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Variation of Structural Index of Peters Half Slope in Determining Magnetic Source-Depth

[1]Adegoke, James A. and [2]Layade, Gideon O.

[1]*Department of Physics, University of Ibadan, Nigeria*
[2]*Department of Physics, Federal University of Agriculture, Abeokuta Nigeria*

ABSTRACT

The geophysical analysis and interpretation of magnetic data to characterize subsurface has been on the increase with Peter's half slope method being one of the earliest quantitative techniques of depth determination. This was used with varying structural indices of 1.2, 1.6 and 2.0 on a digitized aeromagnetic map for Ogbomoso area with sheet number 221 within longitudes $4^0 00^/$ E and $4^0 30^/$E and latitudes $8^0 00^/$ N and $8^0 30^/$ N, covering the total area of 55 km by 55 km (3025 km^2). The data was gridded and delineated into profiles at 100 m interval. Filtering process was applied to remove the regional gradient and other possible magnetic noises, subsequently various geological bodies' size and depth to the top of the magnetic source were calculated. The result of the selected profiles revealed different ranges of depth depending on the basement indicator considered. The depth range are 750 m-2333.3 m for very thin body, 562.5 m -1750.0 m for Intermediate thickness, and 450 m – 1400 m for very thick body respectively.The overall result from all the analyses indicate the presence of magnetic mineral resources in the locality which spread across the surveyed region of the earth crust.

Keywords: magnetic anomaly, half slope, structural index, depth, crust

INTRODUCTION

In global geophysics, magnetic surveying over oceanic ridges provided vital clues that led to the theory of plate tectonics and revealed the polarity history of the Earth's magnetic field since the Early Jurassic [2]. Magnetic surveying consists of (1) measuring the terrestrial magnetic field at predetermined points, (2) correcting the measurements for known changes, and (3) comparing the resultant value of the field with the expected value at each measurement station. The expected value of the field at any place is taken to be that of the International Geomagnetic Reference Field (IGRF). The difference between the observed and expected values is a *magnetic anomaly* [11].

Airborne geophysical surveys are an extremely important aspect of modern geophysics compared with ground surveys airborne surveys allow faster and usually cheaper coverage, of large areas [8]. At the largest reconnaissance scale, the most common airborne surveys are aeromagnetic surveys [15]. Until the last couple of decades the other primary application of airborne surveys was in mineral exploration where airborne magnetic EM and radiometric surveys were applied.

Over the last decade there has been increase in the use of airborne magnetics and more recently gravity in the petroleum exploration industry [18]. The early use of potential field methods in petroleum was to map sedimentary basin thickness but newer high resolution surveys are used to investigate basement trends and intra-formational structures [3]. High resolution methods are now being applied in the groundwater, environmental, and engineering areas *e.g.* in the mapping of areas of dryland salinization and more recently for defining properties of mine tailings.

Magnetic data measured on a given plane can be transformed to data measured at a higher or lower elevation, thus either attenuating or emphasizing shorter wavelength anomalies [10]. These analytic continuations lead to convolution integrals which can be solved either in the space or frequency domain. The earliest attempts were done in the space domain by deriving a set of weights which, when convolved with field data, yielded approximately the desired transform [13]; [7]; [1]. Later a rigorous approach to determining the required weights and analyzing their performancewas developed [6].

Very recently, several new approaches have been developed that deal with depth determination and structural index estimation simultaneously. One method [4] calculates the field at many altitudes and scales the field by a power law of the altitude. The depth and index can be obtained by finding extreme points. Another method [17] assumes (like the Euler method) homogeneous potential fields, but applies a similarity transform. Salem et al. [16] presented the enhanced local wavenumber method (ELW) for interpreting profile magnetic data. Based on the 2D Euler equation [19], they showed that deconvolution of the derivatives of the local phase can provide automatic estimates of the source location regardless of the nature of the sources.

In this study the Peter's half slope method will be employed to analyse the aromagnetic data for the location in order to determine the depth to the magnetic mineral source through the structural indices.

MATERIALS AND METHODS

Location of the study area: Ogbomoso is a city in Oyo State, southwestern Nigeria, on the A1 highway. It was founded in the mid-17th century. The population was approximately 645,000 as of 1991; as of March 2005, it is estimated to be around 1,200,000. The majority of the people are members of the Yoruba ethnic group. Yams, cassava, maize, and tobacco are some of the notable agricultural products of the region.Ogbomoso is located on Latitude 8^o 08' 00" and Longitude of 4^o 16' 00" North of the Equator. Ogbomoso, the second largest City in Oyo State after Ibadan, which is the Capital of Oyo State, lies within the derived savannah region and it is a gateway to Northern part of Nigeria from the West. Ogbomoso is 57 Kilometers South West of Ilorin (the Capital of Kwara State) 53 Kilometers North – East of Oyo, 58 Kilometers North – West of Osogbo (Capital of Osun State) and 104 Kilometers North – East of Ibadan (Capital of Oyo State)

Ogbomoso lies in the transition zone forest of Ibadan Geographical region and the Northern savannah region. As a result of this, it is regarded to be of derived savannah vegetation. The Town is seen to be a low land forest Area with Agricultural activities being the major activities carried out on it. The regions around and within Ogbomoso has four seasons like most of the other area in the southern Nigeria. The long wet season starts from March to July; it is the season of heavy rainfall and high humidity. The short dry season is normally in August. This is followed by short wet season and last September to October. The last season is that of harmattanexperienced at the end of November to mid-March. The man annual rainfall is 1-24mm. The variation in rainfall quantities between different between stations is rather in significant both on an annual and monthly basis.

Geology of the study Area: The geology of Ogbomoso (Fig. 2) consists of Precambrian rocks that are typical for the basement complex of Nigeria [14]. The major rock associated with Ogbomoso area form part of the Proterozoic schist belts of Nigeria, which are predominantly, developed in the western half of the country. In terms of structural features, lithology and mineralization, the schist belts show considerable similarities to the Achaean Green Stone belts. However, the latter usually contain much larger proportions of mafic and ultramafic bodies and assemblages of lower metamorphic grade [14].

The gneiss complex which underlies the northern and southern part of the Ogbomoso district comprises a considerable broader area of outcrops. Locally, the rock sequence composes of basically weathered quartzite and older granites. The minerals found in this area constitute mostly amphibolites, amphibole schist, meta ultra mafites and meta pelites. Extensive psammitic units with minor metapelite can also be found. These consist of quartzites and quartz schist. All these assemblages are associated with migmatitic gneisses and are cut by a variety of granitic bodies [14].

Fig. 1: Map of the Location of the study area in street view.

The rocks of the Ogbomoso district may be broadly grouped into gneiss-migmatite complex, mafic-ultra mafic suite (or amphibolite complex), meta sedimentary assemblages and intrusive suite of granitic rocks [12]. A variety of minor rock types are also related to these units. The gneiss-migmatite complex comprises migmatic and granitic, calcareous and granulitic rocks. The mafic-ultramafic suite is composed mainly of amphibolites, amphibole schist and minor metaultramafites, made up of anthophillite-tremolite-chlorite and talc schist [9].

The meta sedimentary assemblages, chiefly meta pelites and psammitic units are found as quartzites and quartz schist. The intrusive suite consists essentially of Pan African (c.600Ma) Granitic units. The minor rocks include garnet-quartz-chlorite bodies, biotites-garnet rock, syenitic bodies, and dolerites [14]; [5].

Peter's Half Slope: Peters in his classical paper on magnetic interpretation [13], presented a rule of thumb to find the depth to the magnetic source. Peter's rule is based on the mathematical expression for magnetic anomalies over vertical dikes with vertical polarization. According to Peters, the half maximum slope distance *(***d***)* is equal (approximately) to 1.6 *h* where *h* is the depth to the magnetic source as shown in figure 3

The digitized aeromagnetic data of Ogbomosho area with sheet no 221 which covers the total area of 55 km by 55 km was processed and transformed into profiles. The transformed data was then converted into an executable grid format through the use of Golden Surfer being application software for geophysical explorations.

The software was also employed in filtering the data in order to remove the regional gradient and possible magnetic noise. To achieve better gridded data, Kriging approach of the software was used from which the coloured map of the location was generated in Figure 4.1 which shows the magnetic intensity values of the area in nanotesla. The area was contoured at the magnetic interval of 40 nT.

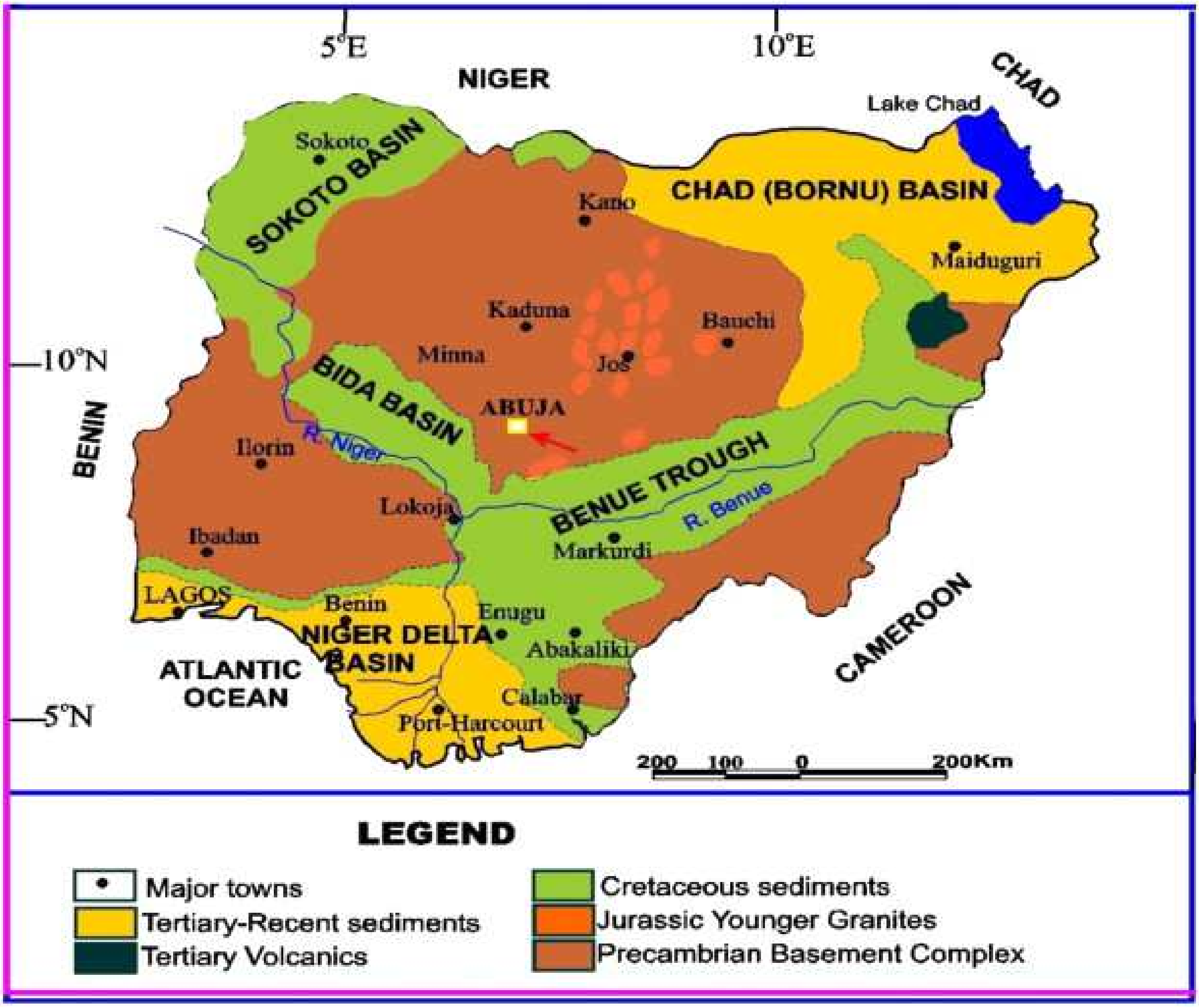

Figure. 2: Geological map of Nigeria (after Obaje, 2009)

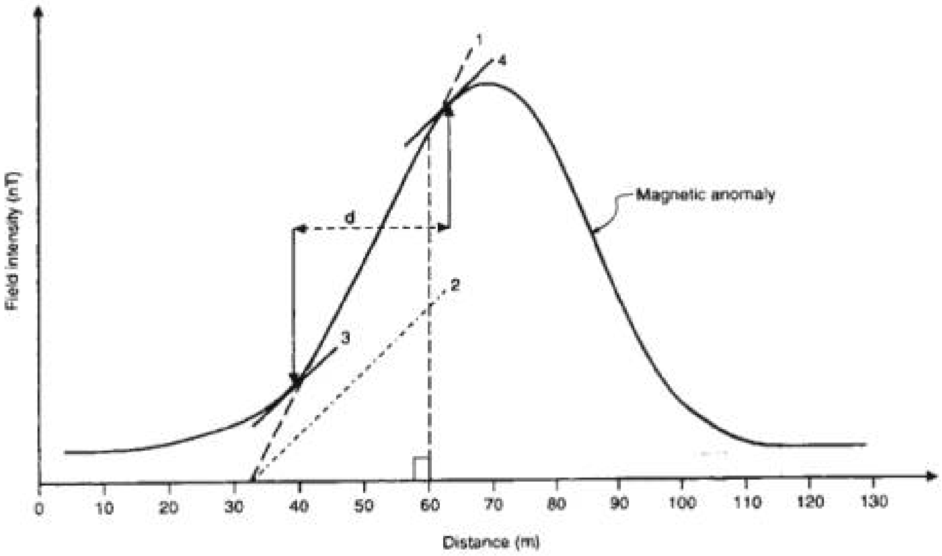

Figure 3: Peter's half slope method of depth-to-basement determination

The application of the Peter's half slope method requires identification and location of the slope or curve with maximum amplitude on the magnetic intensity profile or magnetic anomaly chart created by using the magnetometer. This maximum slope is the most steep part of the magnetic anomaly line on the graph. Then a straight line through the maximum slope, extending beyond the slope's top and bottom end and intersecting with the chart's x-axis beyond the bottom endis the "slope line."

Further,vertical line is drawn, connecting the maximum slope's top end with the chart's x-axis with the vertical line's height measuredwith ruler and its middle point marked. A straight line connecting the slope line's intersection with the x-axis and the middle point of the vertical line is refered to as the "half-slope line."Add two straight lines parallel to the half-slope line and tangent to the magnetic intensity line, touching the curve, but not intersecting it.

Assign the magnetic body an index value or "proportionality factor," ranging from 1.2 to 2, depending on the object's size. Divide distance by index value to find the depth of the object. For bodies having very small width-to-depth ratios as in the case of thin sheets, **d**=1.2 *h* and for bodies having very large width-to-depth ratios, **d**= 2.0 *h*.Therefore, for a 2-D body with vertical sides, uniform and nearly vertical magnetization the following equation holds

d=1.2*h* (very thin body) ………………………………….. (1)
d=1.6*h* (intermediate thickness) ………………………………….. (2)
d=2.0*h* (very thick body) ………………………………….. (3)

Where **d**-the horizontal distance corresponding to half the maximum slope which is tangent to the curve, and *h*-depth to the basement of the body.

RESULTS AND DISCUSSION

Table 1: Magnetic Depth to the sources with Structural Indices

Depth (m) Variation with Structural Index (SI)					
Profile	**Horizontal distance (m)**	**Depth (m) Very thin Body (SI=1.2)**	**Depth (m) Intermediate Thickness (SI=1.6)**	**Depth (m) Very thick Body (SI=2.0)**	**Average Depth (m)**
AA*	2200	1833.33	1375.00	1100.00	1436.11
BB*	2500	2083.33	1562.50	1250.00	1631.94
CC*	2000	1666.67	1250.00	1000.00	1305.56
DD*	2000	1666.67	1250.00	1000.00	1305.56
EE*	2200	1833.33	1375.00	1100.00	1436.11
FF*	900	750.00	562.50	450.00	587.50
GG*	1100	916.67	687.50	550.00	718.06
HH*	1900	1583.33	1187.50	950.00	1240.28
II*	2800	2333.33	1750.00	1400.00	1827.78
JJ*	1900	1583.33	1187.50	950.00	1240.28

Table 2: Range of Depth for various geologic bodies

Structural Index	Range of Depth (m)
Very Thin Body	750.0-2333.3
Intermediate Thickness	562.5-1750.0
Very Thick Body	450.0-1400.0

The analysis and interpretation of aeromagnetic data was done both quantitatively and qualitatively. This implies that in getting substantives information about the lithology of a location, so many factors must be put into consideration [20]. Also, geophysical techniques to be employed must be such that it is suitable for the purpose of the work. Peter's half slope method being one of the earliest quantitative techniques of depth determination was used with structural indices of 1.2-2.0 with which various geological bodies' size and depth to basement were calculated. The result presented in Table 1 and Table 2 were the output of Peters' half slope method with various structural indices for very thin body(SI=1.2), intermediate thickness (SI=1.6) and very thick body (SI=2.0).

The outcome of all the selected profiles revealed different ranges of depth depending on the basement indicator considered. The depth range are 750 m-2333.3 m for very thin body, 562.5 m -1750.0 m for Intermediate thickness, and 450 m – 1400 m for very thick body respectively. To further analyse the data using quantitative approach, the 3-D surface distribution of the magnetic mineral in the locality was generated through the automated method of golden surfer. This is so since the signals generated by the presence of these magnetic minerals can determine to a large extent the depth and geometry of the buried body whether at the near-surface or deep-seated region of the geologic unit of the basement complex. This is presented in Fig.3, fig. 4 and fig. 5 respectively at interval of 40nT on magnetic field scale.

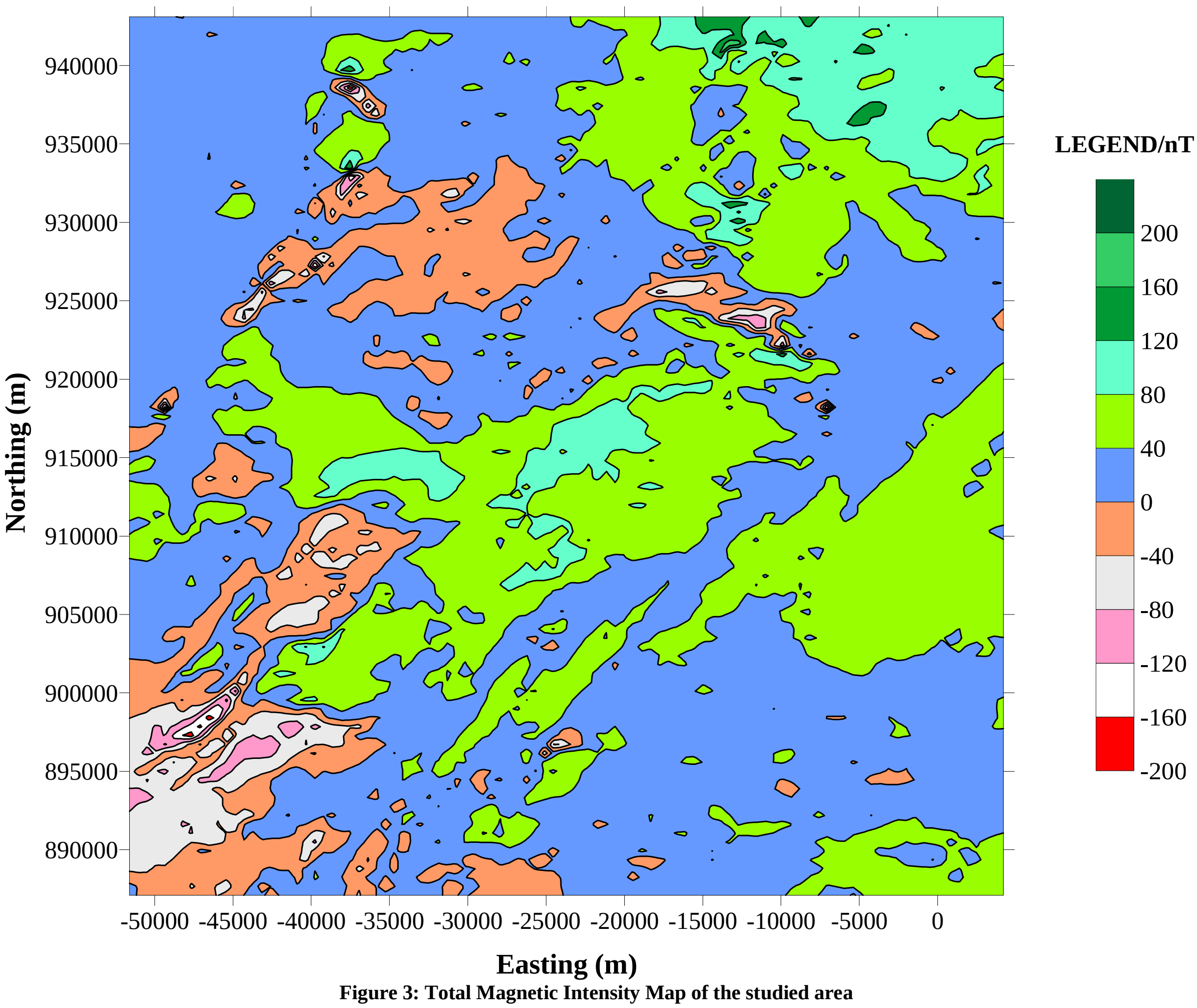

Figure 3: Total Magnetic Intensity Map of the studied area

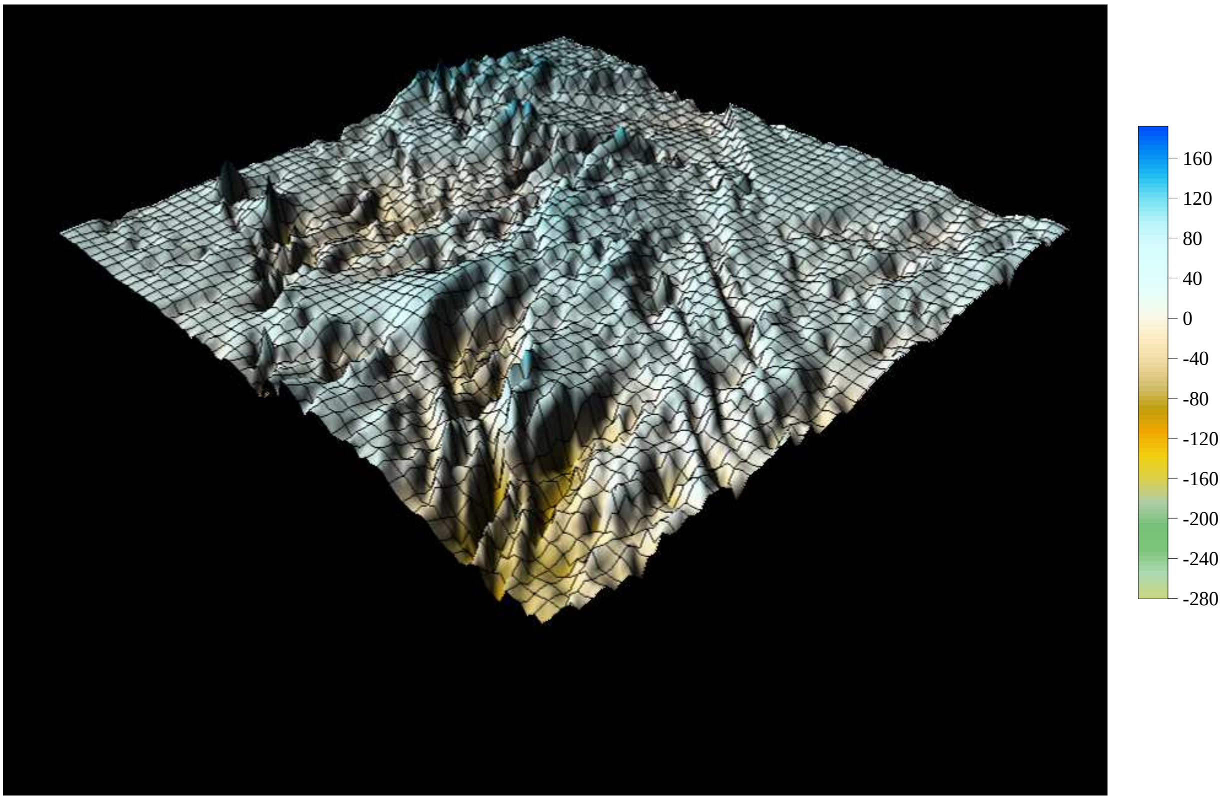

Figure 4: 3D-Surface distribution of the magnetic mineral in the locality

CONCLUSION

The aeromagnetic analysis and interpretation of the studied area was carried out which has revealed the prospect of magnetic mineral exploration. The depth to the top of the magnetic material has helped to delineate the area as of low and high of magnetic anomaly as a result from the selected profiles. Lithologically, the study have further helped to better understand the formation of the rock within the basement complex. The variation of structural index plays an important role in the classification of magnetic mineral as of thin body with the depth range of 750.0 – 2333.3 m, intermediate thickness with depth 562.5 – 1750.0 m, and very thick body with depth 450.0 – 1400.0 m. This indicates that the thickness of the magnetic body is inversely proportional to its depth as the very thin body produced the deepest depth while the very thick body produced the shallow depth with faults and fractured zone.

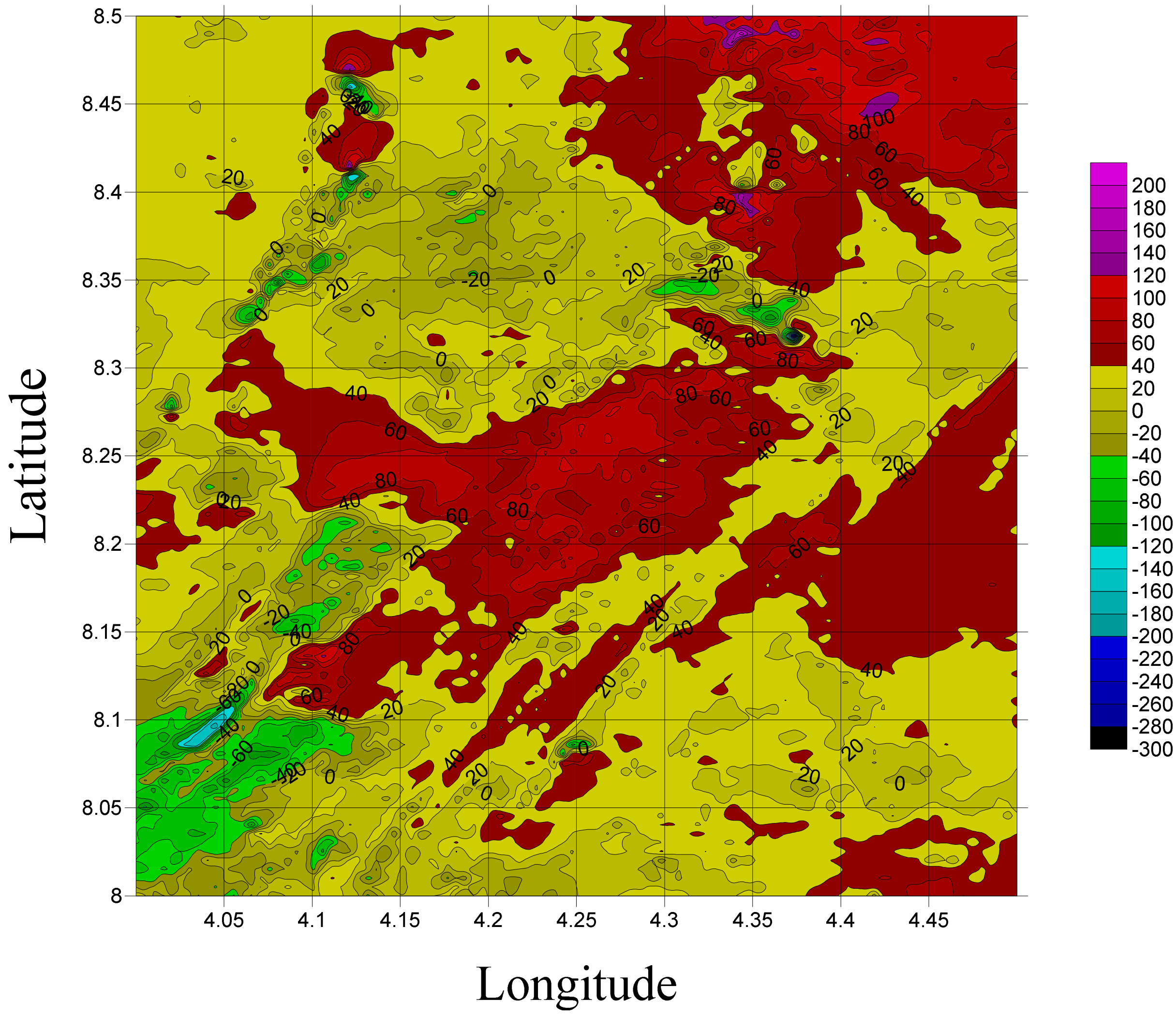

Figure 5: A gridded contour map of the study area in Geographical coordinates.

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