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Estimation of Magnetic Basement Depth of Oyo Area from Aeromagnetic Data

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Abstract

This work involves the application of airborne magnetic data over Oyo town and its environ on geographical latitudes of $7^0 30' N$ to $8^0\,00' N$ and longitudes of $3^0\,30' E$ to $4^0\,00' E$ south western Nigeria. The main objective of this study is to define the depth to the crystalline basement in the study area by means of the magnetic automated processing techniques. Locations and depths to magnetic contacts were estimated from the total intensity magnetic field using Horizontal gradient magnitude (HGM), Analytic signal amplitude (ASA) and Local wavenumber (LWN). The digitized magnetic intensity data of Oyo area, south western Nigeria was analyzed to estimate depths to magnetic sources as well as source locations. The total magnetic intensity values ranges from -143.8 nT to 147.0 nT suggesting contrasting rock types in the basement complex. The magnetic basement depth results ranges from 0.528 km to 4.85 km for ASA, 0.674 km to 2.28 km for HGM while 0.0993 km to 1.69 km for the LWN method which overestimated source depths when compared with HGM and ASA functions. Thus, Oyo and its environs is dominated with basement rocks and have considerable variations both in the physical characteristics of rocks and structural geometries.

Keywords: Aeromagnetic, Local wavenumber, upward continuation, Geological structure, Magnetic susceptibility

1.0 Introduction

Geophysical investigation of the earth involves the study of physical properties of the ground, thereby providing vital information on subsurface material conditions by taking measurements at or near the earth's surface that are influenced by the internal distribution of physical properties [1]. The main source of the magnetic field and the cause of the circular variation remained a mystery since rapid fluctuations seemed to be the odds with the rigidity of the Earth, and until this century an external origin of the field was seriously considered. In 1838, Gauss was able to prove that the entire field has to be of internal origin. Gauss used spherical harmonics and showed that the coefficients of the expansion, which he determined by fitting the surface harmonic to the available to the magnetic data at that time. To acquire the variation in the earth magnetic field, there is need to carry out magnetic survey. Magnetic method is a geophysical technique that exploits the appreciable differences in the magnetic properties of minerals within the main objective of characterizing the earth's subsurface. In order to cover a large expanse of land, airborne magnetic survey is required. Aeromagnetic data allow fast coverage of large and inaccessible areas for subsurface reconnaissance, which makes magnetic data analysis an essential tools in geophysical exploration. Airborne magnetic data is the gathering of magnetic data by small aircraft over a large expanse of land (which may be or not accessible) and interpreting the data using several interpretation techniques. It is a means of arriving at ore deposit within a geographic area [2]. Aeromagnetic data records variation in the magnitude of the earth's magnetic field in order to detect local changes in the properties of the underlying geology.

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Airborne magnetic data collected over region under study becomes a potential source of valuable information containing signal related to hidden magnetic lithology and subsurface structure of area under consideration. It has been established that crystalline basement complex in some parts of West Africa have direct correlation between the yield of bore wells and their proximity to faults and dykes determined from aeromagnetic data [3]. In this study, a digitized aeromagnetic data of Oyo area, southwestern part of Nigeria as obtained by Nigerian Geological Survey Agency in 2009 were employed to estimate both structural and source parameters associated with the study area using gradient techniques.
The study is Oyo and it's environing an inland town in Oyo state, southwestern Nigeria. It bounded in the north by Kwara State, in east by Osun State, in the south by Ogun State and in the west partly by Ogun State and partly by Republic of Benin. Oyo is bounded by latitude $7^0 30' N$ to $8^0 00' N$ and longitude $3^o 30' E$ to $4^\circ 00' E$ with an area of about 3,025 square kilometres situated in southwestern Nigeria (Figure 1). Oyo falls within the basement complex of geological setting of southwestern Nigeria characterized by basement complex rocks of Precambrian age consisting of older and younger granites and metasedimentary rocks [4]. Ibadan area is composed of biotite, granite gneiss, migmatite biotite gneiss, biotite muscovite granite, hornblende granite and schists [5].

2.0 Data Source and Analysis of Airborne Magnetic Data

Oyo town and it's environ is covered by an aeromagnetic survey conducted by Nigeria Geological Survey Agency of Nigeria in. The aeromagnetic data (Sheet No. 241) were obtained using a proton precession magnetometer with a resolution of 0.1nT. The airborne geophysical work was carried out by Fugro Airborne Surveys. Aeromagnetic surveys were flown at 500m line spacing and 80m terrain clearance. The flight line direction was in the direction 135 azimuths while the tie line direction was in 45 azimuths. The average magnetic inclination, declination and field strength across the survey was 9.75^0, 1.30^0 and 32,742.556 *nT* respectively. The geomagnetic gradient was removed from the data using International Geomagnetic Reference Field (IGRF). The processing of the magnetic anomalies is based on the analysis of the computer digitised information using geostatistical gridding method at different altitudinal levels from complied total magnetic data of the study area as shown in Figure 3. This method produces visually appealing maps from irregularly spaced data and attempts to express trends in the data.

Theoretical Analysis

In order to achieve the aim of this study which is investigation of the subsurface structures within the area under consideration, several interpretational techniques were adopted. These approaches are the vertical integration (VI) method to delineate linear structures, analytic signal method to enhance the amplitude of the magnetic intensity, susceptibility mapping to inferred magnetic minerals.

Vertical Derivatives

The vertical derivative (gradient) operator is often applied to airborne magnetic data to sharpen the edges of anomalies and other significant features [6]. The algorithm is given by [7]

$$A(u,v) = A(u,v)\left(\frac{\left(u^2+v^2\right)^{0.5}}{n}\right)^n \quad (1)$$

where *A* (*u*,*v*) is the amplitude present at those frequencies, and *n* is the order of the derivative. The first vertical gradient of aeromagnetic data was calculated using Geosoft package V.6.4.2.[8]

3.0 Horizontal Gradient Magnitude (HGM)

Horizontal gradient is a simple approach to locate linear structures such as contacts and faults from potential field data using Equation 2. In magnetic field (x, y), the horizontal gradient magnetic HG (x, y) is given by [9,10].

$$HG(x,y) = \left[\left(\frac{dM}{dx}\right)^2 + \left(\frac{dM}{dy}\right)^2\right]^{1/2} \quad (2)$$

where $\frac{dM}{dx}$ and $\frac{dM}{dy}$ = horizontal derivatives of the total magnetic filed

HGM is the simplest approach because it does not require vertical derivatives. Since it does not require the calculation of vertical derivatives, it requires a number of assumptions about the sources, which are:

(i) The regional magnetic field is vertical,
(ii) The source magnetization is vertical,
(iii) The contact is vertical,
(iv) The contact are isolated and
(v) The sources are thick [11].

In order to satisfy the first two assumptions, it is necessary to apply a standard phase shift to the data known as RTP. Once the field is reduced to pole, the regional magnetic field will be vertical.
Horizontal gradient method employs special functions that are calculated from the HGM, which is a function of the transformed potential field causative sources. This method pinpoints the local maxima of the HGM curve of the transformed potential field data [12] given by Equation (3)

$$HGM = \frac{\sim d}{h^2 + d^2} \tag{3}$$

where,
h = distance to the contact
d = depth to the top of the contact
$\sim =$ Constant define by magnetic susceptibility across the magnetic contact, the Earth magnetic field strength and inclination. This function has a bell shape over contacts that are similar to that of analytic signal [13].

Analytic Signal

Concepts of Analytic Signal Method (ASM) for magnetic data were discussed in detailed in [14-17]. The analytical signal amplitude of the magnetic anomaly field can be effectively used to map the edges of 3-D and 2-D bodies [17]. Marson and Kingele [18] defined analytic signal of vertical magnetic gradient produced by 3D source as

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

4.0 Local Wavenumber Method

The local wavenumber method is a magnetic interpretation technique for estimation of sources parameters such as depth, source location, dip and apparent magnetic susceptibility from magnetic data. This method is based on the extension of complex analytic signal to estimate magnetic basement depth and other source parameters.
From the analytic signal amplitude, the determination of the local phase and local wavenumber for grid based data have been made easier using existing methods reported in [19-24]. Considering 2 – D source in which the dimension in the y direction extends to infinity, then the analytical signal associated with total magnetic field intensity in x and z direction $M(x, z)$ of the anomaly is given in complex function form as,

$$A(x, z) = |A| e^{j\bar{}} \tag{5}$$

j is the imaginary number $\sqrt{-1}$ and $\bar{}$ is local phase which is the ratio of the vertical component of magnetic gradient to horizontal component of magnetic gradient, given by

$$\bar{} = \tan^{-1}\left[\frac{\partial M/\partial z}{\partial M/\partial x}\right] \tag{6}$$

From the analytic signal amplitude, amplitude of analytic signal and local phase defined in Equations (5) and (6) respectively.

5.0 Results and Discussion

It has been established that the main use of any aeromagnetic and their derivative maps (enhancement maps) in mineral prospecting are to make deduction from the maps[25]. Also from the range of total magnetic intensity values of the processed data, information on subsurface litho logy, trend and geological structures can be revealed. The total magnetic intensity grid was created using a minimum curvature gridding algorithm with a grid cell size of 50metres. The grid values fit the profile data to within 1nT for 99.98% of the profile data points. The average gridding error is below 1nT. After performing a gridding of sheet number 241 of the study area, the output of the gridding is shown in Figure 3
In Figure 3, the total magnetic intensity values ranges from -143.8 *nT* to 147.0 *nT* as shown in Figure 3 suggesting contrasting rock types in the basement complex of the study area. The survey area is characterized by cluster short wavelength anomalies in the entire area as shown in Figure 4. The short wavelength components may be attributed to shallow magnetic sources. Inspection of Figure 3 reveals that the entire study area is basement complex which agrees with the geological map of study. The vertical gradient of the magnetic intensity was calculated using equation (1). The vertical derivatives deals with amplitude of narrow magnetic anomalies and enhances the higher frequency shallow sources as shown in figures 5 and 6. In Figures 5 and 6, the vertical derivative maps helps to highlight details and break in anomaly texture of subtle and local short wavelength magnetic anomalies are emphasized.

The source location and depth solutions are shown in Figures 7, 8 and 9 for ASM, HGM and LW respectively. Standard error of 15% was used on each method.

For each of the Figures 7,8 and 9, the centre of each circle coincides with the location of a maximum for that function, while the diameter of the circle is proportional to the depth estimated for the source at that point. The depth results obtained from ASM revealed depth range limit of 0.528 – 4.85 km, while HGM gave an estimated depth magnetic basement source ranges from 0.674 – 2.28 km. LW method revealed an estimated magnetic basement depth ranges from 0.0993 – 1.69 km

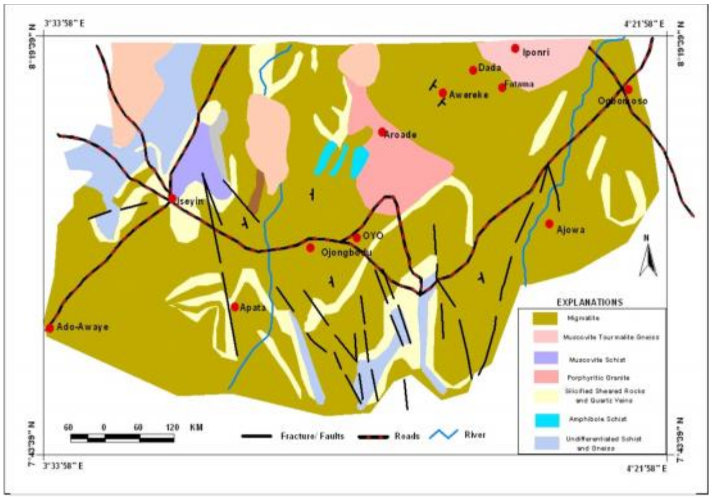

Fig. 1: Geological map of Oyo area (sheet number 241)

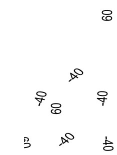

Fig. 2: Contour map of oyo (sheet number 241)

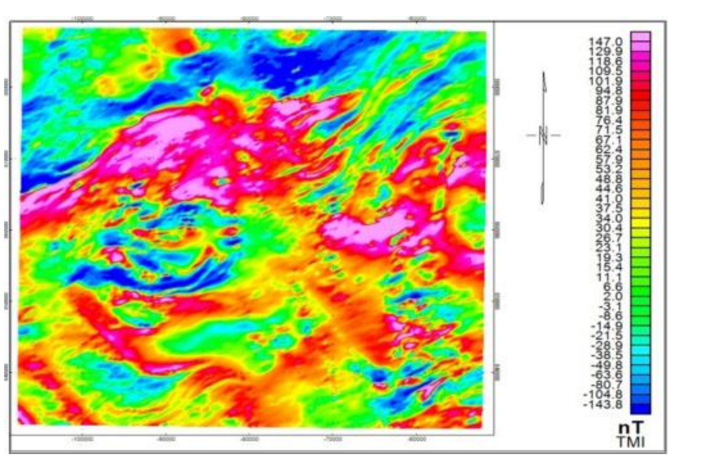

Figure 3: Total magnetic intensity Map of Oyo (Sheet number 241)

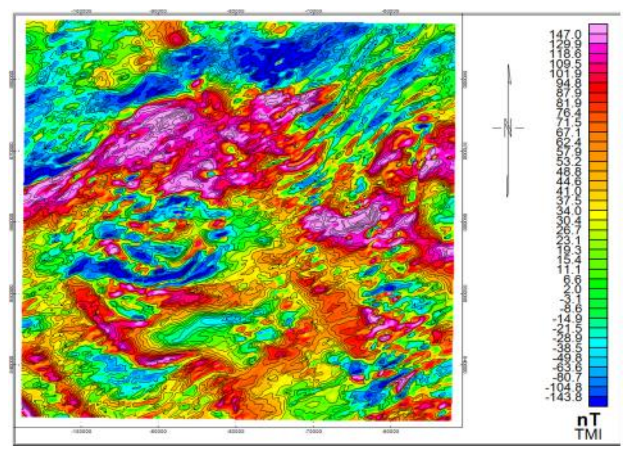

Figure 4: Total Magnetic Intensity Contour Map of Oyo (Sheet number 241)

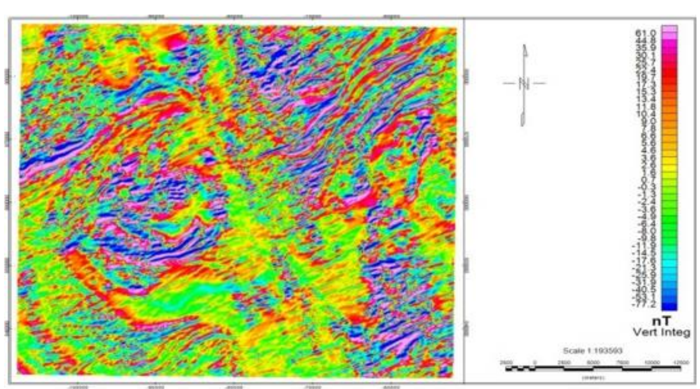

Figure 5: Vertical Derivative Map of the study area

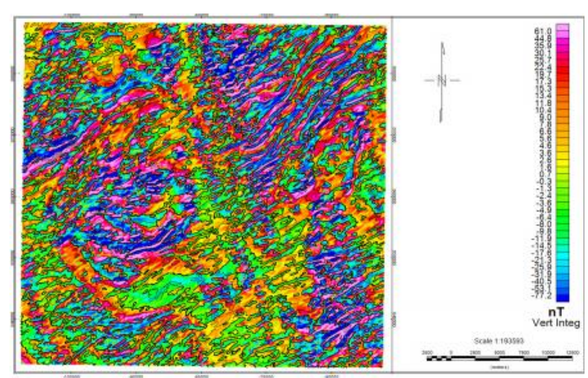

Figure 6: Vertical Derivative Contour Map

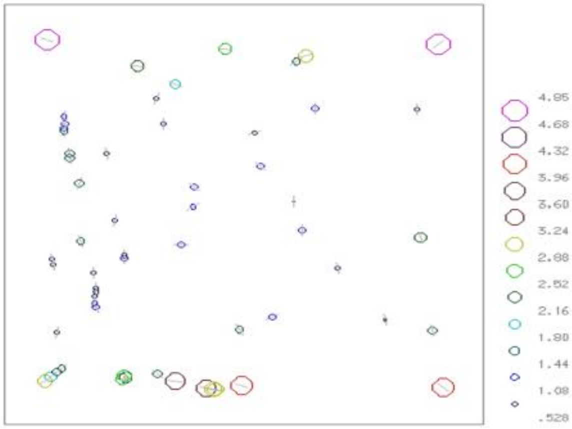

Figure 7: Source and depth location map using (ASM)

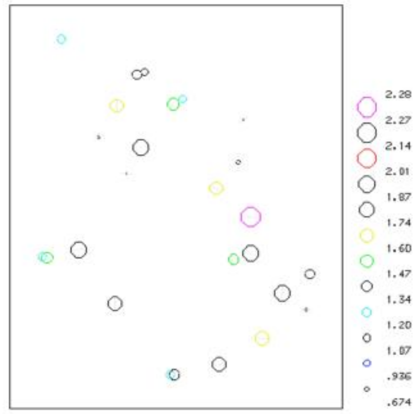

Figure 8: Source and depth location map using (HGM)

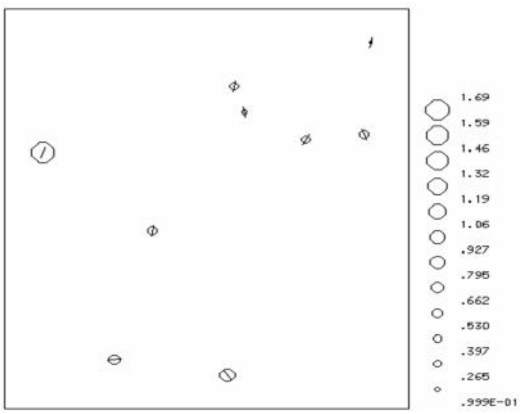

Figure 9: Source and depth location map using (LW)

6.0 Conclusion

Analysis of aeromagnetic data provides valuable geological information about the area under study. The result obtained from this study show that the study is dominated with basement rocks and have considerable variations both in the in the physical characteristics of rocks and structural geometries. In general, the prominent features are the high magnetic zones believed to be region where magnetic anomalies are likely to be fully deposited in the study area. The location and depth to magnetic basement have been estimated from the maxima of the ASM, HGM and LW functions of total magnetic intensity data.

7.0 References

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