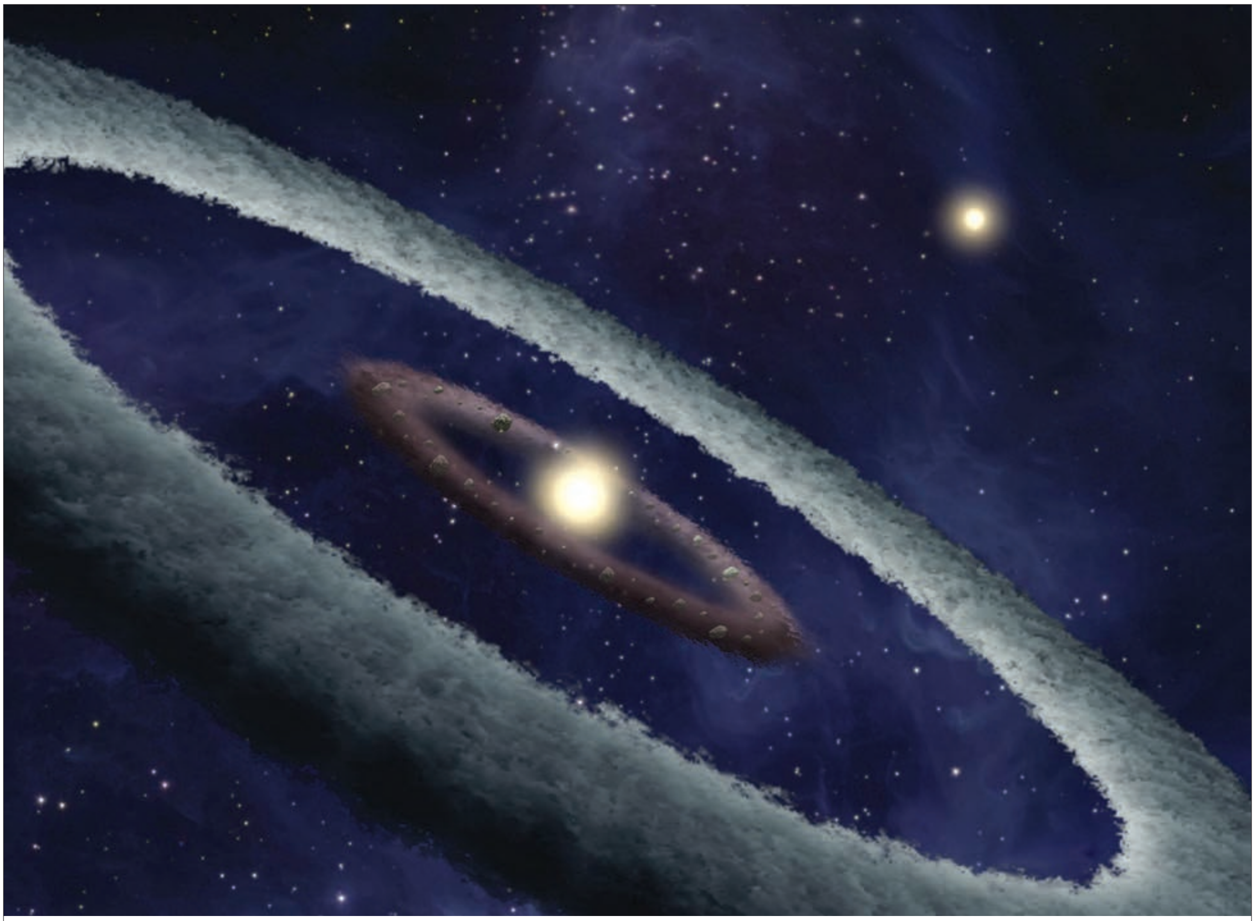

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Application of Thin Sheet Model for the Analysis and Interpretation of Aeromagnetic Data

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ABSTRACT

An aeromagnetic map for Ogbomoso area within longitudes 4°00 and 4°30'E and latitudes 8°00 and 8°30'N which covers the distance of 55 by 55 km (3025 km^2) study area was acquired. The map was digitized, gridded and delineated into profiles at 100 m interval of which some profiles were selected, processed and regional gradient removed. Reduction-to-pole of the total magnetic field intensity was carried out, the contour map and surface distribution of the magnetic minerals was obtained using semi-automated geophysical software. To carry out a quantitative analysis and interpretation thin sheet model was used to study the magnetic anomaly of the area and subsequently determine the average depth to the magnetic mineral source, magnetic angle and the angle of dip. The results obtained reveals 150-265.2 m of depth with combined magnetic angle of 39.8-53.1° and angle of dip of 66.9-81.3°, respectively. The result from the analysis indicates the presence of magnetic mineral resources in the locality which spread across the surveyed area while some are found at fairly near-surface, others are located at a deep region of the crust.

Key words: Aeromagnetic data, magnetic mineral, ogbomoso, anomaly, thin sheet

INTRODUCTION

The purpose of magnetic surveying is to identify and describe regions of the Earth's crust that have unusual (anomalous) magnetizations (Dobrin and Savit, 1988). In the realm of applied geophysics, the anomalous magnetizations might be associated with local mineralization that is potentially of commercial interest or they could be due to subsurface structures that have a bearing on the location of oil deposits. Most rocks of the earth's crust contain crystals with magnetic minerals, thus most rocks have a certain amount of magnetism which usually has two components: Induced by the magnetic field present while taken measurement and remnant which formed during geologic history (Reijers, 1996).

Over the last decade, there has been increase in the use of airborne magnetics and more recently gravity in the petroleum exploration industry (Telford *et al.*, 1990). 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 (Ebner, 1995). 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.

Most of these methods have a long history, preceding the computer age. Modern computing power has increased their efficiency and applicability tremendously, especially in the face of the ever-increasing quantity of digital data associated with modern airborne surveys. Most filters and interpretation techniques are applicable to both gravity and magnetic data. As such, it is common when applicable to reference a work, describing a technique for filtering magnetic data when processing gravity data and vice versa. Cooper and Cowan (2003) introduced the combination of visualization techniques and fractional horizontal gradients to more precisely highlight subtle features of interest. The total gradient (analytic signal) is another popular method for locating the edges of magnetic bodies. For magnetic profile data, the horizontal and vertical derivatives fit naturally into the real and imaginary parts of a complex analytic signal (Nabighian, 1972, 1974, 1984; Craig, 1996).

One important goal in the interpretation of magnetic data is to determine the type and the location of the magnetic source. This has recently become particularly important because of the large volumes of magnetic data that are being collected for environmental and geological applications. To this end, a variety of semiautomatic methods, based on the use of derivatives of the magnetic field, have been developed to determine magnetic source parameters such as locations of boundaries and depths (Blakely, 1995; Nabighian *et al.*, 2005).

The study of anomaly in mineral exploration has been a subject of great importance in our contemporary times especially in the south-western part of Nigeria. This work analyses and interprets aeromagnetic data of some part of Ogbomoso. The stages of magnetic data interpretation generally involve the application of mathematical filters to observed data. The specific goals of these filters vary, depending on the situation. The general purpose is to enhance anomalies of interest and/or to gain some preliminary information on source location or magnetization.

MATERIALS AND METHODS

Location of the study area: Ogbomoso is a city in Oyo State, south-western 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°08'00" and Longitude of 4°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 km south west of Ilorin (the Capital of Kwara State) 53 km north-east of Oyo, 58 km north-west of Osogbo (Capital of Osun State) and 104 km North-East of Ibadan (Capital of Oyo State) (Fig. 1).

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 harmattan experienced at the end of November to mid-March. The man annual rainfall is 1-24 mm. The variation in rainfall quantities between different 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 (Rahaman, 1976). The major rock associated with

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

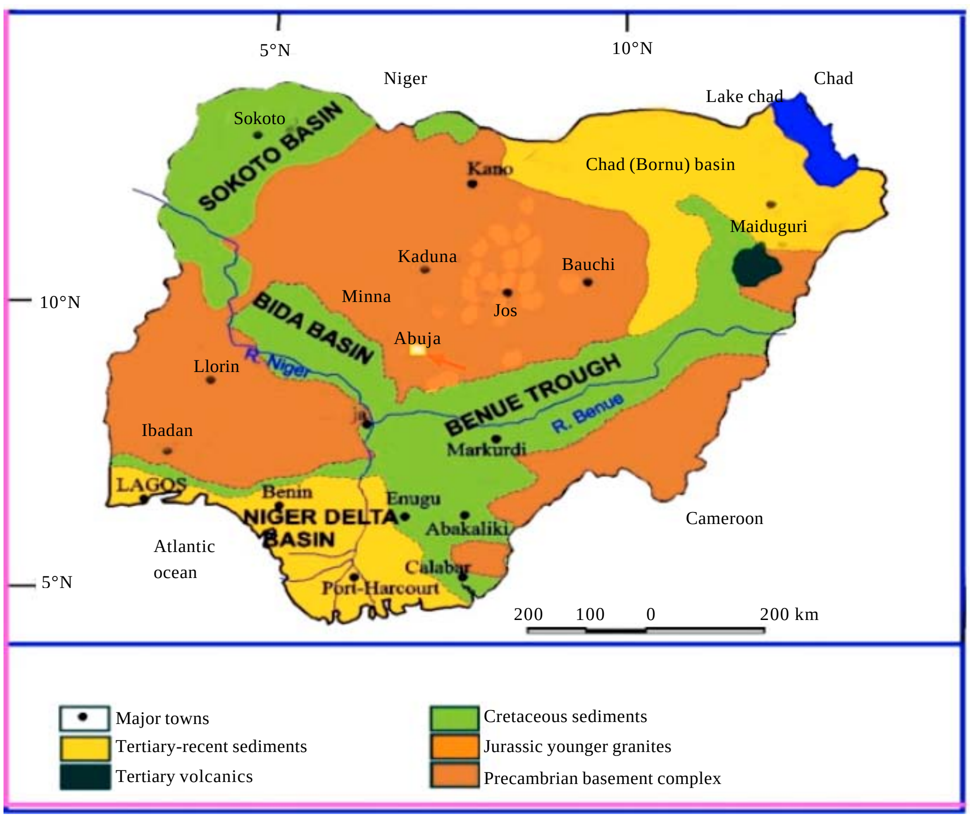

Fig. 2: Geological map of Nigeria (after Obaje, 2009)

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 (Rahaman, 1976).

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 (Rahaman, 1976).

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 (Oyawoye, 1964). 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 (Jones and Hockey, 1964). 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 (Rahaman, 1976; Folami, 1992).

Data correction and filtering: The Aeromagnetic map for Ogbomosho was acquired from the Nigeria Geological Survey Agency (NGSA). The data which covers the total area of 55 by 55 km (3025 km^2) was on the scale of 1:100000 and later converted to Excel-readable format by the use of Geosoft Oasis Montaj.

The obtained data was along a series of NE-SW with a flight line spacing of 500 m and time line spacing of 5000 m. The flight line direction was 135° Azimuth while the line direction was in 45° Azimuth. The flying altitude was 80 m above the terrain. By the International Geomagnetic Reference Field formula (Finlay *et al.*, 2010), the geomagnetic gradient was removed and average magnetic inclination and declination were given as 9.75 and 1.30°, respectively.

The digitized Total Magnetic Intensity (TMI) data was further corrected by removing the regional gradient and noise through the process of Trend Analysis in Excel and Euler Deconvolution Geophysical Software for windows by Cooper (2000). Subsequently Reduction to Pole (RTP) was carried out on the data for proper analysis and interpretation. The digital map was scaled at 1 km grid and had been upward continue to 1 km above mean sea level.

The xyz-digitized data was marked into profiles at 100 m interval and selected profiles were later processed by the application of Surfer(R) Version 10. The Total Magnetic Field of the area was generated in surface distribution and contour maps, respectively.

Thin sheet model: This study examines the use of thin sheet model in the determination of depth to basement of the magnetic source. The approach among others is a rapid method. In applying this model, the characteristics estimators are chosen based on lengths of the profile that can be readily indentified, not exceeding the sides of the anomaly by too much. The method does not involve too many calculation but rather can be obtained rapidly (Am, 1972) and is independent of the based level and origin. In furtherance of the analysis, the surface distribution of total magnetic intensity of the area was done.

The general expression for the magnetic anomaly over a sheet along a line perpendicular to its strike is after Gay (1963):

$$F(x) = P\frac{x\sin\theta + h\cos\theta}{x^2 + h^2} \tag{1}$$

For a typical magnetic anomaly curved produced by a sheet with h = 1 km, P = 100 units and $\theta = 60°$ it is then taken that from Eq. 1 the distance X_m between the maximum and the minimum on F(x) is obtained as:

$$X_m = 2h\ \text{cosec}\theta \tag{2}$$

and A, the total amplitude (from negative to positive peak) is given by:

$$A = {}^{P}\!/_{h} \tag{3}$$

When the zero level of the anomaly is assumed to be at the negative peak, Eq. 1 modifies to:

$$F(x) = P\left[\frac{x\sin\theta + h\cos\theta}{x^2 + h^2} - \frac{\cos\theta - 1}{2h}\right] \tag{4}$$

The condition for ½ A points on F(x) is:

$$X^2\text{-}2xh\ \tan\theta\text{-}h^2 = 0 \tag{5}$$

Denoting the distance between two points where F(x) is equal to ½ A as $X_{½}$, then we have:

$$x_{½} = 2h\sec\theta \tag{6}$$

Similarly, the distance between the points where F(x) is equal to ¼ A and ¾ A are given, respectively as Eq. 7 and 8 by:

$$x_{¼} = h\frac{2\sqrt{3}}{2\cos\theta - 1} \tag{7}$$

and:

$$x_{¾} = h\frac{2\sqrt{3}}{2\cos\theta + 1} \tag{8}$$

It then implies that from Eq. 5, 6, 7 and 8 the following analytical relations may be derived:

$$h = \frac{x_{1/4} . x_{3/4}}{\sqrt{3}(x_{1/4} - x_{3/4})} \tag{9}$$

or:

$$h = \frac{x_{1/2} . x_{3/4}}{2\left(\sqrt{3}x_{1/2} - 2x_{3/4}\right)} \tag{10}$$

or:

$$h = \frac{x_m . x_{1/2}}{2(x_{1/2}{}^2 + x_m{}^2)^{1/2}} \tag{11}$$

and:

$$\theta = \cos^{-1}\left[\frac{x_{3/4} + x_{1/4}}{2(x_{1/4} - x_{3/4}}\right] \tag{12}$$

$$\theta = \tan^{-1}\frac{x_{1/2}}{x_m} \tag{13}$$

where, h-the depth to the basement and θ-the combined magnetic angle.

RESULTS AND DISCUSSION

The analysis and interpretation of aeromagnetic data was done by using both the quantitative and qualitative approach. This implies that in getting substantives information about the lithology of a location, so many factors must be put into consideration. Also, geophysical techniques to be employed must be such that it is suitable for the purpose of the work. It is obvious that there are various geophysical methods and models that have been used in literatures in order to determine the depth-to-basement of magnetic material through the study of their anomaly.

Geophysical software was employed in filtering the data in order to remove the regional gradient and possible magnetic noise. To achieve better gridded data, Kriging approach was used from which the coloured map of the location was generated in Fig. 3 which shows the magnetic intensity values of the area in nanotesla. The area was contoured at the magnetic interval of 40 nT.

The surface distribution of the magnetic mineral in the locality was performed 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. 4 and 5, respectively at interval of 40 nT on magnetic field scale.

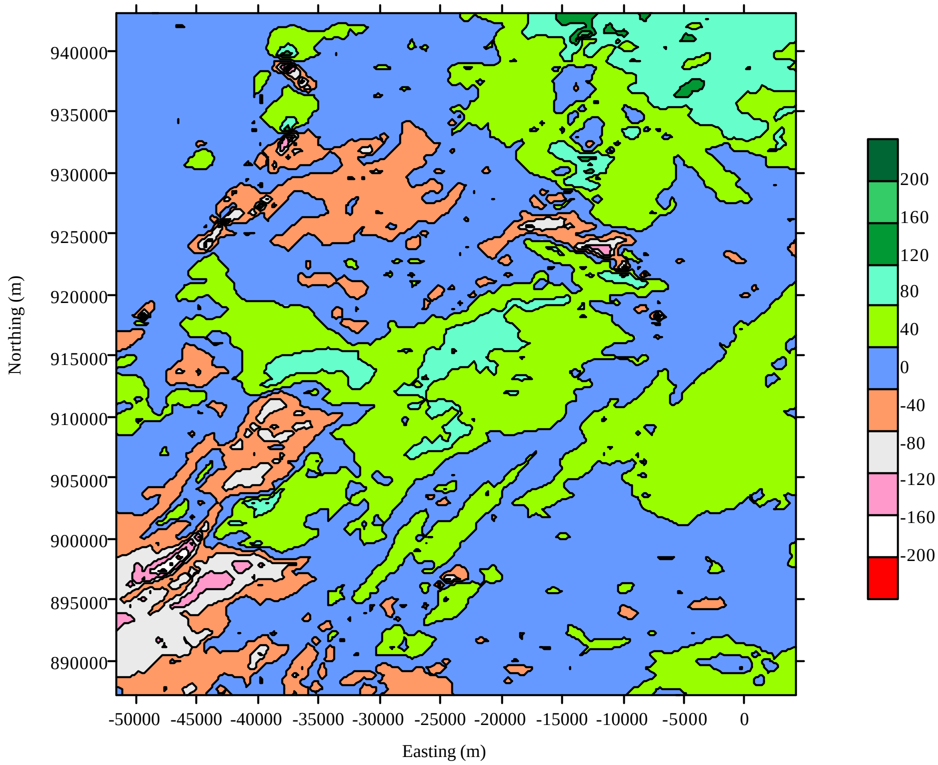

Fig. 3: Coloured map of the total magnetic field intensity

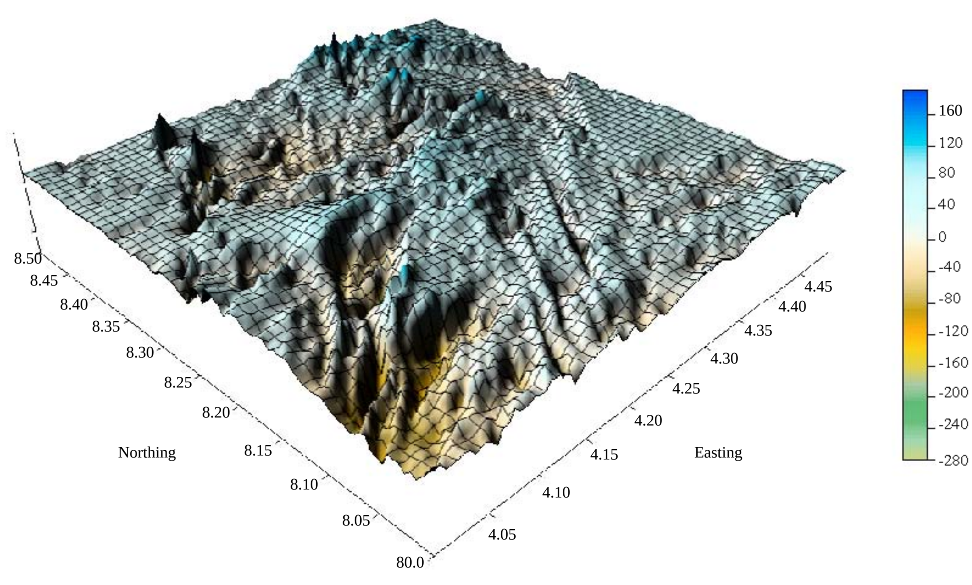

Fig. 4: Surface distribution of magnetic mineral showing anomaly spikes

Moreover, in a quantitative manner thin-sheet model was adopted in determining the depth to the basement of the buried object. In applying this model, the characteristics estimators were chosen. The model does not involve in too many calculation but rather obtain rapidly and

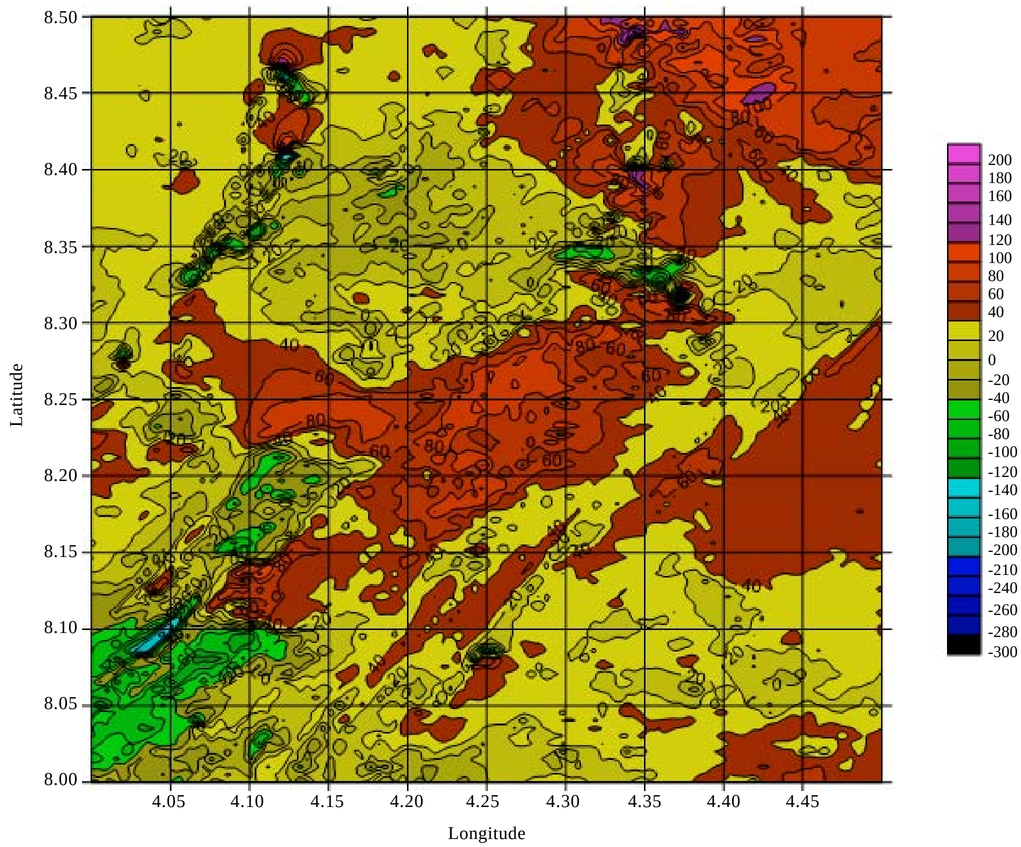

Fig. 5: A gridded contour map of the study area in geographical coordinates

Table 1: Result showing the determined geologic parameters

Profile	Distance at max amplitude X, m	Horizontal scale-off distance at 0.75 max amplitude $X_{(3/4)}$ m	Horizontal scale-off distance at 0.5 max amplitude $X_{(1/2)}$ m	Horizontal scale-off distance at 0.25 max amplitude $X_{(1/4)}$ m	Depth to the source h (m)	Combined magnetic angle, θ (°)	Total amplitude A (nT)	Location of origin at x = 0 (nT)	Angle of dip δ (°)
A-A′	375	250	500	875	150.0	53.1	30.0	24.0	66.9
B-B′	625	500	750	1000	240.1	50.2	25.0	20.5	69.8
C-C′	625	500	500	750	195.2	38.7	33.0	29.4	81.3
D-D′	375	250	500	625	150.0	53.1	67.0	53.6	66.9
E-E′	375	375	500	750	150.0	53.1	49.0	39.2	66.9
F-F	500	375	500	1000	176.8	45.0	53.0	45.2	75.0
G-G′	750	375	750	1000	265.2	45.0	39.0	33.3	75.0
H-H′	750	500	750	1000	265.2	45.0	41.0	35.0	75.0
I-I′	750	500	625	1000	240.1	39.8	42.0	37.1	80.3
J-J′	500	375	500	625	176.8	45.0	90.0	76.8	75.0

independent of the based level and origin. The result is presented in Table 1. In analyzing the data, vertical magnetic field was chosen and the horizontal scaled-off distances for various profiles were calculated. The results shows that the depth to basement of the magnetic body lies within the range of 150-265.2 m, the combined magnetic angle of the geologic body in the locality fall between 39.8 and 53.1° and the angle of dip recorded values in the range of 66.9-81.3°.

CONCLUSION

The airborne data of Ogbomoso was acquired and corrected with the aid of reduction-to-pole method in order to position the ambient field on the pole and to further remove any trace of magnetic noise due to secular and regional variation. Thin sheet model was applied for the analysis and interpretation of the aeromagnetic data of some part of Ogbomoso in Oyo state south-western Nigeria. This was done to determine the depth to the top of the magnetic source, the combined magnetic angle and the angle of dip, respectively.

The result of the analysis revealed that the maximum depth to the top of the magnetic source recoded was 265.2 m while the minimum was 150.0 m. The result further shows that the average depth to the magnetic source within the locality was found to be 200.9 m with the combined magnetic angles lies between 39.8 and 53.1° and the angle of dip ranging between 66.90-81.3°. Thin sheet model have been used to investigate and validate the prospect of magnetic mineral exploration in the locality as near surface which is economical and cost effective.

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