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Werner Deconvolution Technique for the Interpretation of Residual Aeromagnetic Anomalies of Igbeti Schist Belt; Implication for Marble Exploration

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Abstract - Determination of the straight down range of geologic formation between geographic latitude 8.30 ^{0}N to 9 ^{0}N and longitude 3.30 ^{0}E to 4.30 ^{0}E of the Igbeti schist belt became a thing of interest due to the on-going exploration in the region. Aeromagnetic field intensity anomaly data of the bound were then acquired, separated off regional field and a corresponding residual map obtained was later used applying Werner deconvolution method filtering tool. Three magnetic profiles were selected and labelled for the interpretation on the residual anomalies. The result shows that the depth to magnetic source has a maximum value of 1,000 m toward the subsurface in all the profiles selected, indicating the shallow nature of the magnetic source in the area. Based on the structural index shown, it further reveals solutions for contact and dyke which indicates that there are boundaries which separate rocks from one another and the presence of dyke formation. The implication of identical signature from all profiles is that the marble deposit is relative uniform extending to a great depth in the area.

Keywords: schist, aeromagnetic anomaly, Werner deconvolution, depth to magnetic source

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Introduction

Background

The magnetic method is conceivably one of the ancient methods of geophysical exploration. It actually became a popular method a period after the World War II (Likkason, 2014). Currently, with exactness and perfections in instrumentation, direction-finding, and platform compensation, the method is now applied to map the entire crustal section at various scales from powerfully magnetic basement at a very great scale to feebly magnetic sedimentary contacts at slight scale. Other methods which include the magnetic data treatment, filtering, display, and interpretation have also advanced especially with the advent of high performance computers and colour raster graphics.

Effective applications of the magnetic method require an in-depth understanding of the basic principles of magnetism, the precautions in collections of data, removal of background noises, filtering, and interpretation. Interpretations may be limited to qualitative approaches which simply map the spatial location of anomalous subsurface conditions, but under favourable circumstances, the technological status of the method will permit more quantitative interpretations involving specification of the nature of the anomalous sources. However, it is conceived that no single geophysical method in its isolation can provide critical solution to a wide variety of problems. However, seldom does the magnetic method yield an unambiguous answer to an investigation problem. As a result, it is generally used in concert with other geophysical and geological data to limit its interpretation ambiguities.

The magnetic method has in recent times expanded from its initial use solely as a tool for finding iron ore to a common tool used in exploration for minerals, hydrocarbons, ground water, and geothermal resources. The magnetic method is now widely used in studies focused on water-resource valuation (Smith and Pratt, 2003), environmental pollution subjects (Smith *et al*., 2000), seismic hazards (Langenheim *et al*., 2004), geothermal resources (Smith *et al*., 2002), regional and local geologic mapping (Finn and Morgan, 2002), and mapping unexploded ordnances (Butler, 2001)

Magnetic anomalies arise from series of distortions of the magnetic field produced by magnetic material buried in the earth crust or perhaps the upper part of the mantle. Magnetic anomalies of geologic interest to explorationists are of two types: induced anomalies and remanent anomalies (Zohdy *et al*., 1990). Induced anomalies are the result from the earth field, and the intensity of magnetization depends on the magnetic susceptibility. Its direction also is the same as that of the earth field. Because of the dependence on the direction of the earth field, magnetic anomalies produced by similar bodies may differ widely with geographic location. Remanent anomalies are the result of "permanent" magnetization of a body and the amount of magnetization depends on the geologic history of the rock. Its direction is related to the local direction of the earth field at the time of formation of the rock. However, magnetic anomalies are a combination of the two types of which only the residual anomalies are of interest, and the regional anomalies due to earth materials are dominant and are ignored in the approximate interpretation of results (Yaoguo and Douglas, 1998).

Several types of information can be obtained from interpretation of magnetic surveys. The character of a magnetic anomaly is often indicative of the type of rock producing the anomaly, and an experienced interpreter can identify a foretell rock type on the basis of character of the magnetic anomalies observed. Quantitative interpretation of individual magnetic anomalies yields information such as depth of burial, extent, other geologic arrangement, and magnetic properties of rock units. The most common use of magnetic data in Geophysics is to map the depth to the magnetic basement rock (Zohdy *et al*., 1990).

The Werner deconvolution method is a suitable technique of the depth determination method due to the fact that the horizontal gradient of the total field caused by the edge of a thick interface body is equivalent to the total field from a thin dike designed. Other methods of depth determination include the Spectral analysis, Euler deconvolution, Werner deconvolution, the Wavelet method, and the Local Wave Number Methods. The Werner deconvolution method is principally better at delineating contacts and dyke depth estimation. This technique belongs to automatic depth estimate methods as it uses vertical derivatives to estimate depth to the magnetic anomalies. The Werner deconvolution function assumes the source bodies to be either dykes or contacts with infinite depth extent (Ku and Sharp, 1983). This research is carried out in order to predict depth to magnetic sources (dyke and contact) using Werner deconvolution method in the interpretation of geophysical magnetic data over Igbeti marble deposit area of Nigeria. The method also separates an anomaly from the interference caused by adjoining anomaly which will ensure accurate result. The specific objectives of this work are to estimate the depth to top of both dyke and contact solutions within the area.

Geological/Stratigraphical Setting

The studied area, Igbeti, is a town located in the northern part of Oyo State, Nigeria. The area lies between the coordinates of 8.5 ^{0}N to 9.0 ^{0}N latitude and 3.5 ^{0}E to 4.5 ^{0}E longitude. Igbeti is known as Marble City, because almost all her land is rich in marble, based on the past studied and mining activities going on there. Igbeti is also called 'Onile Oye' (the land of winter) which she derived from her endless cool weather. The geology of the area is largely characterized by incessant granitic outcrops of old Precambrian basement complex (Figure 1). This results in an intense undulating surface feature. Thus, the characteristic winter in the area could be a result of convention current of the land breeze originating from the high-rise outcrops present in the area.

The Basement Complex rocks cover almost 100% of the total land surface area of Oyo State (Ayinla, 2014). With these composite of rocks, Oyo State of Nigeria has various minerals ranging from metallic, non-metallic, to industrial minerals, and various grades of gemstones. Igbeti falls within the schist belt zone of the state known for complex geology and mineral resources endowment, and hosts the semiprecious and precious metals, base metals, and gemstones.

Methods and Materials

Working data were acquired from High Resolution Aeromagnetic (HRAM) Data compiled by Furgo Airborne Service on behalf of the Nigeria Geological Survey Agency (NGSA) in 2009. The Composite Total Magnetic Field Intensity (CTMI) map of sheets 200 and 201 were obtained in comma-separated values (csv) format and in a half degree sheet from NGSA. The total magnetic field intensity (Figure 2) consists of two components; regional and residual fields. The TMI field data was there after filtered off the regional field to produce the residual field map of interest which is later used for the interpretation (Figure 3). Polynomial fitting of the first order was employed in this research in order to separate the two components to obtain the said residual field of interest.

The equation of the total magnetic field for a thin dyke with infinite strike length and depth extent had been given by Usman *et al.* (2014) as:

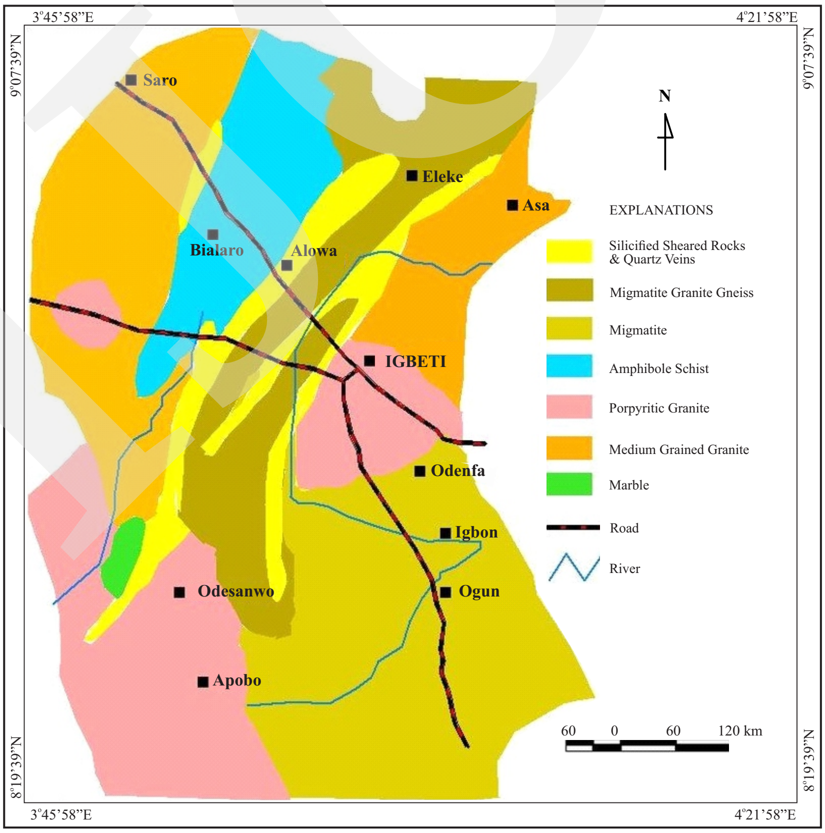

Figure 1. Geological map of Igbeti area (Layade *et al*., 2016).

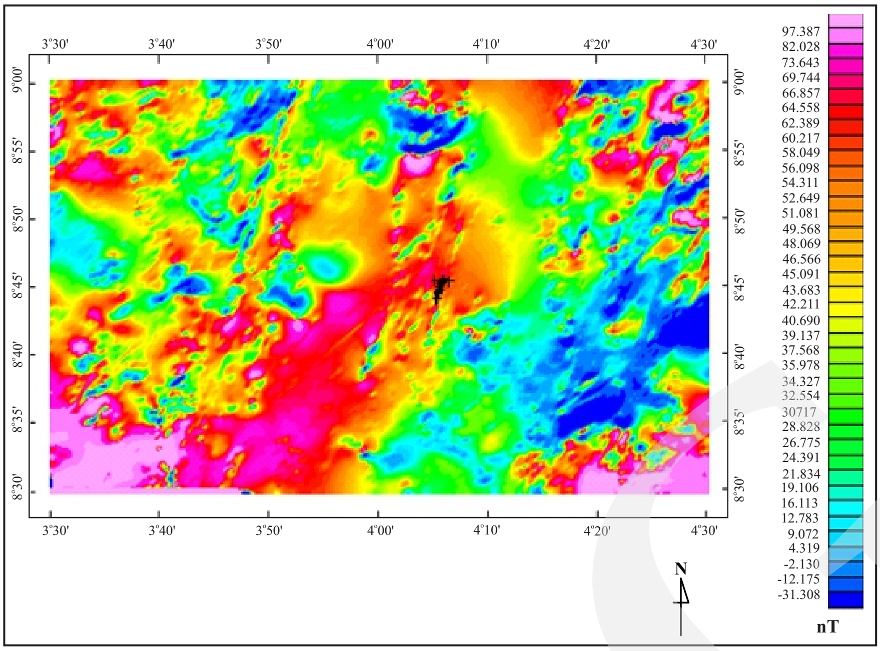

Figure 2. Total magnetic intensity map of the studied area.

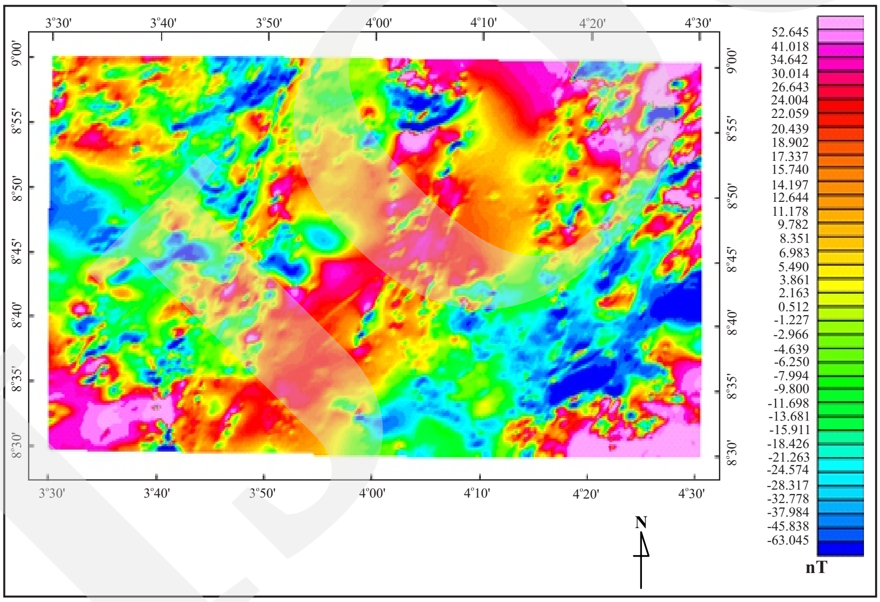

Figure 3. Residual map of the TMI.

$$F(y) = \frac{A(y-y_0)+Bz}{(y-y_0)(y-y_0)+z^2} \quad \text{........................ (1)}$$

where:

F is the intensity of the total field;

y_0 is the distance between the pragmatic point and the estimate of the top of dyke;

y is the expanse along the profile;

z is the distance to the top of the dyke from the pragmatic point, and;

A and B are the functions of the field strength, susceptibility, and geometry of the dyke (Telford *et al*., 2001). The Equation (1) can be written in:

$$y^2F(y) = -Ay_0 + Bz + Ay + 2y_0yF(y) - y_0^2F(y) - z^2F(y) \quad \text{..................... (2)}$$

if it is substituted into Equation (2)

$a_0 = -Ay_0 + Bz$

$a_1 = A$

$b_0 = -y^2 - z^2$ and

$b_1 = 2y_0$

and then there is:

$$y^2F(y) = a_0 + a_1y + b_0F(y) + b_1yF(y) \quad \text{.... (3)}$$

The depth (z) and the surface point directly above the centre of the point of the dyke (y) can be determined from the solution of Equation (3) using the relation:

$$y_0 = \frac{1}{2}b_1 \text{and } z = \pm\frac{1}{2}\sqrt{-4b_0 - {b_1}^2} \quad \text{........... (4)}$$

The susceptibility and dip can be obtained from the functions *A* and *B*.

If there is a possibility of interference and assume that the interference can be represented by a polynomial of some degree, the interference polynomial can be added to Equation (1), resulted in Equation (5) as follows:

$$F(y) = \frac{A(y-y_0)+Bz}{(y-y_0)(y-y_0)+z^2} + C_0 + C_1y + C_2y^2 + \cdots + C_ny_n \quad \text{...................... (5)}$$

where *n* is the order of the interference polynomial and *C0, C1, C2*... are the coefficients. There is a total of ($n+5$) unknowns and therefore ($n+5$) equations and ($n+5$) points are required to solve for the unknowns (Hartman *et al*., 1971). A first or second order polynomial is generally sufficient, so that six or seven points are required for solution.

Ku and Sharp (1983) added interference terms in the form of a polynomial $c_0 + c_1 + c_2y^2$ to the total magnetic anomaly to take into consideration the main dipole field and regional gradient as follows:

$$F(y) = TMAG = \frac{A(y-y_0)+BD}{(y-y_0)(y-y_0)+D^2} + C_0 + C_1y + C_2y^2 \quad \text{....................... (6)}$$

Upon rearrange, there is

$$a_0 + a_1y + a_2y^2 + a_3y^3 + a_4y^4 + b_0F(y) + b_1yF(y) = y^2F(y) \quad \text{............................. (7)}$$

where:

$a_0 = -Ay_0 + BD + C_0D^2 + {y_0}^2C_0$

$a_1 = A - 2C_0y_0 + C_1D^2 + C_2D^2$

$a_2 = C_0 - 2C_1y_0 - C_2{y_0}^2$

$a_3 = C_1 - 2C_2y_0$

$a_4 = C_2$

$b_0 = -{y_0}^2 - D^2$

$b_1 = 2y_0$

If there is the value of $F(y)$ at seven appropriate points, it should be able to obtain the values of these seven unknowns simply by solving seven simultaneous linear equations. In terms of these unknowns, there is:

$y_0 = \frac{1}{2}b_1$

$D = \sqrt{-b_0 - {y_0}^2}$

$C_2 = a_4$

$C_1 = a_3 + 2y_0C_2$

$C_0 = a_2 + 2C_1y_0 + C_2{y_0}^2$

$A = a_1 + 2C_0y_0 - C_1D^2 - C_2D^2$ and

$B = \frac{1}{D}[a_0 + Ay_0 - C_0D^2 - C_0y^2]$

Results and Analysis

Three preferred profiles across the existing marble mining pits in the area were chosen across the residual anomaly map, *i.e.* Lines 1, 2, and 3 (Figure 4) for the purpose of depth estimation along the profiles. The results were then analyzed along each profile.

Profile 1

This profile, about 11 km long traverses across the mining sites in the studied area. The

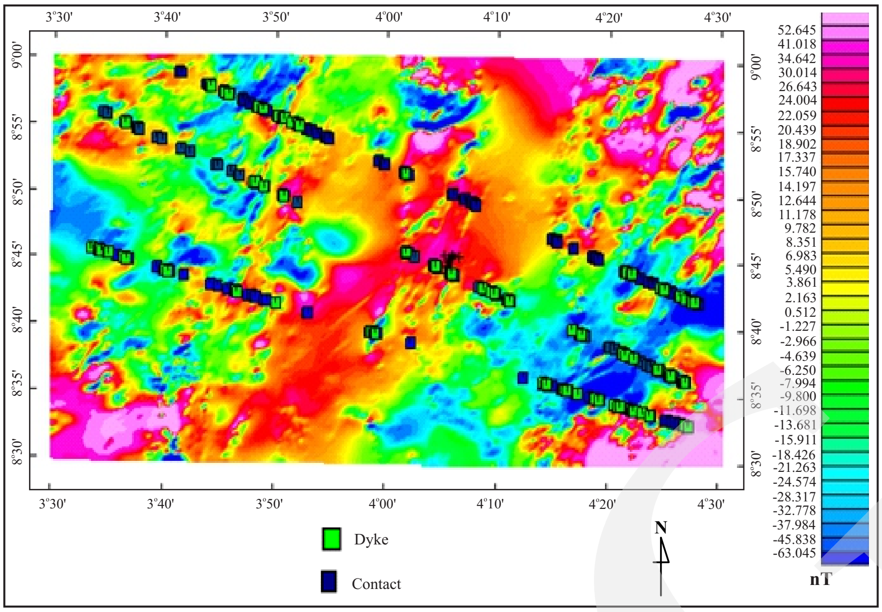

Figure 4. Residual map of the studied area showing selected profile Lines 1, 2, and 3.

residual field range is between -0.1 nT and +0.17 nT (Figure 5a). Along this profile, there are about 107 solutions generated for both dyke and contact models with about 18 for dyke solutions and others for contact (Figure 5b). Generally, the depth to basement range for both dykes and contacts along the profile is 0 m – 950 m. The solution of depth to basement for contact model ranges from 10 m to 950 m and for dyke ranges from 120 m to 900 m.

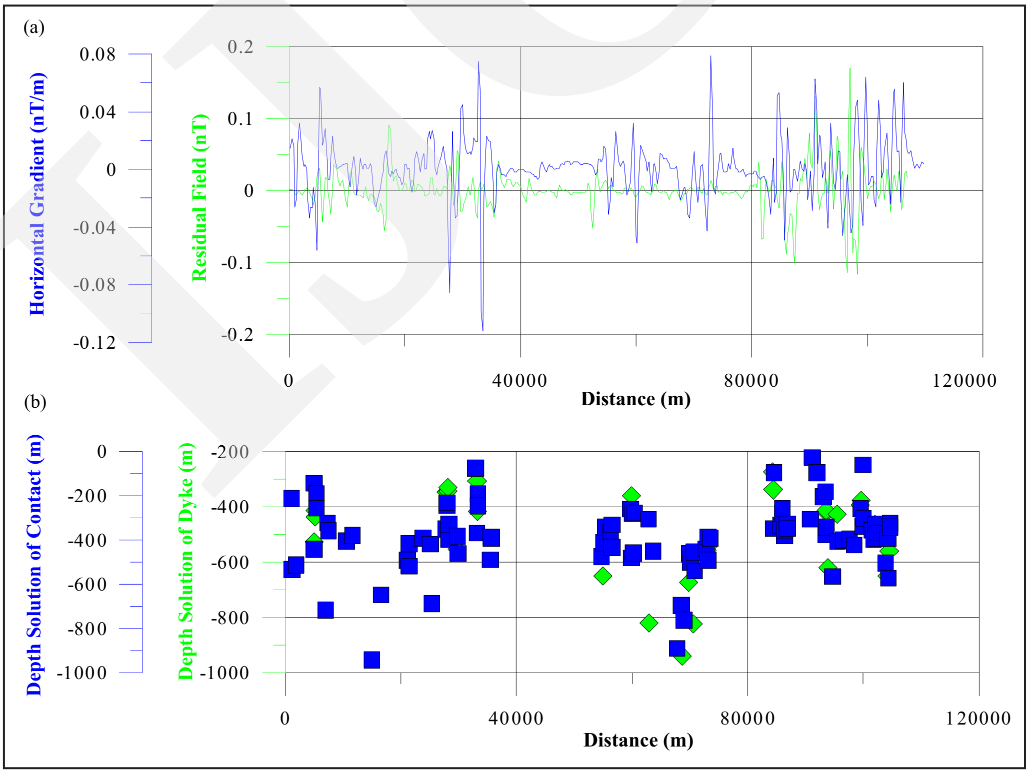

Figure 5. Werner depth solution plot for profile Line 1.

Profile Line 2

This profile, selected slightly above profile 1 is about 95 km in length across the studied area. The residual field range is between -150 nT and +40 nT (Figure 6a). Along this profile, there are about 106 solutions generated for both dyke and contact model with about 12 for dyke solutions and others for contact (Figure 6b). Generally, the depth to basement range for both dykes and contacts along the profile is 0 m - 1,000 m. The depth to basement solution of contact models ranges from 200 m to 1,000 m and that of dyke ranges from 500 m to 1,000 m.

Profile Line 3

This profile, selected slightly below profile Line 1 is about 11 km in length trending in the NE - SW of the studied area. The residual field range is -175 nT to +50 nT (Figure 7a). Along this profile, there are about 120 solutions generated for both dyke and contact model with about 35 for dyke solutions and others for contact (Figure 7b). The depth ranges to basement along the profile vary from 5 m to 850 m. The depth to basement solution of contact models ranges from 350 m to 800 m, and that of dyke ranges from 300 m to 800 m.

The Total Magnetic Field Intensity over Igbeti schist belt produced clearest anomalies which cut diagonally older rocks in the terrain as shown in the profile Lines 1, 2, and 3. There are often a strong remanent magnetization due to rapid cooling and considerable amount of magnetite minerals present (Maunde *et al.*, 2013). An enigmatic feature of the dyke anomalies is the regular shape of their anomaly along strike lengths, often showing a consistent direction of remanent magnetization.

The basement depth depicts the depth of solutions of dyke and contact models within the marble schist belt. It is evident that the area has a depth associated with magnetic anomalies at a range of about 0 – 1,000 m. The depth of the dyke solutions ranges from 0 – 1,000 m, while that of the contact solutions ranges from 120 m to 1,000 km all through the profile lines drawn in the schist belt. The areas with higher depth, may define some intrusive which may be associated with the many dyke solutions within the basement geology of the Igbeti marble schist belt.

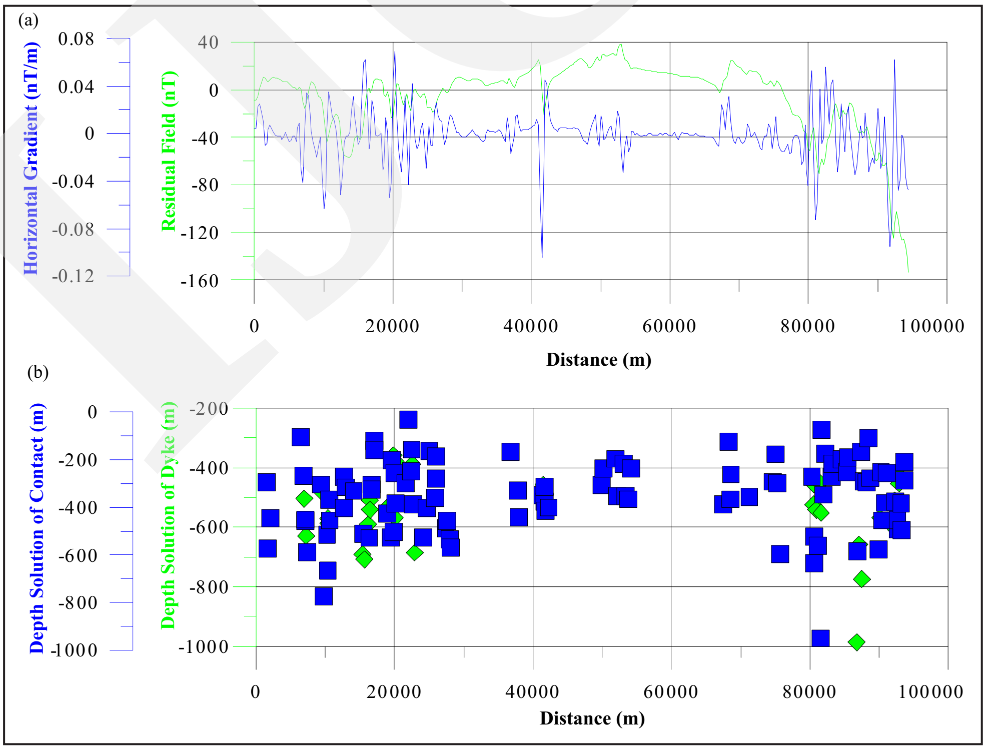

Figure 6. Werner depth solution plot for profile Line 2.

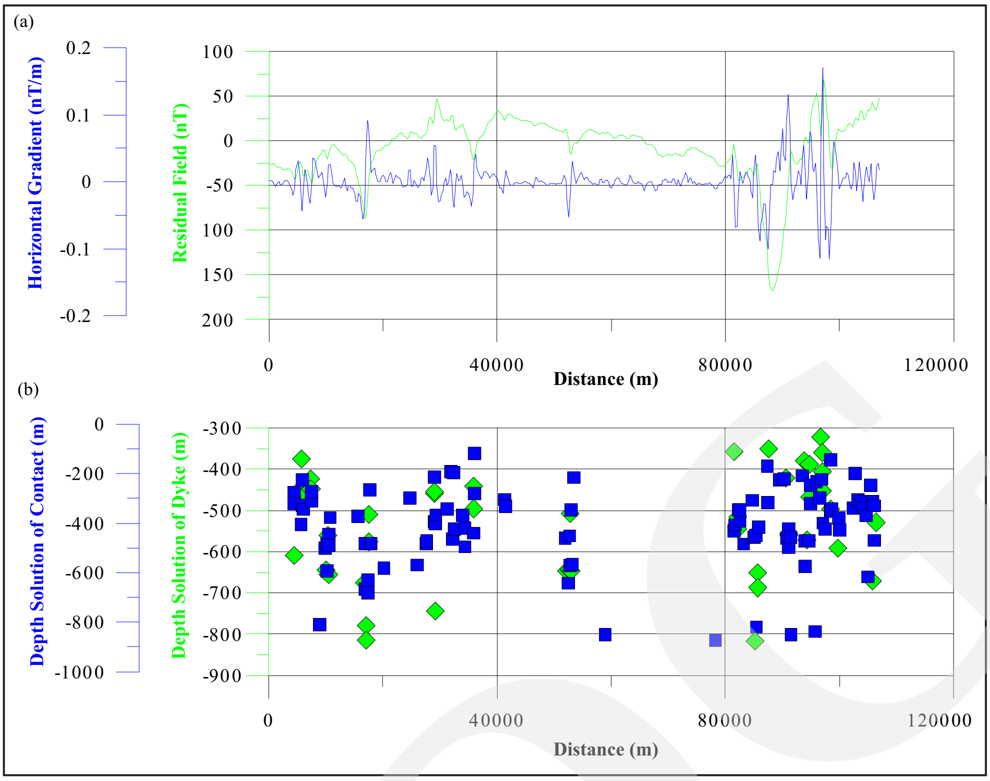

Figure 7. Werner depth solution plot for profile Line 3.

Conclusions

The depth of the Igbeti geologic basement was estimated as 0 – 1,000 m with Werner deconvolution process. It could also be observed that there are enough contact solutions than the dyke solutions at different depth ranges within the studied area implicating that there are geological boundaries separating rock bodies from another. The estimated location, depth, and width of the Igbeti schist dyke would assist miners to easily mine the dyke for construction and other purposes. The method can also be applied to field data and extended to gravity anomalies.

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