomalies [17]. The Standard 3D Euler approach is based on Euler's homogeneity equation, which may be understood as a structural index that links the potential field (gravity or magnetic) and its gradient components to the source locations through the degree of homogeneity N [18]. The approach not only assesses depth but also uses a structural index. When used together, the structural index and depth estimations can be used to locate and determine the depth of a range of geologic features, including dykes, faults, and magnetic contacts.

For every grid position inside a sub grid (window), the algorithm simultaneously solves Euler's equation using the least squares approach. Along each row, a square window with predetermined dimensions (number of grid cells) is dragged over the grid. A system of equations is solved at each grid point, yielding the four unknowns (x, y, and z, which represent the background value, depth estimate, and position in the grid, respectively), together with their standard deviations, for a particular structural index [19]. Ref. [18] demonstrated that the form of Euler's homogeneity relation might be expressed as:

$$(x - x_0)\frac{\partial F}{\partial x} + (y - y_0)\frac{\partial F}{\partial y} + (z - z_0)\frac{\partial F}{\partial z} = -N(B - T), \quad (5)$$

where the location of a magnetic source whose total field T is observed at (x, y, z) is denoted by (x_0, y_0, z_0). The regional value of the entire field is B. For thin two-dimensional dyke structures, the best estimates are obtained with a structural index of 1, whereas structural indices of 0 to 0.5 provide the best results for contacts. The specificity of the selected parameters, such as the grid cell size, window size, structural index, specified depth uncertainty tolerance, etc., determines the relevance of the position and depth estimates obtained by 3D Euler Deconvolution. According to the software Geosoft, the grid spacing and the wavelength of the anomalies to be examined should be taken into consideration while choosing the grid cell size units of 20.

3. RESULTS

3.1. WERNER DECONVOLUTION

The five aeromagnetic profiles' calculated depth estimates linked to magnetic basement dikes or faults/contacts are shown in Figure 5(a-c). These estimates produced more contacts (circles) than dikes (diamond shapes) for the field's horizontal gradient. Since there are differences in the magnetic fields at each of the five profiles' places of intersection, contact solutions rather than dike solutions result. This may provide as evidence that the contact-like solutions are cracks found in the research area's basement structures.

4. DISCUSSION

It is possible that the minerals move through these geologic structures as they form. The lineaments' variations in magnetic field intensity vary from profile to profile and run in a NE- SW direction at 1200 m depth, 0.0022462 nT of susceptibility, 5.60 dip angle, and 35.00 km horizontal distance (Figure 5a). The profile (Figure 5b) travels 33.00 km in a southwest to northeast direction. The magnetic susceptibility is 0.0029160 nT, the angle of dip is 81.20, and the depth to the source anomaly is 380 m.

A lineament that runs in an SW-NE direction was found to intersect the location of the reported tin mineralization. This magnetic anomaly was found to occur at a depth of approximately 700.0 m, with a susceptibility value of 0.0018926SI, an angle of dip of 20.90, and a horizontal distance of 30.00 km (Figure 5c). The horizontal distance in Figure 5d is approximately 30.00 km, the depth is 600.00 m, and the susceptibility value is 0.0058118SI. The angle of dip is 34.40.

The rocks with magnetic susceptibility values ranging from 1.8926×10^{-3} to 5.8118×10^{-3} nT are igneous rocks, specifically biotite, garnet, pegmatite, tourmaline, olivine, phyllite, quartzite, and dolomite [20, 21]. On the other hand, the rocks with dip angle values between 5.60 and 81.20 may be Pan African shallow structures. The anomaly in the dikes model is found at a deeper depth than that of the contact model [22], and the orientation of the lineaments/fractures is NW-SE, which is consistent with the patterns found for basement structures in earlier research [23, 24]. The Pan-African orogeny is most likely when the trends of the lineaments and fractures were developed.

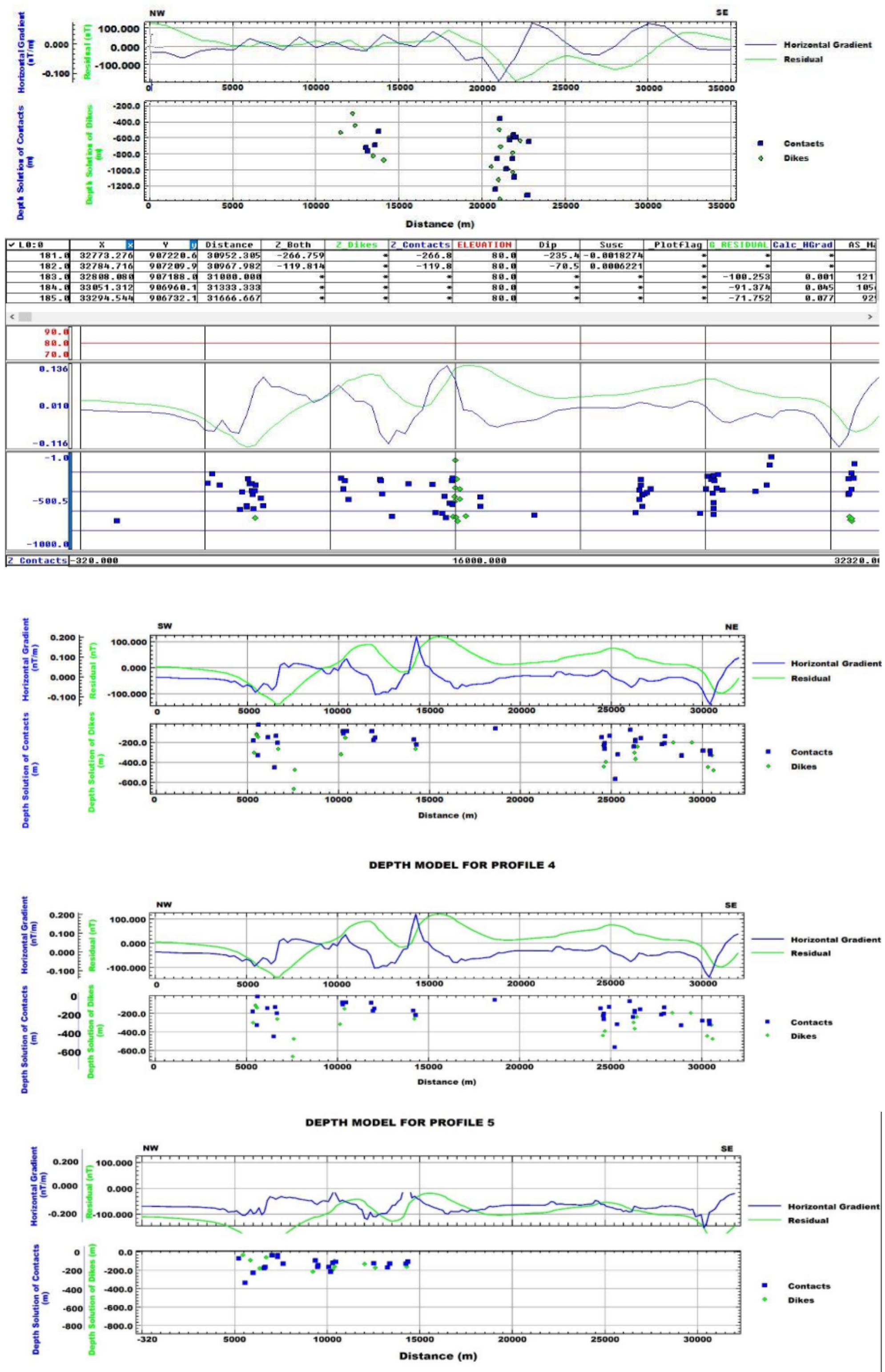

Figure 5. Depth model for Werner profile for 1 to 5.

3D Euler deconvolution solutions for all lineaments for the study area, with depths varying from 50 to 1000 m, are displayed in Figure 6. Unlike Werner deconvolution, which is skewed toward profiles, this provides an insight into the approximate depth range of all the lineaments and fractures over the entire map.

5. CONCLUSION

Using aeromagnetic data sets, the Werner and Euler deconvolution algorithms have shown to be useful in estimating the depths to the sources of magnetic anomalous entities. According to the study's depth and dip values, the lineaments and fractures are comparatively shallow structures with a tendency that is compa-

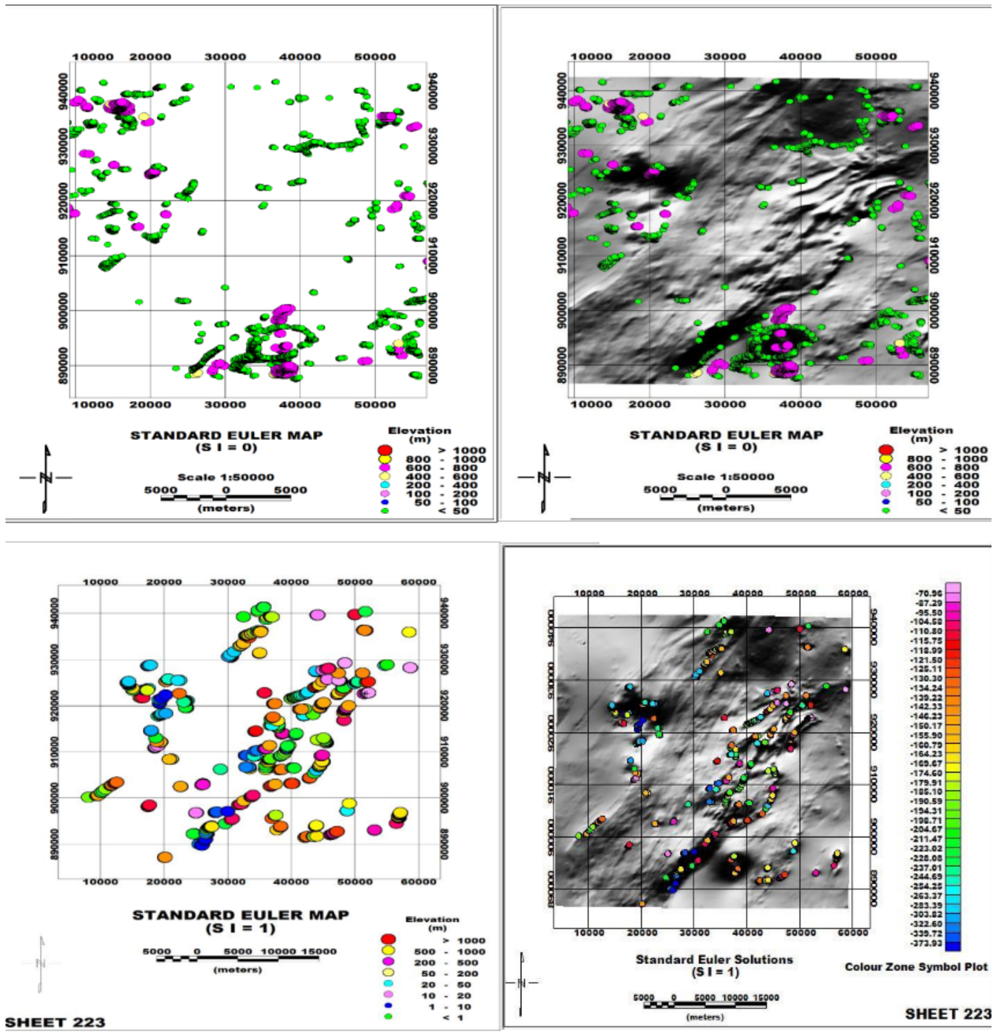

Figure 6. 3D Euler deconvolution for structural indices of 0 to 1.

rable to the complex basement structures seen in Nigeria. The range of magnetic susceptibility values in the region, which correspond to variations in the mineral composition, is 1.3416×10^{-3} to 4.5118×10^{-3} nT. This picture depicts the igneous rocks in the research area, including biotite, garnet, pegmatite, olivine, phyllite and quartzite.

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