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Estimations of Depth to Magnetic Contacts and Dykes of Extended Areas in a Typical Southwestern Basement Terrain Using Aeromagnetic Data

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Abstract

Aeromagnetic data of an extensive area covering sheets 243 and 244 (Ilesa-Ado-Ekiti) from the Nigerian Geological Survey Agency (NGSA) were subjected to data enhancement filters and thereafter profiled into eleven (11) lines and interpreted quantitatively using forward modeling method to estimate depths to magnetic dykes and contacts of all lines. The profile depths solution revealed depths to dykes ranged from 209 – 494 m and depths to contact ranges from 35 – 498 m. Also, Euler De-convolution solution of structural index one (1) used to model dykes revealed depths ranging from 177-4389.8 m while Euler De-convolution of structural index 0.5 used to model contacts revealed depths ranging from 162-3262.8 m. Lastly, the Local Wave Number (LWN) result showed that depths to the magnetic contacts ranges from 277.2-4529.7m and which resolved best for deepest seated contact. The results obtained from this work are vital information for recognition of geological features such as contacts and dykes.

Key words:

Geological features, Lineament, Euler deconvolution, local wave number, magnetic contacts

Citation:

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1. Introduction

The depth to magnetic source is very important in geological and geophysical interpretation of subsurface structures. There have been many research literatures on estimation of depth of a source from magnetic data in which different techniques have been developed to estimate that magnetic source depth [1,2]. At a profound depth in the earth, solid rock melts due to its high ambient temperature to form a magma which intrudes into cracks or fractures within a rock and solidifies to form younger rocks. This also applies to lava which is a magma that erupts to the surface where it rapidly cools to form a rock. As a result dyke and sill are forms of intrusive igneous rocks as they are formed in crack or fracture of their country rock hosting them[3].

A dyke is a sheet of rock that forms in a fracture or crack within pre-existing rock body or host country rock and cut the old rock vertically. It can either be magmatic or sedimentary in nature. Magmatic dykes are consequent to flow of magma into a crack which solidifies as layers or mass of rock [4,5].They can be of any igneous composition ranging from deep-sourced high temperature ultramafic rocks to lower temperature silica-rich felsic rocks. Their presence is an indicator of some large scale tectonic event in the past, which strained the rock allowing the magma to flow in it [4,6].

In general, the obvious formation of dykes and sills is linked to the metal rich fluids movement and magma which solidified in a cracks or fractures within country rocks and this explains the origin of many metal mineral deposit types as they are in many cases metal bearing rock that results from this magma movement or intrusion. Magnetic contact is actually the top of basement rock or country rock hosting other geological features such as dyke, sills, fracture, fissures, veins, fault and many more [7,8].

The study area considered extends from Ilesha to Ado-Ekiti, Southwestern Nigeria, covered by the knitted sheet (combined sheet of 243 and 244) as seen in figure 1. The investigated areas are located between latitudes 4°30ˈ and 5°30ˈ and longitudes 7°30ˈ and 8°30ˈ and a single map of this extent was obtained by knitting the aeromagnetic maps of Ilesha and Ado-Ekiti.

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This research is focused on depths to magnetic contacts or basements and dykes present in host basements of the investigated areas (Figure 1). This is possible due to contrast in magnetic anomalies of the subsurface features.

Figure 1. Location of Study Area (Ilesa-Ado-Ekiti, Southwestern Nigeria) [9]

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1.1 Geology of the Study Area:

The geology of the study area is majorly crystalline (Precambrian basement complex) and sedimentary rocks (Cretaceous recent sediments). The investigated area is located between latitudes 4°30ˈ and 5°30ˈ and longitudes 7°30ˈ and 8°30ˈ and a single map of this extent was obtained by knitting gridded maps of the aeromagnetic data of Ilesha and Ado-ekiti. The different areas merged together are extension of another and they have similar geological formation. The regions covered by the extended map (Ilesha and Ado-ekiti) rocks are older granite (found in Ibokun and ado-ekiti), undifferentiated metasediment (found in Ilesgha, Oshogbo, Ikogosi) and undifferentiated basement (found in Ilesha, Ibokun, Ifelodun, Effon-alaiye, Ijero-ekiti, Egosi, Ewe, Otun, Ado-ekiti, and Ifaki) and quartzite (found in Ikogosi, Erinmo and Effon-alaiye) as seen in Figure 2. The study area is a fragment of the basement complex of southwestern Nigeria as described by [10]. The basement complex of Nigeria is zoned in the western part of the Pan-African shield as described by [11] occurring in the mobile zone of the Pan-African reactivation area between the West-African craton to the west and the Congo craton to the southeast. The geology comprises of Precambrian rocks that are representative for the basement Complex of Nigeria [12]. The study area is occupied by granite-gneiss, amphibolite, schist, muscovite schist, quartzite and quartz-schist [13,14,15]. Similarly the rocks are structurally distributed into two main segments by two major fracture zones known as the Iwaraja faults in the eastern part and the Ifewara faults in the western part [16]. All these assemblages are associated with migmatitic gneisses and are cut by a variety of granitic bodies [12,17,18]. The gneiss-migmatite complex contains migmatitic and granitic, calcareous and granulitic rocks and the intrusive suite comprises essentially of Pan African (c.600 Ma.) granitic units [8,12,16,19].

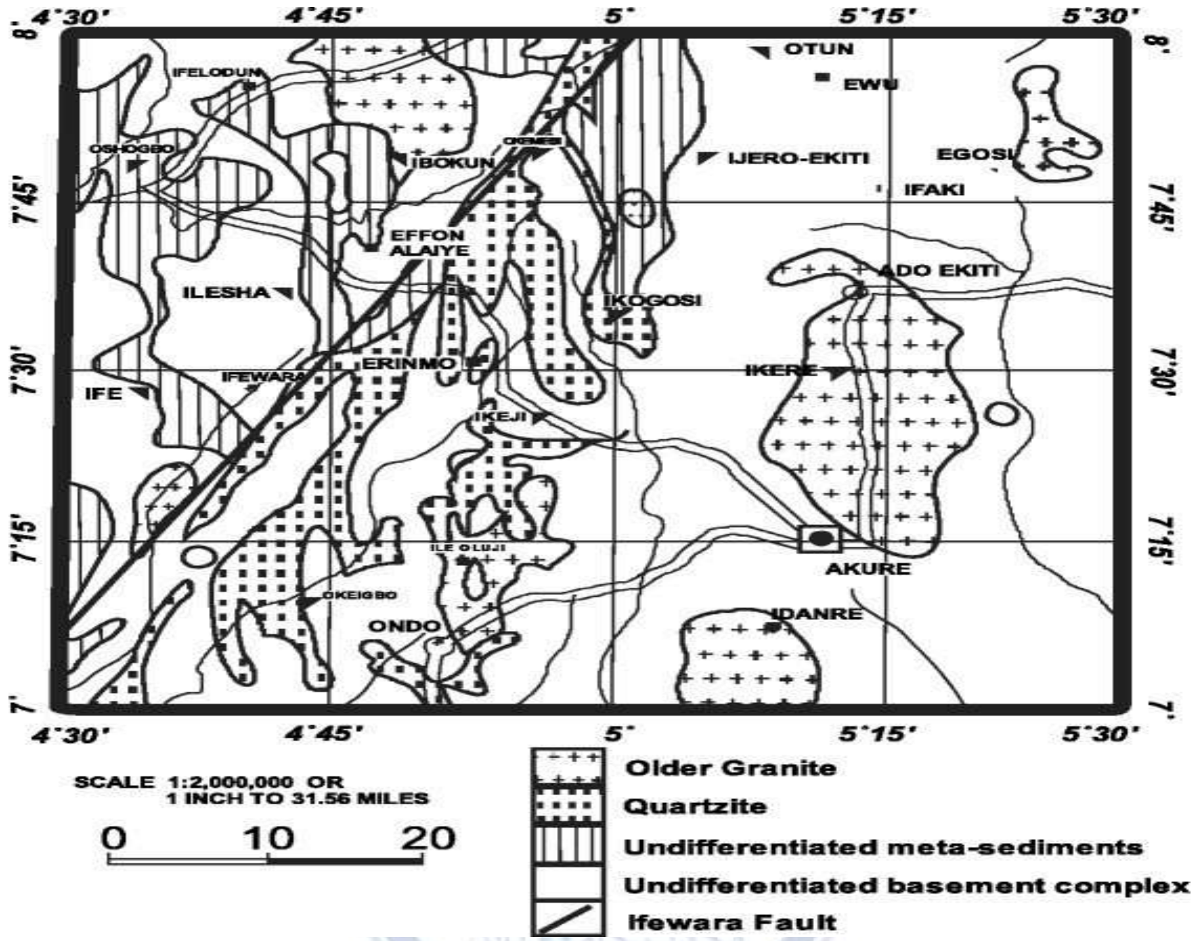

Figure 2. Geological Map of the Study Area [19].

1.2 Theoretical Background

The performance of magnetic fields can be characterized by a vector quantity called magnetization, M. The magnetic induction B, which is made of the ambient earth's field and magnetic material in the subsurface is related to M by:

$$B(R) = \frac{-\mu_O}{4\pi} \int M\,(R_O).\ddot{\nabla}_o \frac{1}{R-R_o} dV_o \qquad (1)$$

Where:

μ_O is known as permeability of free space

R and R_0 are the observation and source locations, respectively.

B represents the total magnetic field, Magnetic moment (M) and change in volume, dV_o.

$$B = \mu_0(1-k)H = \mu\mu_0 H \quad (2)$$

Where:

k is the magnetic susceptibility, H is the magnetizing force, μ is the magnetic permeability.

The earth's magnetic field, B, varies between 20,000nT in the equator and 60,000 nT at the pole [8].

1.2.1 Euler De-Convolution

The Euler De-convolution is measureable analytical tool and solution of potential field problem that applies forward modeling to detect irregular sources and define their depths by De-convolution using Euler's homogeneity relation [20,21,22,23]. The Euler's homogeneity equation links the magnetic field and its gradient components to the location of the source of an anomaly, with the degree of homogeneity expressed as a structural index [8]. The apparent depth to the magnetic source is derived from Euler's homogeneity equation (Euler De-convolution). The structural index (SI) is a measure of the fall-off rate of the field with distance from the source. Euler's homogeneity relationship is written for magnetic data as:

$$(x-x_0)\frac{dT}{dx} + (y-y_0)\frac{dT}{dy} + (z-z_0)\frac{dT}{dz} = N(B-T) \quad (3)$$

Where:

$\frac{dT}{dx}, \frac{dT}{dy}$ *and* $\frac{dT}{dz}$ represent first order derivatives of the magnetic field along x-, y-, and z-directions respectively. Likewise (x_0, y_0, z_0) is the position of a magnetic source, whose total field magnetic anomaly at point (*x*, *y*, *z*) is T and the regional field is B. *N* is structural index which is the amount of rate of decay of field with distance and adopts altered values for diverse forms of

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magnetic source. The structural index (SI) is governed the geometry of the source and its variance as shown in table 1.

1.2.2 The P Depth and Analytic Signal Estimation

The P depth is an extension in Oasis montaj [24] that can be used to calculate depth to contact and dyke using analytical signal Hilbert Transform. The analytic signal is the square root of the sum of the squares of the derivatives in the x, y, and z directions:

$$|A(x,y)| = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2} \qquad (4)$$

The analytic signal is useful in locating the edges of magnetic source bodies, particularly where remanence and/or low magnetic latitude complicates interpretation. Euler De-convolution is often used. However, when applied to map data, it can be difficult to search through the many solutions it produces when looking for local clusters that can indicate the locations of the corners of magnetic source bodies. The analytical signal technique first calculates the analytical signal of the input profile using a Hilbert Transform. Local peaks in the analytical signal profile are interpreted as corners of source bodies and the shape of the peak contains information about the depth to the corner in the absence of high-frequency noise and aliasing [25,26,27,28].

1.2.3 Local Wave Number Method (LWN)

LWN is a quick, easy and powerful forward modeling technique centered on addition of complex analytical signal and used for estimating depths of magnetic sources. It accuracy has been verified to be ±20% in tests on real data with drill hole control. The accuracy is similar to that of Euler De-convolution. However LWN has advantage that it produces a more complete set of harmonized solution points and is easier to use [26]. This technique is applied for 2-D slopping contact and 2-D dipping thin-sheet. For the dipping contacts, the maxima of LWN (K), are positioned right over the remote contact edges and are not dependent of the magnetic field inclination, dip, declination, strike and any remanent magnetization. The depth is estimated without assumptions about the thickness of the source bodies. For magnetic field, M, the local wave number [28] given by:

$$K = \frac{\frac{\partial^2 M}{\partial x \partial z}\frac{\partial M}{\partial x} - \frac{\partial^2 M}{\partial x^2}\frac{\partial M}{\partial z}}{(\frac{\partial M}{\partial x})^2 + (\frac{\partial M}{\partial z})^2} \quad (5)$$

The depth is calculated at the source edge from the reciprocal of the local wave number (K).

2. Materials and Methods

Aeromagnetic data obtained from the Nigeria Geological Survey Agency [9] on a total magnetic intensity map scale of 1:100,000 were filtered and interpreted to give result for our set objectives. These data were two separate sheets of neighboring areas. A process of gridding, spike elimination was carried out earlier to other filtering tasks to give the target result. The two separate gridded data were knitted together to form a single grid. This single (resultant) grid was passed through butterworth filter and subsequently Gaussian and reduction to equator filters (Figure 1). Reduction to equator field map was made in to profiles of eleven. The quantitative interpretation methods were carried out on the reduction to equator field of eleven profiles using Euler extensions, Source parameter imaging extension and P-depth extension of Oasis Montaj to produce forward modeling results of the RTE field data which were passed through them. And all the aforementioned extensions are depth finder extensions which either estimate depth to magnetic contact or dyke/sill or both. The gridded maps made with Oasis Montaj were later passed into Surfer for more quality maps.

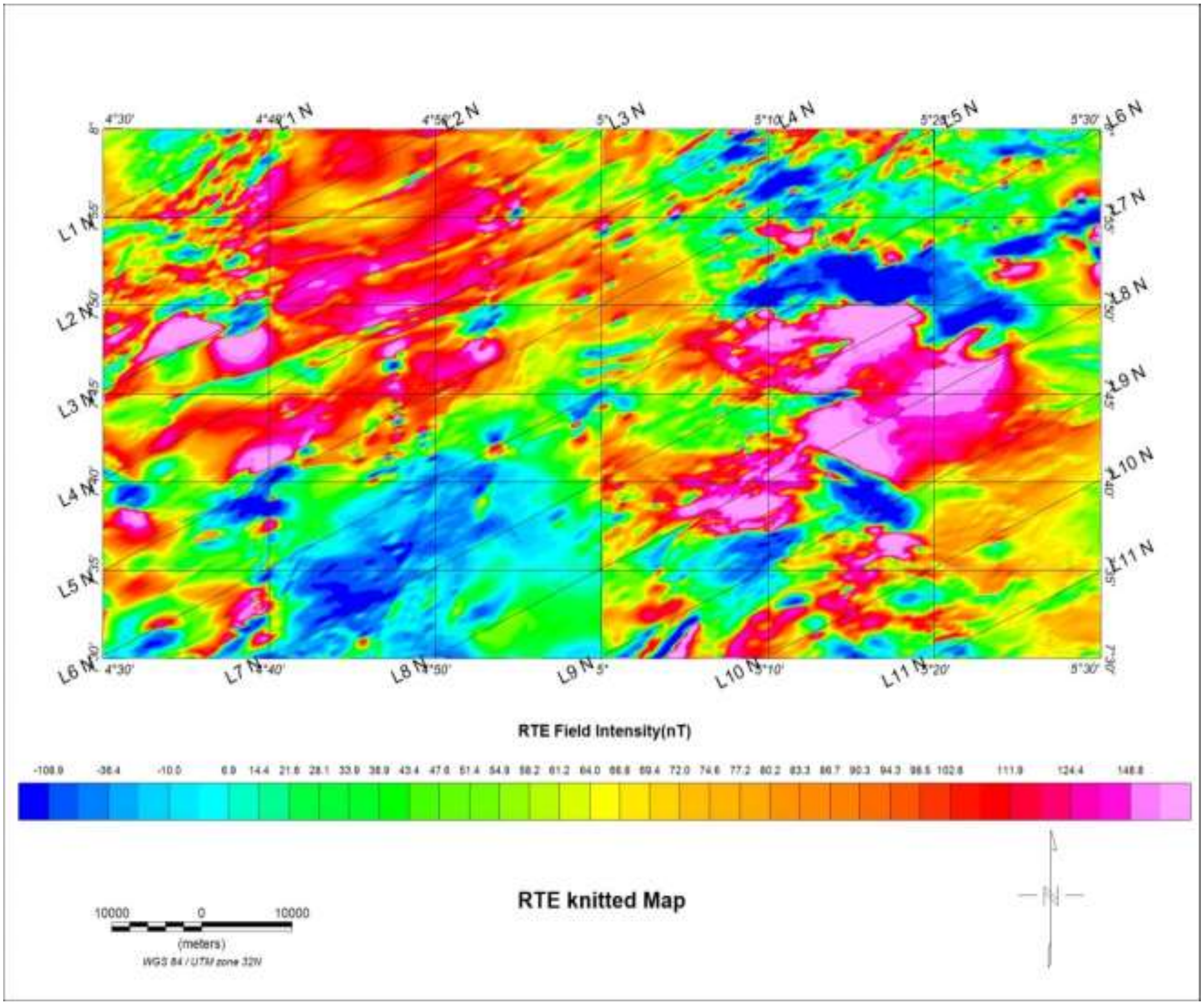

Figure 3: Reduction to equator field map

3. Results and Discussion

3.1 Euler De-convolution

Forward modeling method was carried out on the reduction to equator field using the Euler De-convolution method by choosing different structural indices (0.5 and 1) to model the depths of two distinguished subsurface features. The De-convolution solution of the study area showed depths to magnetic contacts which ranged from 162-3262.8m for structural index 0.5. The shallowest seated magnetic basement was found to be 162m from mean ground level to its top and deepest seated magnetic basement was found to be 3262.8m from mean ground level to its top.

The De-convolution solution of the study area depicted depths to dykes ranged from 177-4389.8m for structural index 1. The shallowest seated dyke was found to be 177m from mean ground level to its top and deepest seated magnetic dyke was found to be 4389.8m from mean ground level to its top. These are shown in Table 1, Figures 4 and 5.

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Table 1. Euler De-convolution results

SN	Euler-Deconvolution	
	N=0.5	N=1
1	162m-3262.8m	177m- 4389.8m

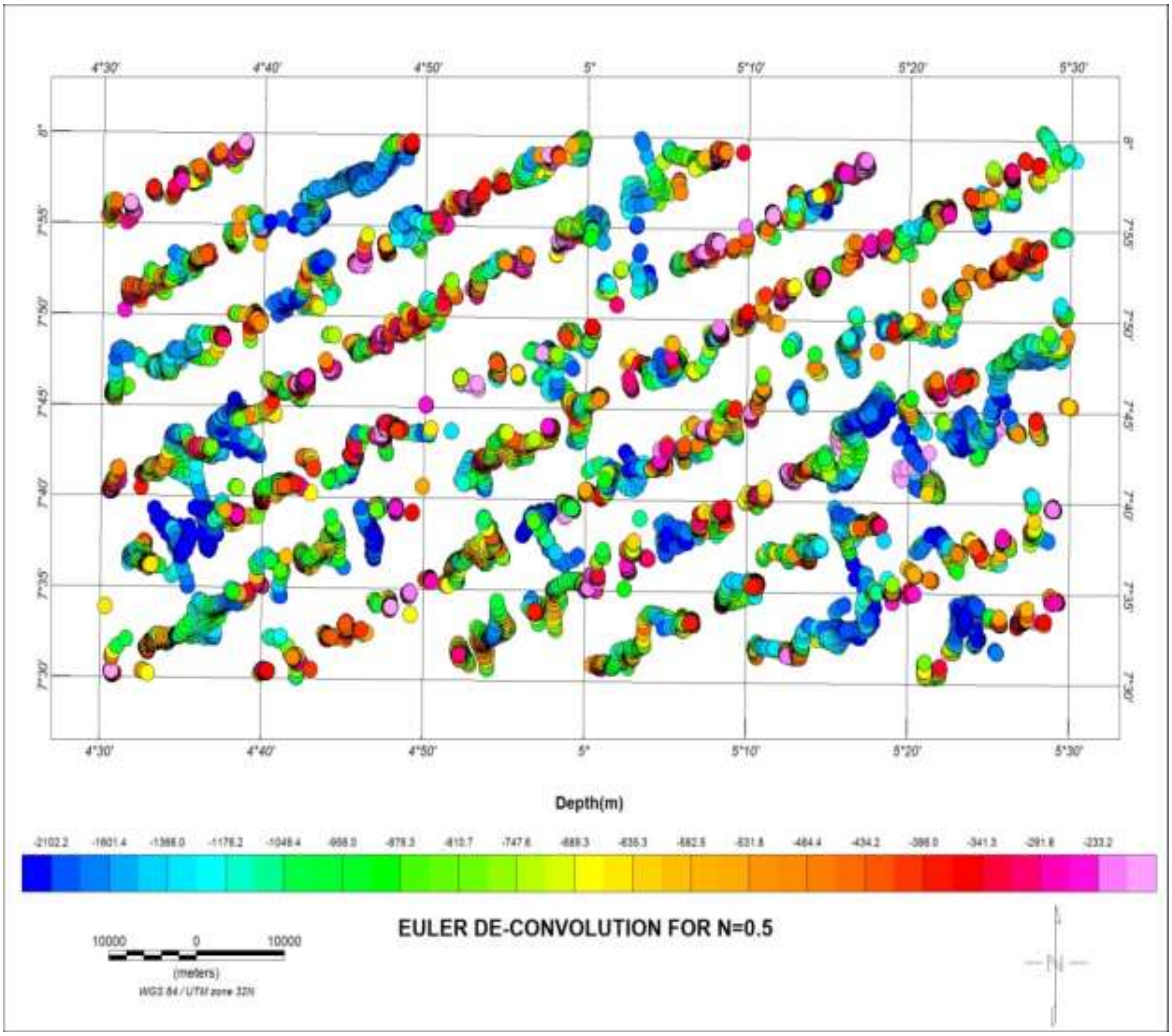

Figure 4: Euler De-convolution for N = 0.5

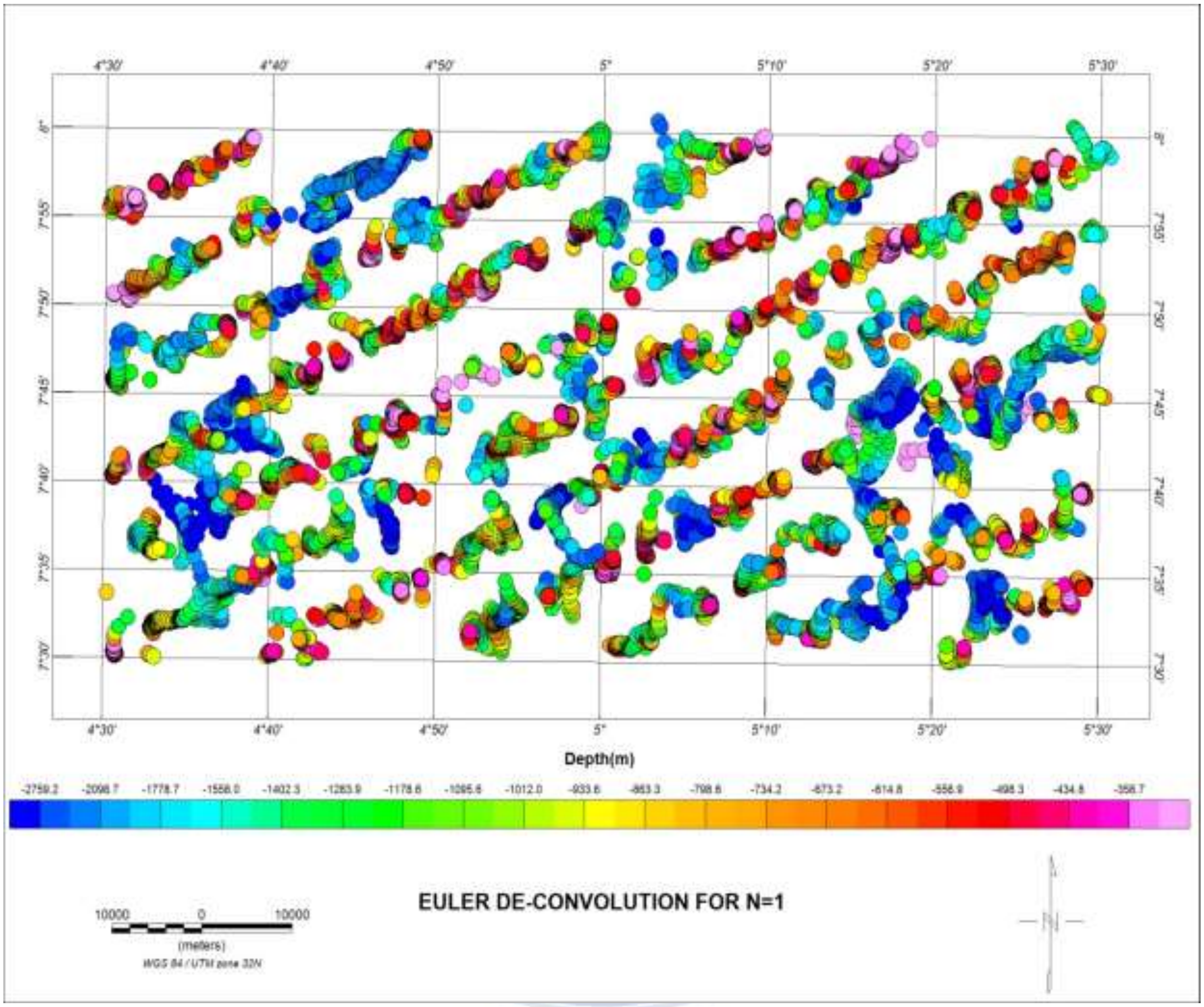

Figure 5. Euler De-convolution solution for N = 1

3.2 Local Wave Number Method (LWN)

Forward modeling method was carried out on the reduction to equator field to model contacts using the variation in their local wave numbers. The LWN solution exposed depths to magnetic contacts which ranged from 277.2-4529.7m. The shallowest seated magnetic basement was found to be 277.2m from mean ground level to its top and deepest seated magnetic basement was found to be 4529.7m from mean ground level to its top (Figure 6). This method resolved well for deep seated contact as seen in its range compared to other methods discussed in this

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paper. This revealed deepest contact is in an undifferentiated basement complex that is found between Ibokun and Okemesi as obtained by comparing Figure 6 and Figure 2.

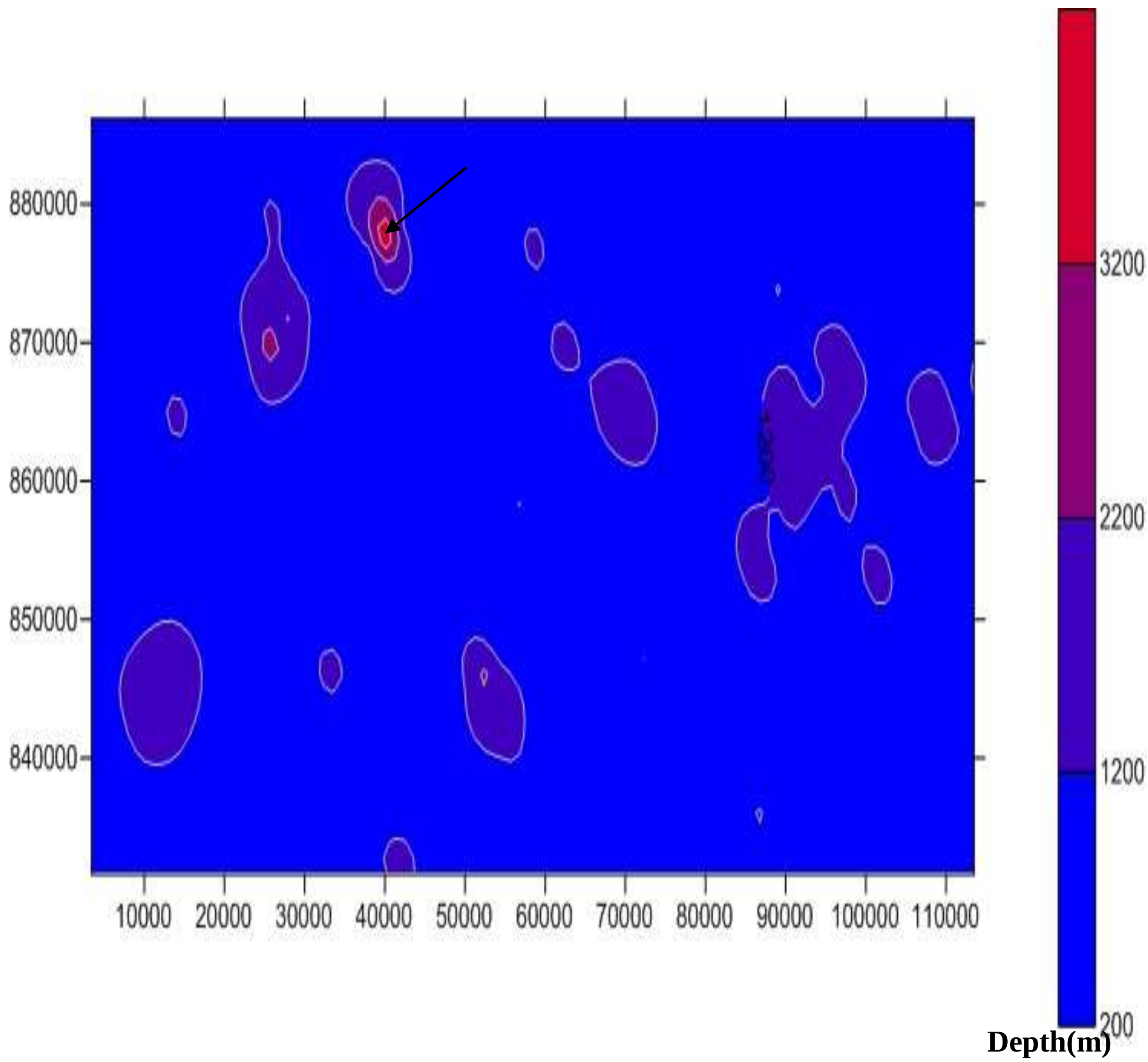

Figure 6. Local Wave Number depth solution to Magnetic sources

3.3 The P-depth and Analytical signal

This forward modeling method was carried out on the reduction to equator field to predict depths to the magnetic contacts as well as the dykes. The analytical signal depth solution revealed depths to magnetic contacts ranged from 35.0-498.1m. The shallowest seated magnetic basement was found to be 35.0m from mean ground level to its top and deepest seated magnetic basement was found to be 498.1m from the mean ground level. The analytical signal depth solution revealed depths to dykes ranged from 208.9-498.4m. The shallowest seated dyke was found to be at 208.9m from the mean ground level to its top and deepest seated dyke was found to be at 498.4m from the mean ground level as shown in table 2 and figures 7and 8.

Out of the adopted forward modeling methods, this method proved effective and resolved well for shallow seated subsurface features. The magnitudes of the predicted features are quite lower compared to what were had in other methods. It resolved best for shallowest seated contact of depth 35.0m from the mean ground level. This shallowest contact is found between Ikogosi and Ado-ekiti as had by comparing Figure 2 and Figure 7.

Table 2. P-depth solution

SN	Profile Number	Number of Contacts	Number of Dykes	Depths of Contacts(m)	Depths of Dykes(m)
1	1	39	4	48-498	432-494
2	2	55	1	145-473	485
3	3	91	5	66-497	412-478
4	4	139	1	50-494	430
5	5	145	13	46-493	323-494
6	6	158	8	35-476	380-492
7	7	140	2	49-487	268-471
8	8	93	1	39-491	335
9	9	97	2	68-497	209-491
10	10	47	6	45-426	322-498
11	11	33	2	70-440	345-479

This analytical signal depth solution was interpolated and krigged using surfer golden software to produce Figures 7 and 8.

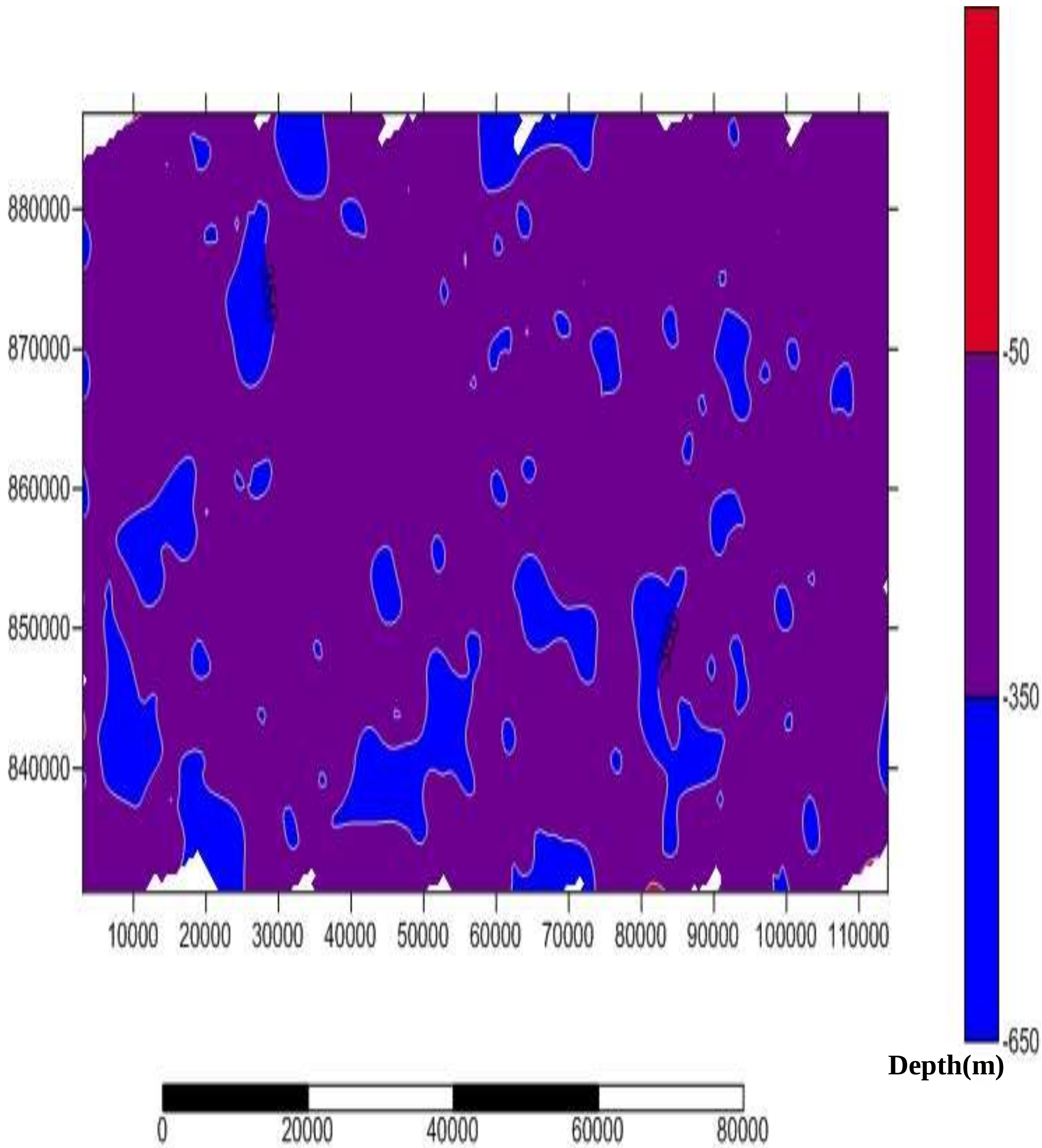

Figure 7. P-depth solution to Magnetic contacts

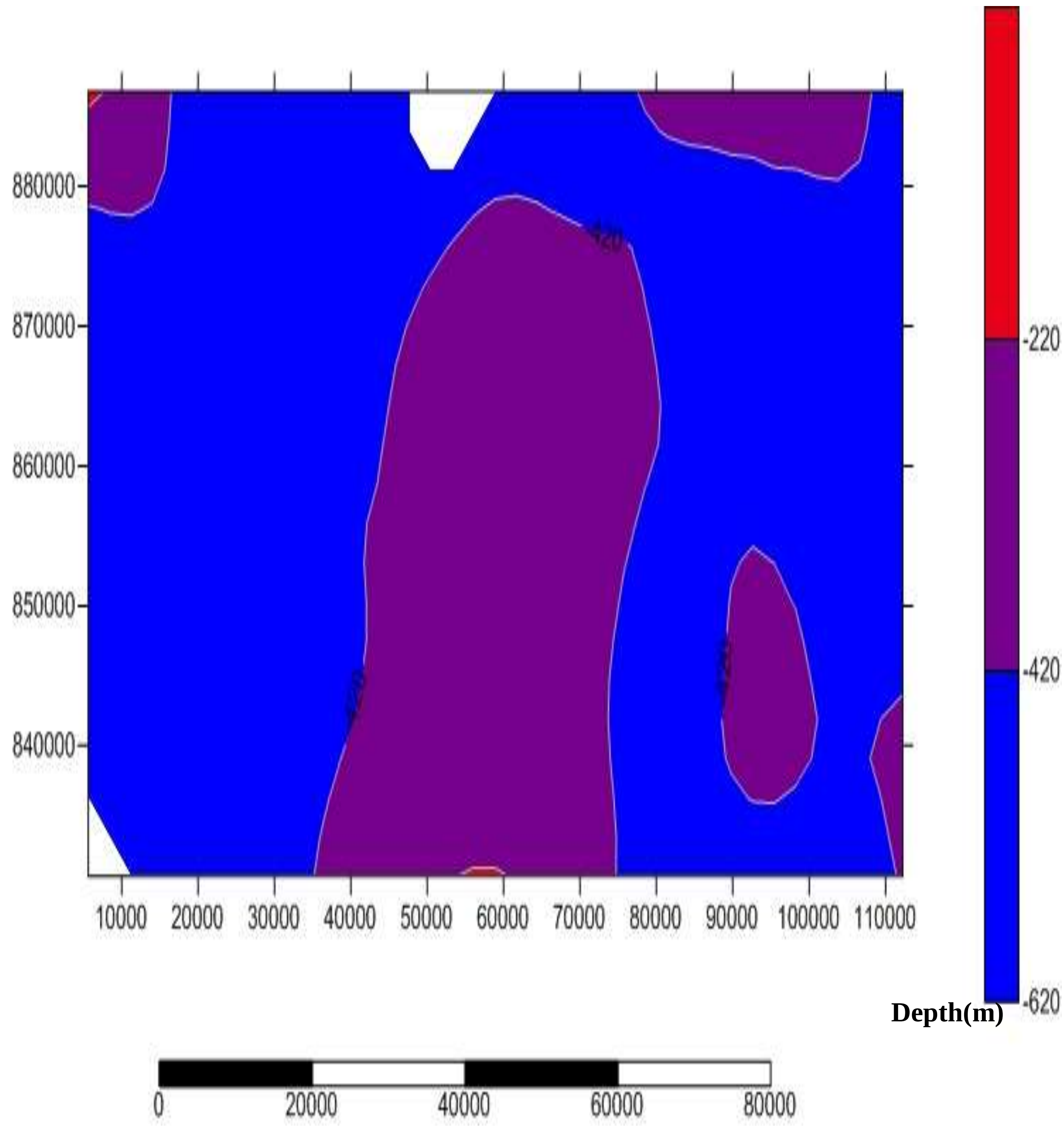

Figure 8. P-depth solution to Magnetic dykes

The former is for contacts and the latter is for dykes and their legend bars displayed support the earlier suggested depths. Profile 5 has the highest number of dykes with 13 dykes, followed by profile 6 with 8 dykes. The profiles with smaller numbers of dykes are 2, 4 and 8 with 1 dyke each. Other profiles with relative high number of dykes are profile 10 with 6 dykes, profile 3 with 5 dykes and profile 1 with 4 dykes. Profiles 7, 9 and 11 have 2 dykes each. All these dykes suggested to be dominating those areas covered by the profile lines are an indication of past tectonic activity in those areas as mapped. However the interpolation of the profile data predicted more values than indicated in Table 2 shown in Figure 7. These extended values obtained via interpolation suggest more dykes which could be present in areas not covered by the profile lines but are dykes within the study area. The same explanation holds for more results of contacts shown in Figure 8.

The areas cut by the profile lines are: profile 1 (Osogbo), profile 2 (from Osogbo to Ibokun), profile 3 (Osogbo to Ibokun), profile4 (Ilesha to Otun), profile5 (Ilesha to Egosi), Profile6 (Ilesha to Egosi), profile7 (Ilesha to Egosi), Profile 8 (Erinmo to Egosi), profile9 (Ikogosi to Ado-ekiti), profile10 (Ado-ekiti), and profile11 (Ado-ekiti).

4. Conclusion

The patterns of the results obtained are in accordance with subsurface formation. The values predicted for dykes are higher than contacts (top of basements) which provided an insight that the dykes are found in the magnetic basements. This is true because dykes are metalliferous structures formed through metallic rich magma that intruded in cracks or fractures within basements where they solidified. The depths of the predicted dykes have given a positive note for exploration consideration but the lateral and the vertical extents of the dykes are of great importance and are major determinant in economy geology. However, the estimation of these important parameters is not part of these findings. Therefore the explicit results obtained here can be used as an aid in investigating the lateral extent of the dykes and the vertical extent of the dykes from their contacts in economy geology of large scale mining project.

Conflict of interests.

There are non-conflicts of interest.

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