An Estimation of Magnetic Contact Location and Depth of Magnetic Sources in Ilesha, Nigeria, Using Magnetic Gradient Techniques

V. C. Ozebo[1,3,*], C. O. Ogunkoya[1], V. Makinde[1] and M. O. Omeike[2]
[1]*Department of Physics, Federal University of Agriculture, Abeokuta, Nigeria*
[2]*Department of Mathematics, Federal University of Agriculture, Abeokuta, Nigeria*
[3]*Department of Physics, University of Lagos, Akoka, Yaba, Nigeria*

Mapping the subsurface structures in the study area can shed some light on the structural location of mineral deposits, its relation to tectonic instability and the depth of magnetic bodies. This study presents an interpretation of the aeromagnetic data at Ilesha, located in Osun State of southwestern Nigeria, to map the subsurface locations of the area. The structural interpretation of magnetic data was achieved by applying the Horizontal Gradient Method (HGM) and the Analytic Signal Method (ASM), an advanced interpretation technique that provides contact locations and depths of magnetic sources. Results of these two methods revealed a two-source depth model. The depth of the deeper magnetic source bodies range from 1.46km to 2.55km with an average of 2.01km for ASM, and 2.92km to 5.48km with an average of 4.20km for HGM. These magnetic source bodies were identified with the magnetic basement. The shallower magnetic sources ranging in depth from 0.348km to 1.28km with an average depth of 0.814km for ASM, and 0.478km to 2.50km for HGM could be attributed to near-surface magnetic rocks that intruded into the sedimentary formations.

1. Introduction

Magnetic method is one of the best geophysical techniques to delineate subsurface structures. Generally, aeromagnetic maps reflect the variations in Earth's magnetic field. These variations are related to changes of structures, magnetic susceptibilities and/or remnant magnetization. Sedimentary rocks, in general, have low magnetic properties as compared to igneous and metamorphic rocks, which tend to have a much greater magnetic content. Thus, most aeromagnetic surveys are useful to map the structure of the basement and intruded igneous bodies from basement complex [1].

Aeromagnetic mapping allows fast coverage of large areas for subsurface reconnaissance survey, which makes magnetic data analysis an essential tool for geophysical exploration. The processing of these data sets can provide important evidence of regional scale basement faulting in Ilesha, Southwestern Nigeria, and thus provides better understanding of the framework of the region.

Aeromagnetic survey mapped spatial variation in the magnetic field of Earth's crust. It was used to produce geological interpretation of an area [2].

The airborne survey of the study area was carried out by Nigeria Geological Survey Agency. The data was acquired along parallel flight line oriented in a NW – SE direction at 500m flight line spacing, while the tie lines were spaced at 2km directed to NE – SE direction. The aeromagnetic map used in this study extended between $7°37'0''N$ and $7°39'57''N$ of latitude and from longitude $4°44'0''E$ to $4°46'37''E$ in Osun State, Nigeria.

1.1. Local geology

The geology of Ilesha area consists of Precambrian rocks that are typical for the basement complex of Nigeria [3]. The major rocks associated with Ilesha area form a part of the Proterozoic schist belt of Nigeria, which is predominantly developed in the western half of the country. In terms of structural features, lithology and mineralization, the schist belt of Nigeria shows considerable similarities to the Achaean Green Stone Belt [3,4,5].

The topographical map and the generalized geological map of the study area are presented in Figs. 1 and 2, respectively.

*cozebo@unilag.edu.ng

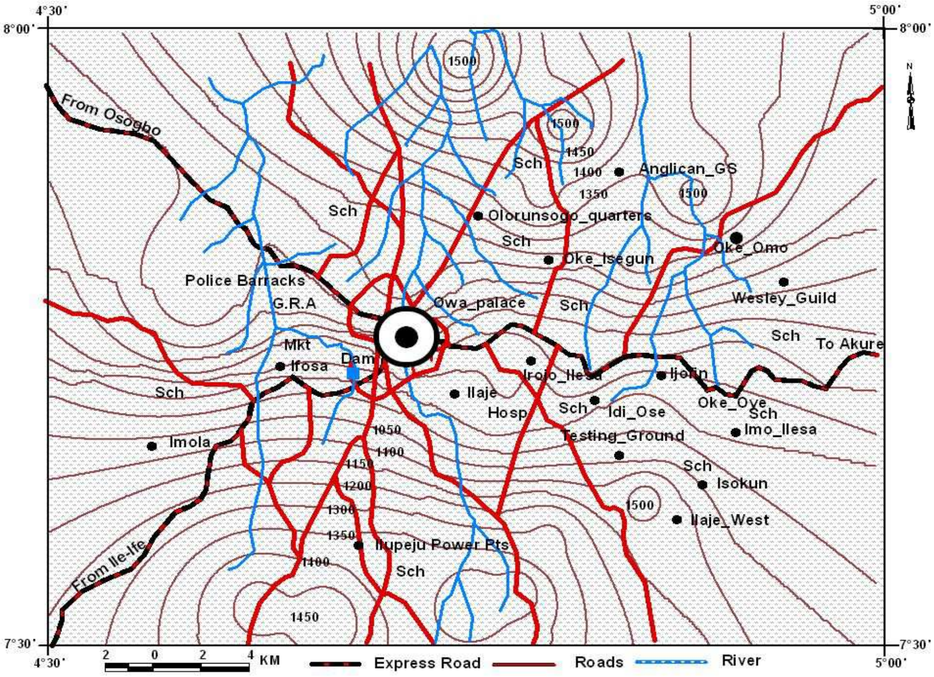

Fig.1: Topographical map of the study area.

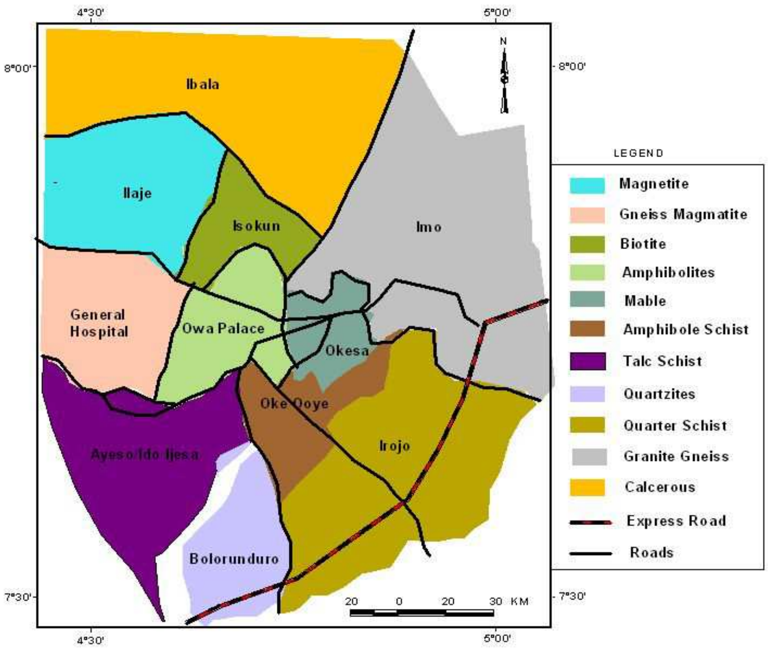

Fig.2: Generalized geological map of the study area.

The rocks of the Ilesha district may be broadly grouped into gneiss-migmatite complex, mafic-ultra mafic suite (or amphibolites complex), meta-sedimentary assemblages and intrusive suit of granitic rocks. A variety of minor rock types are also related to these units. The gneiss-migmatite complex comprises magmatic, granitic, calcerous, and granulitic rocks. The mafic-untramafic suit is composed of amphibolites, amphibole schists and minor meta-ultramafites, made up of authophillite-tremolite-chlorites and talc schist. The meta-sedimentary assemblages, chiefly metapelites and psamitic units, are found as quartzites and quarter schist. The intrusive suite consists essentially of Pan African granitic units. The minor rocks include garnet-quartz-chlorite bodies, biolite-garnet rock, syenitic bodies and dolerites [3,6,7].

Rocks in Ilesha schist belt are structurally divided into two main segments belt as the major fracture zones usually called Iwaraja faults in the eastern part and the Ifewara faults in the Western part of Ilesha. [6,7,8,9].

2. Materials and Methods

Methods to produce the discrete analytic signal from a discrete real-valued signal were discussed by [10]. The result shows that the direct method of zeroing the negative frequencies, or using Hilbert transform filters, have undesirable defects. They presented an alternative which is similar to the 'quadrature' filters used in modern designs.

Ansari and Alamdar [11] used analytic signal as reduction to the pole operator and applied it on the synthetic magnetic data and on the real magnetic data from an area in Shahrood region of Iran. The result show that least difference is relevant to the causative body location and the analytic signal can be used as substituent method for conventional reduction to the pole.

A study on the ground magnetic survey of Magadi area of Southern Kenya rift was carried out by [12], with the aim of locating depths to magnetic bodies with sufficient magnetic intrusions. A model whereby the faults in the region provide escape of water as hot springs was proposed.

Kayode et al. [8] focused on fault delineation when performing the ground magnetic study of Ilesha East.

Olowofela et al. [13] discussed source location and depth estimation from digitized aeromagnetic data acquired from a basement complex formation. The result showed a shallow depth range limit for HGM and LWN as 0.588km and 0.607, respectively.

Onyedim et al. [14] used aeromagnetic data to investigate the morphology of the basement beneath the pile of sediments in a part of the middle Benue trough. Their result shows that the basement surface is block faulted resulted in a series of depression separated by high angle faults. The shallowest ridge is about 0.11km deep while the deepest sub-basin is about 5.5km deep

Theophile et al. [15] applied the Horizontal Gradient Method, the Analytic Signal Method and the 3-D Euler de-convolution on aeromagnetic data to locate buried faults in South East Cameroon. It was also applied to the aeromagnetic data from South East Cameroon to delineate the subsurface structures. Their result revealed deep tectonic features, which were not known at that time.

Ram et al. [16] wrote a note on the qualitative appraisal of aeromagnetic image of Chhattisgarh basin. He used the aeromagnetic map of the area to extract the geologic information from the mapped and imaged the anomalies in a systematic way.

In this research, we attempt to remotely estimate the location of the source of magnetic anomaly as well as the depth of the magnetic basement in the area using ASM and HGM. The availability of the Aeromagnetic data of this area will allow a fast coverage for subsurface reconnaissance survey, and hence makes magnetic data analysis an essential tool of geophysical exploration. The processing of these data can provide important evidence of regional scale basement faulting in Ilesha, Southwestern Nigeria and thus for understanding the framework of the region.

The aeromagnetic data of Ilesha area (Sheet number 243) was obtained as a part of a nationwide aeromagnetic survey sponsored by the Nigeria Geological Survey Agency. It covers Ilesha West and Ilesha East. The data were acquired along a series of NW-SE flight lines with a spacing of 500m. The tie lines occur at about 2 km in a direction of NE-SE. The geomagnetic gradient was removed from the data using the International Geomagnetic Reference Field (IGRF). The data was made available in X, Y, Z format, where X values represent the distance of a point from the origin pointing towards the east direction; Y values represent the distance of a point from the origin in the ordinate direction whereas the Z values represent the values of the total Magnetic Intensity at a point. Contoured maps of the original data on the scale of 1:100,000 as shown in Fig. 3. The total area covered was about 3025 km^2.

The digitized aeromagnetic data of Ilesha area of sheet number 243 was first extracted and transformed using Golden Software 2D Surface Mapping Program (Surfer Version 8.0). The data was then converted to a gridded format to obtain the different maps.

The gridded data was now used to obtain contour map, surface maps, wireframe map and shaded relief map of the study area for further discussion (Figs. 3, 4, 5 and 6), respectively.

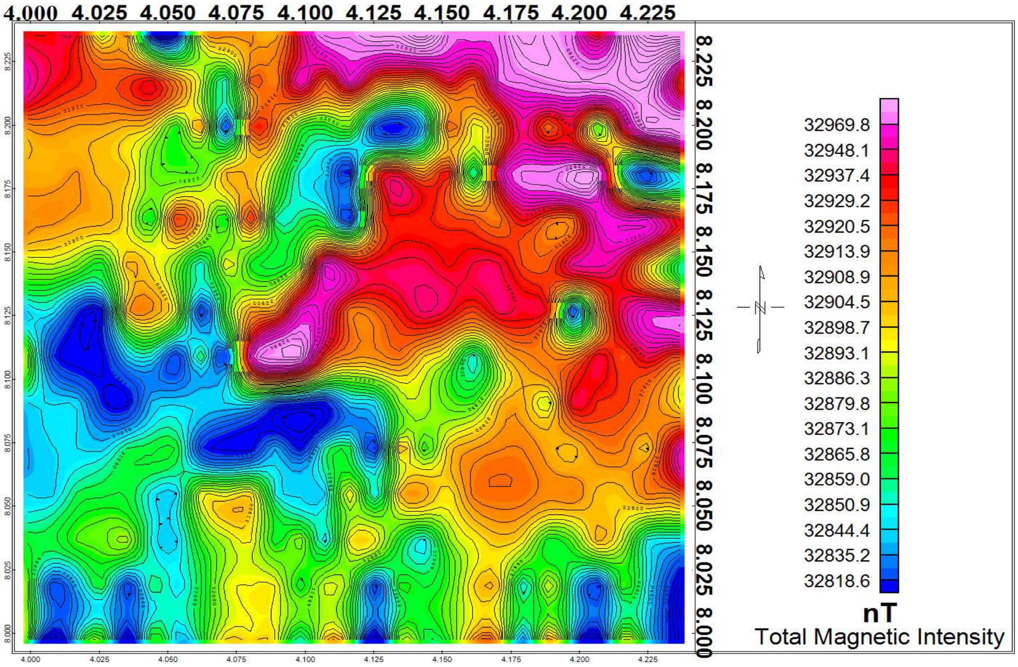

Fig.3: Contour Map of Total Magnetic Intensity.

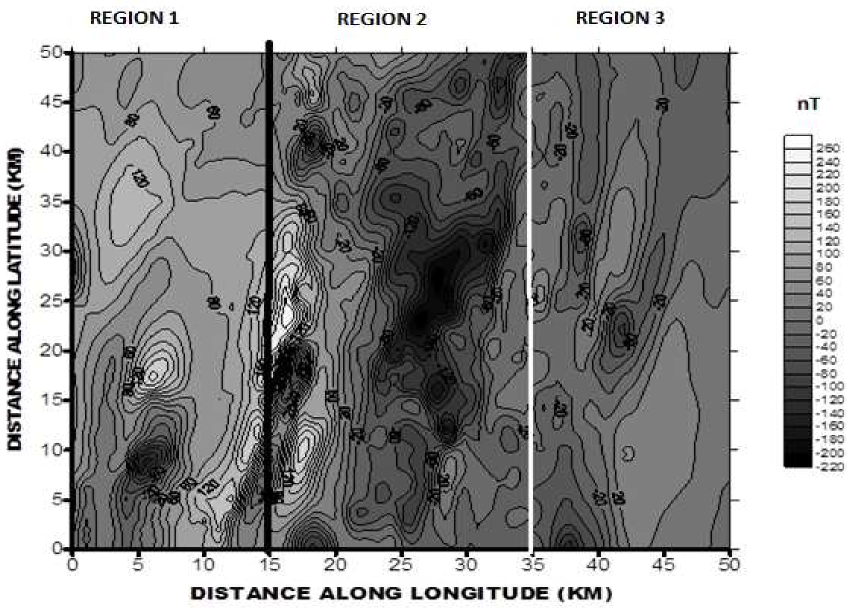

Fig.4: Contour Map of the Study Area.

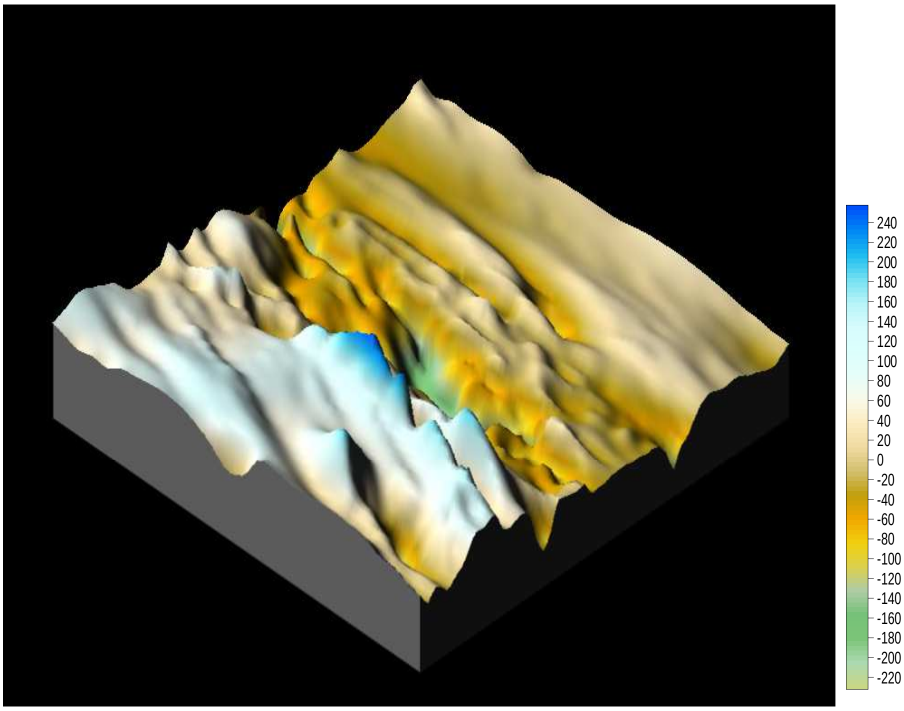

Fig.5: Surface Map of Study Area.

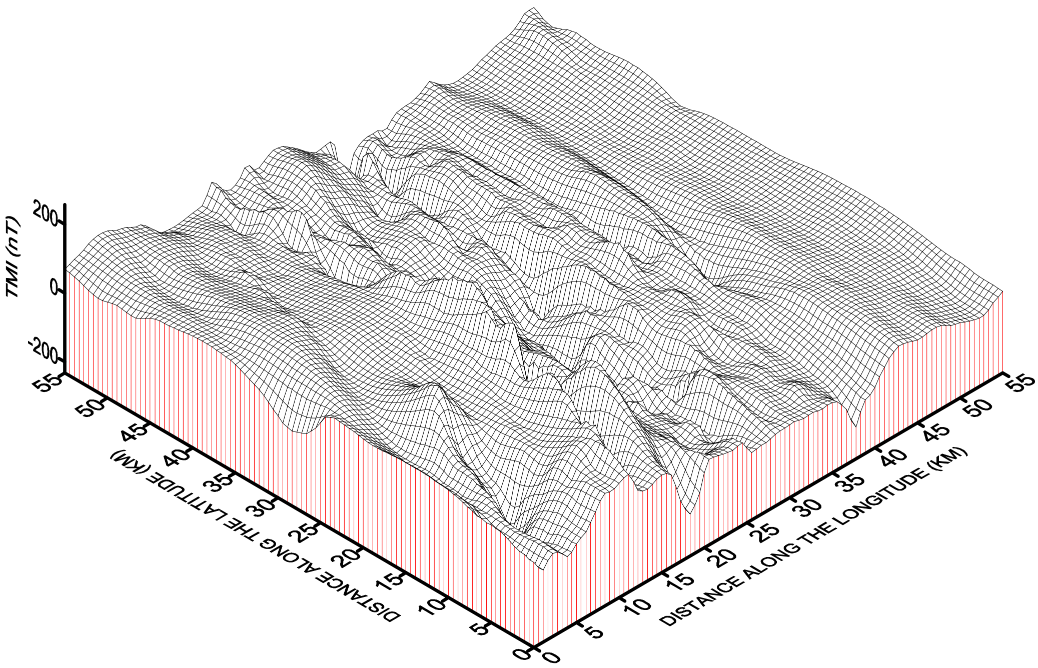

Fig.6: Wireframe Map of Study Area.

Since the primary objective of this study is to estimate the depth of the magnetic basement and to locate the magnetic source contact, it was necessary to process the aeromagnetic data in a manner that would both enhance the analysis and facilitate the computation of locations as well as depth to magnetic sources.

The last step was to process the gridded aeromagnetic data using potential field (PF) software on the Horizontal Gradient Method and the Analytic Signal Method. The result was presented using PLOTDEP program in the PF software (Figs. 7 and 8).

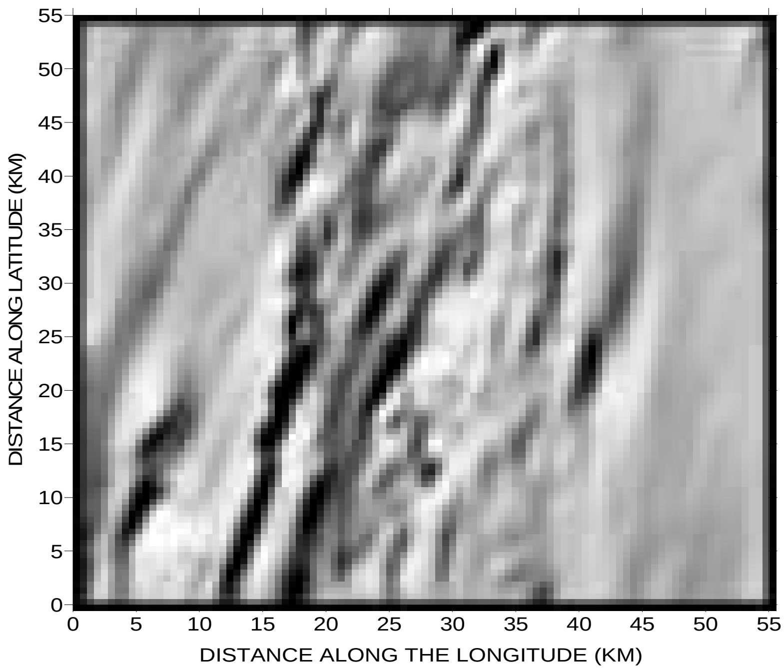

Fig.7: Shaded Relief Map of Ilesha.

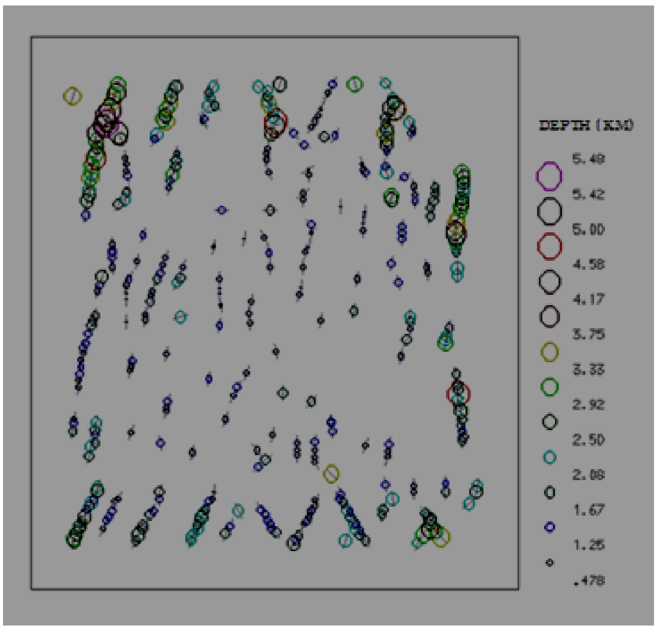

Fig.8: Depth and contact location from Horizontal Gradient Method (HGM).

2.1. Reduction to the pole (RTP)

The goal of reduction to the pole is to take an observed total magnetic field map and produce a magnetic map that would result to an area being surveyed at the magnetic pole. Assuming that all the observed magnetic field of the study area is due to induced magnetic effects, pole reduction can be calculated in the frequency domain using the following operator [17].

$$\mathrm{L}(\theta) = \frac{1}{\sin(\mathrm{I})\cos(\mathrm{I})\cos(\mathrm{D}-\theta)^2} \qquad (1)$$

$Where, \theta = the\ wavenumber\ direction$
$I = Magnetic\ inclination$
$D = Magnetic\ declination$ [16]

In reduction to the pole procedure, the measured total field anomaly is transformed into the vertical component of the field caused by the same source distribution magnetized in the vertical direction. The acquired anomaly is therefore the one that would be measured at the North magnetic pole, where induced magnetization and ambient field are both directed downwards [18].

2.2. Horizontal Gradient Method (HGM)

The Horizontal Gradient Method has been used extensively to locate the contacts of density contrast from gravity data [19] or Pseudo-gravity data [20]. Meanwhile, [18] stated that the horizontal gradient of gravity anomaly caused by a tabular body tends to overlie the edges of the body if the edges are vertical and well separated from each other.

The Horizontal Gradient Method is also considered as the simplest approach to estimate the contact locations (e.g. faults). It requires a number of assumptions about the sources and the assumptions are: the regional magnetic field is vertical, the source magnetization is vertical, the contacts are vertical, the contacts are isolated, and the sources are thick [21].

The advantage of the HGM according to [21] was its least susceptibility to noise in the data because it only required the calculations of the two first-order derivations of the magnetic field vector.

If M (x, y) is the magnetic field and the horizontal derivations of the field are ($\frac{\partial M}{\partial x}$ and $\frac{\partial M}{\partial y}$) then the horizontal gradient HG (x,y) is given by

$$HGM\ (x,y) = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2} \qquad (2)$$

Once the field is reduced to pole, the regional magnetic field will be vertical and most of the source magnetizations will be vertical. Once the HG data is obtained, the data were upward continued analytically.

2.3. Analytic Signal Method (ASM)

The amplitude of the Analytic Signal (AS) of magnetic anomaly can be defined according to [1] as the square root of the sum of the vertical and two orthogonal horizontal derivatives of magnetic field such as

$$/AS\ (x,y)/= \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2 + \left(\frac{\partial M}{\partial z}\right)^2} \qquad (3)$$

The horizontal and vertical derivatives of the magnetic field are Hilbert transform pairs of each other [22]. The Analytic Signal Method has been successfully applied in the form of profile data to locate dike bodies [23,24,25]. Moreover, the approach was further developed by [26] for the interpretation of aeromagnetic maps and applied at Lake Huron and across Cabot Strait between Cape Breton and Newfoundland in eastern Canada. An improvement of this approach in the interpretation of aeromagnetic data was presented by [27]. Furthermore, [28] presented a variation of the approach also known as local wave number.

The analytic signal of magnetic anomalies can be easily computed. The horizontal derivative can be calculated directly from a total field grid using a simple 3x3 difference filter. Also, both the horizontal and vertical gradients can be calculated in the frequency domain using the conventional Fast Fourier Transform (FFT) technique. Meanwhile, [29] calculated the vertical derivative from the vertical integral of the magnetic field in order to produce a result that was more similar to the analytic signal of Pseudo-gravity. A method was developed in [1] from which the depth of a contact model can be calculated from ASM in a least-squares sense.

The advantage of this method of magnetic data enhancement is that its amplitude function is always positive and does not need any assumption of the direction of the magnetized body [30].

3. Results and Interpretation

A computer software package SURFER 8 was used to plot the structural map of the gridded data and the contour maps obtained are shown in Figs. 3-7.

The aeromagnetic contour map (Fig. 4) partitioned into three regions. Regions 1 and 3 have low relief magnetic values, whereas Region 1 (0-15km along the longitude) is dominated by a positive low magnetic anomaly. Region 2 (ground distance 10km-35km of longitude) is juxtaposed by the high variation in anomaly signature of the contour lines, whereas Region 3 (ground distance 35km-50km of longitude) is characterized by low positive and negative magnetic anomaly. Thus the low gradient with positive and negative contours in Region 3 and Region 1 exist over the sedimentary surface, while high gradient with both positive and negative contours are dominant in Region 2 of the contour map.

A visual inspection of Fig. 4 shows that the contour lines of region 1 and 3 are widely spaced indicating that the depth of the magnetic basement is relatively large as compared to those in Region 2. A positive magnetic anomaly is a signature of the magnetic field strength that is higher than the regional average, which is also indicative of hidden ore and geologic structure whereas a negative magnetic anomaly is a signature of magnetic field strength that is lower than the regional average.

The sedimentary cover is generally considered to be almost non-magnetic and the anomalies are sourced from the crystalline basement [31] It may, therefore, be inferred from the identified regions of Fig. 4, and the locations of the spikes in Figs. 5, 6 and 7, that Region 1, which is of low magnetic intensity, represents the sedimentary region of the study area while Region 3, with intermediate magnetic intensity is of granitic rock composition. Meanwhile, region 2, which exhibits high magnetic intensity, may represent the basic igneous rocks of the study area.

Fig. 6 represents the wireframe of the study area after gridding, which shows the apparent amplitude of magnetic source in the area. Comparing Figs. 5 and 6, the area without spikes (40km-55km along the longitude) indicates the sedimentary zone of the study area.

Fig. 7 is the image (raster) map of the total field data. The contours enclosing areas with similar magnetic values are shaded or represented by different colors. The map legend illustrates the variation of colors from black to white as the magnetic field values increases.

The geophysical data for different profiles were analyzed using potential field (PF) software. The Horizontal Gradient Method and the Analytic Signal Method were then performed and presented using the HDEP, ASDEP and PLOTDEP computer programs. The results obtained are shown in Figs. 8 and 9. The estimated depth is presented in Table 1.

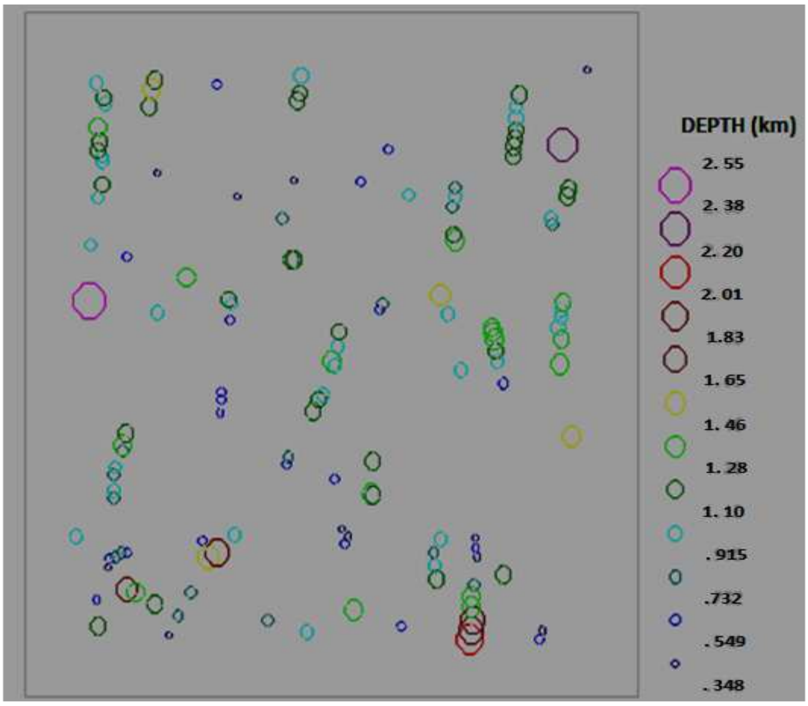

Fig.9: Depth and contact location from Analytic Signal Method (ASM).

Table 1: Depth to basement of magnetic sources using HGM AND ASM

Technique	Shallow sources (km)	Average	Deeper sources (km)	Average
HGM	0.478-2.500	1.489	2.920-5.480	4.200
ASM	0.348-1.280	0.814	1.460-2.550	2.010

The depth of source interpretation for aeromagnetic field data provides important information on basic architecture for mapping areas where basement is shallow enough for mineral exploration. Magnetic basement is an assemblage of rocks that underlies sedimentary basins and may also outcrop in places. If the magnetic units in the basement occur at the basement surface, then the depth determination will map the basin floor morphology, relief and structure [13]. The result of ASM for study area indicated a two-depth source model with the depth of the deeper sources identified with crystalline basement. Two important magnetic layers can therefore be identified in the table above, with an average basement depth of 2.01km and 4.20km for the Analytic Signal Method and the Horizontal Gradient Method, respectively. The first layer with average distance of 4.200km may be attributed to magnetic rocks of the basement, lateral variation in basement susceptibilities and intra-basement features like faults and fractures.

The second magnetic layer, comprising of 0.814km for ASM and 1.489km for HGM (on the average), may be attributed to magnetic rocks, which intruded into the sedimentary formations. For each circle of Figs. 8 and 9, the center coincides with the location of the maximum for that function, whereas the diameter of the circle is proportional to the depth estimated for the source at that point.

4. Conclusions

The Horizontal Gradient Method and the Analytic Signal Method have been successfully applied to aeromagnetic data of Ilesha to locate the contact of the magnetic bodies and also determine their depth to magnetic basement. Depth ranges are between 0.478km-5.48km for HGM and 0.348-2.55km for ASM.

The centre of each circle in Figures 8 and 9 coincides with the location of the magnetic sources. It also showed that magnetic bodies do not occur at random but are generally aligned along definite vertical axes.

The Horizontal Gradient Method shows more magnetic sources and the contacts are more continuous, whereas the Analytic Signal Method identified with less magnetic sources is less continuous.

The area with spikes in Figs. 4 and 5, the localized small closures observed in the contour map in Fig. 3 could be the faulting and fractures due to basement intrusions and illegal mining already reported in the study area.

For the contact location, the Analytic Signal Method does not make the same assumptions and does not result in displaced contacts. However, the Analytic Signal contacts are less continuous and their directions can be influenced by flight line in the data.

Regions where the analytic signal contacts are isolated and not aligned with flight lines may provide reliable contact locations whereas cases of discontinuity of the ASM contacts may be supplemented by the HGM.

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