Original scientific paper

Received: May 17, 2016
Accepted: November 8, 2016
DOI: 10.1515/rmzmag-2016-0018

Interpretation of aeromagnetic data over Abeokuta and its environs, Southwest Nigeria, using spectral analysis (Fourier transform technique)

Interpretacija aeromagnetnih podatkov z območja Abeokuta in okolice v jugozahodni Nigeriji ob uporabi metode spektralne analize (fourierjeve transformacije)

Olurin Oluwaseun T.[1]*, Ganiyu Saheed A.[1], Hammed Olaide S.[2] and Aluko Taiwo J.[1]
[1] Department of Physics, Federal University of Agriculture, P.M.B. 2240, Abeokuta, Ogun State, Nigeria
[2] Department of Physics, Federal University Oye Ekiti, Ekiti State, Nigeria
* olurin@physics.unaab.edu.ng

Abstract

This study presents the results of spectral analysis of magnetic data over Abeokuta area, Southwestern Nigeria, using fast Fourier transform (FFT) in Microsoft Excel. The study deals with the quantitative interpretation of airborne magnetic data (Sheet No. 260), which was conducted by the Nigerian Geological Survey Agency in 2009. In order to minimise aliasing error, the aeromagnetic data was gridded at spacing of 1 km. Spectral analysis technique was used to estimate the magnetic basement depth distributed at two levels. The result of the interpretation shows that the magnetic sources are mainly distributed at two levels. The shallow sources (minimum depth) range in depth from 0.103 to 0.278 km below ground level and are inferred to be due to intrusions within the region. The deeper sources (maximum depth) range in depth from 2.739 to 3.325 km below ground and are attributed to the underlying basement.

Key words: aeromagnetic, Abeokuta, basement, intrusive, spectral analysis

Izvleček

Študija prinaša rezultate spektralne analize magnetnih meritev na območju Abeokuta v jugozahodni Nigeriji na podlagi metode hitre Fourierjeve transformacije (Fast Fourier Transform, FFT), izvedene z Microsoft Excel. Gre za kvantitativno interpretacijo aeromagnetnih podatkov (list št. 260), ki jih je posnel Nigerijski geološki zavod leta 2009. Da bi zmanjšali aliasno napako, so prevedli aeromagnetne podatke na 1-kilometrsko mrežo, Metoda spektralne analize je bila uporabljena za oceno prisotnosti magnetnih virov v dveh globinah. Rezultati kažejo, da so magnetni viri porazdeljeni v glavnem v dveh nivojih. Plitvi viri (v minimalni globini) od 0,103 km do 0,278 km globoko pod površinskim nivojem so interpretirani kot izraz globočninskih intruzij. Globlji viri (v maksimalni globini), od 2,739 km do 3,325 km pod površino, pa naj bi ustrezali kamninam podlage.

Ključne besede: aeromagnetni podatki, Abeokuta, geološka podlaga, globočnine, spektralna analiza

Introduction

Magnetic method is one of the oldest geophysical techniques used to delineate subsurface structure and determine the source of specific anomalies present in an area under investigation [1]. Aeromagnetic maps reflect the variations in the magnetic field of the earth. These variations are related to changes of structures, magnetic susceptibilities and/or remnant magnetisation. Sedimentary rocks, in general, have low magnetic properties compared with igneous and metamorphic rock that tend to have a much greater magnetic content. Thus, most aeromagnetic surveys are useful to map the structure of the basement and the intruded igneous bodies from the basement complex [2].

An airborne geophysical survey reflects the variations in the distribution and type of magnetic mineral below the earth surface [3]. The airborne survey of the study area was carried out by the Nigerian Geological Survey Agency. Aeromagnetic data allow fast coverage of large and inaccessible areas for subsurface reconnaissance, which makes magnetic data analysis an essential tool for geophysical exploration.

Abeokuta, the capital of Ogun State, is the most prominent urban settlement of the state and lies within the southwestern Basement Complex of Nigeria. Ogun State is bounded in the west by Benin Republic, in the south by Lagos, in the north by Oyo and Osun and in the east by Ondo State (Figure 1). It is bounded by latitudes 7°00' N to 7°30' N and longitudes 3°00' E to 3°30' E (Figures 1 and 2). The gneiss–migmatite complex is the most widespread rock group in the study area. The gneiss–migmatite complex comprises gneisses, quartzites, calc-silicate rocks, biotite–hornblende schists and amphibolites [4]. The gneisses are the most widespread rock types in the study area. The older granites occur in and around Abeokuta, are late Precambrian to early Paleozoic in age and are magmatic in origin [5].

The study area is Abeokuta, one of the prominent urban settlements in southwestern Nigeria. Abeokuta falls within the basement complex of the geological setting of southwestern

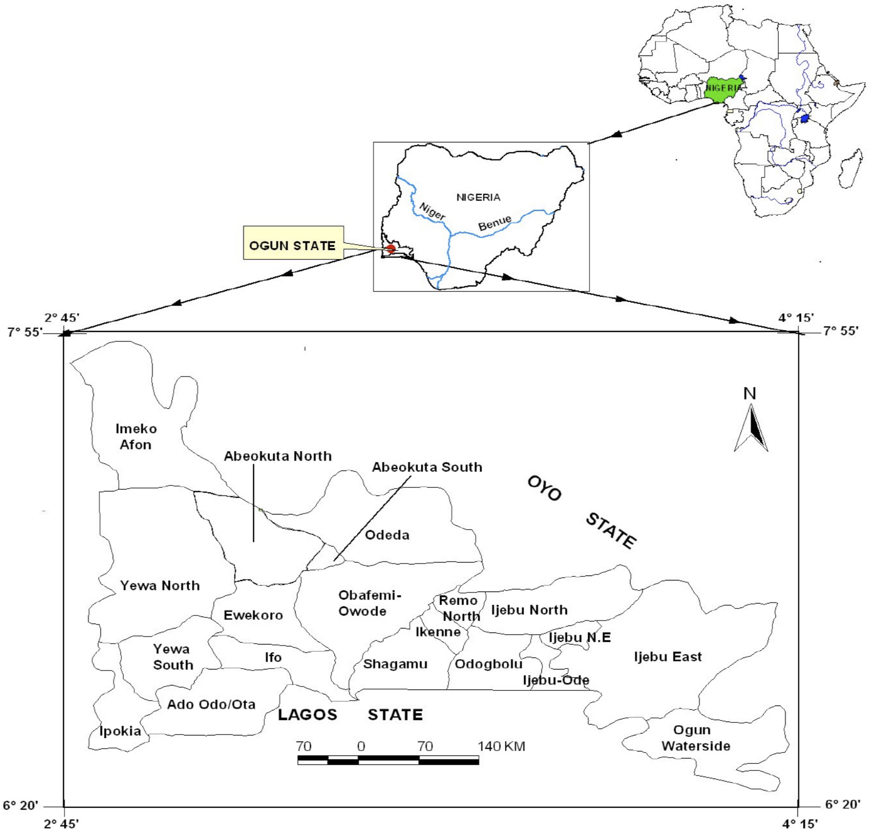

Figure 1: *Location map of Abeokuta and its environs.*

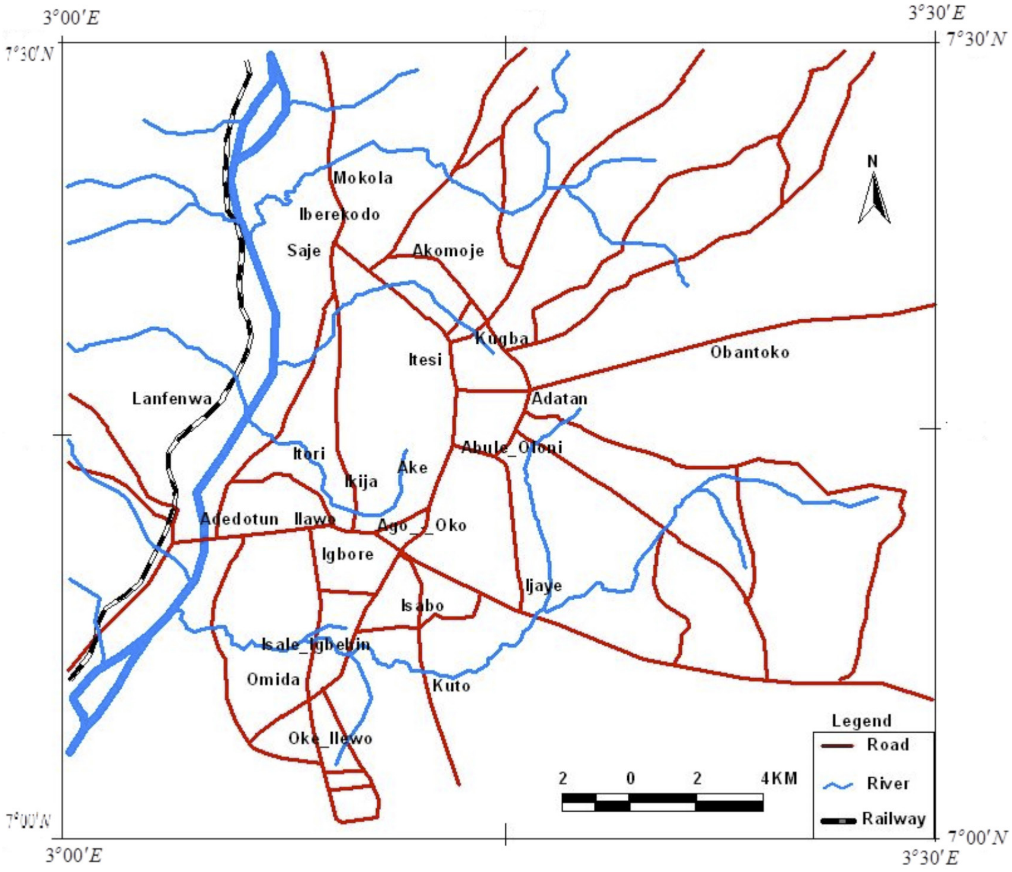

Figure 2: *Map of Abeokuta showing its different parts and the major rivers.*

Nigeria (Figure 3), characterised by the basement complex rocks of the pre-Cambrian age (made up of older and younger granites) as well as the younger and older sedimentary rocks of both tertiary and secondary ages (Figure 4). The areas underlain by basement rocks cover about 40% of the land mass in Nigeria, [6] as shown in Figure 5.

This study deals with the estimation of the basement depth of the observed aeromagnetic data of Abeokuta area using spectral analysis. This method has proved to be a powerful and convenient tool in the processing and interpretation of geophysical data on potential field.

Background and method

The aeromagnetic survey of the study area is part of the high-resolution airborne geophysical survey of Nigeria, involving magnetic, radiometric and limited electromagnetic survey. Abeokuta area was covered by an aeromagnetic survey conducted by the Nigerian Geological survey Agency in 2009. The aeromagnetic data was obtained using a proton magnetometer with resolution of 0.01 nT. All of the airborne geophysical work was carried out by Fugro Airborne Surveys. Aeromagnetic survey was conducted at 500 m line spacing and 80 m terrain clearance. The flight line direction is in the direction 135 azimuths; the tie line direction is at 45 azimuths. The flying line altitude is 80 m above the terrain. The average magnetic inclination and declination across the survey area were 9.75 and 1.30, respectively. The geomagnetic gradient was removed from the data using International Geomagnetic Reference Field (IGRF) formula, epoch 2009.

Analysis of aeromagnetic data

Spectral analysis of potential field data has been used extensively over the years to derive the depth of certain geological features, such as magnetic basement [7–10] or the Curie temperature isotherm [11–13]. Two-dimensional

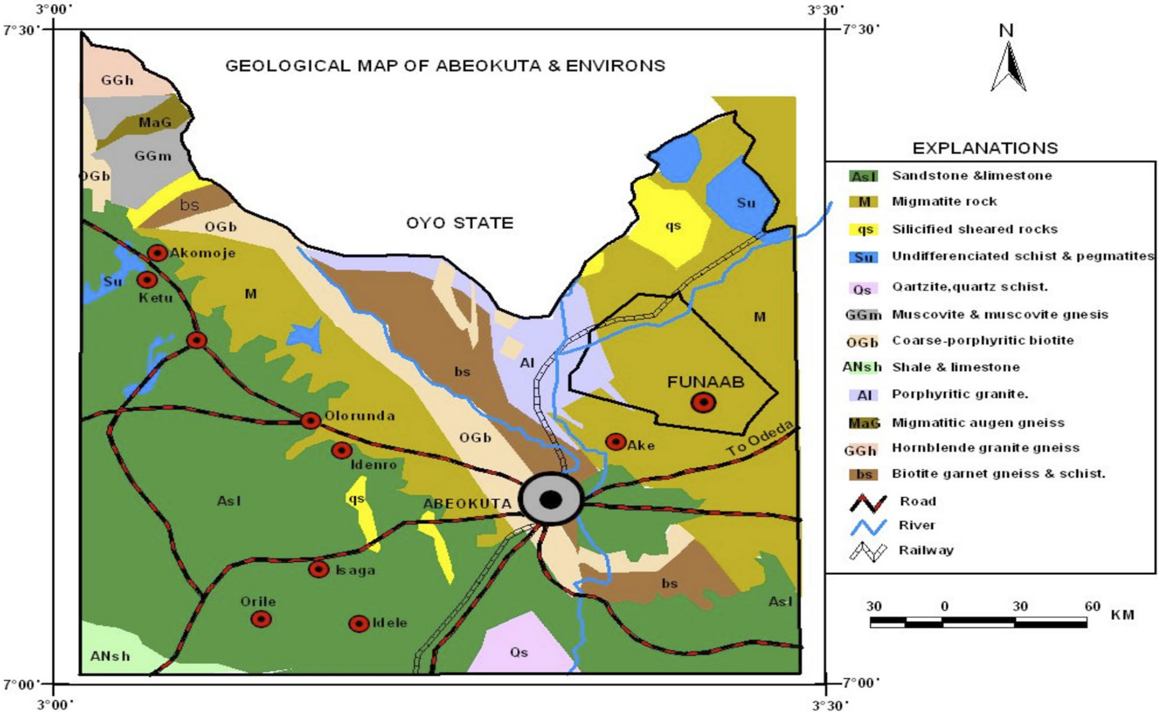

Figure 3: *Geological map of Abeokuta.*

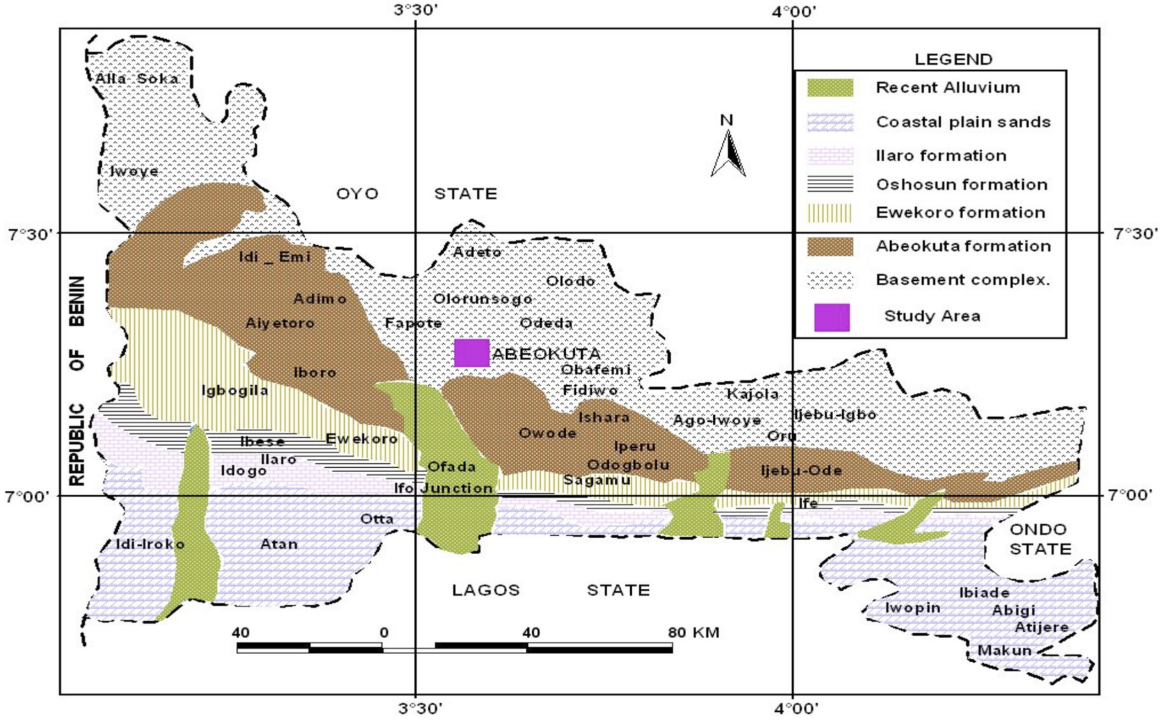

Figure 4: *Geological map of Ogun State showing the study area.*

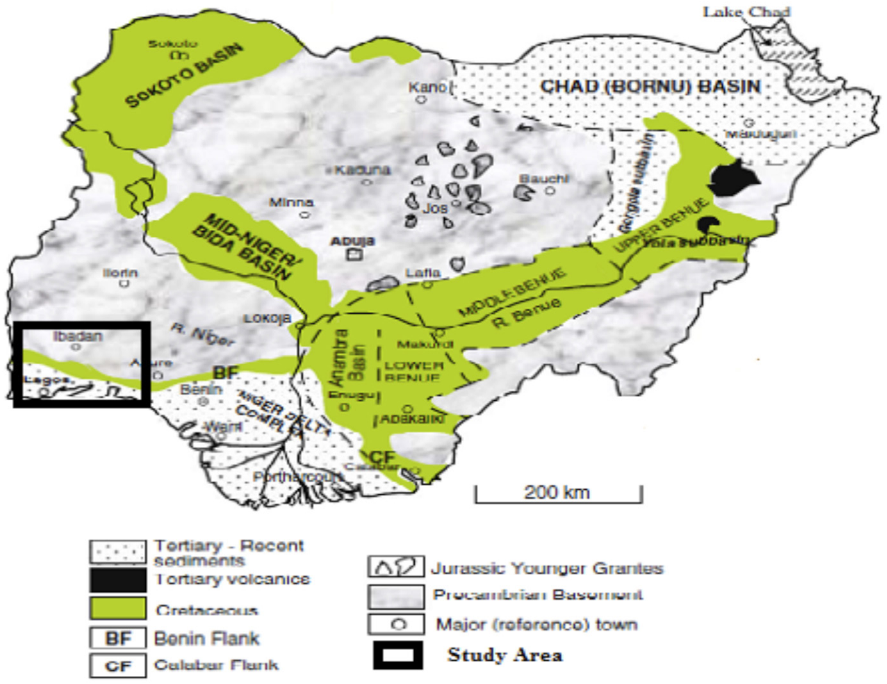

Figure 5: *Basement geological map of Nigeria (Obaje, 2009).*

(2-D) spectral analyses of the potential field data have been used extremely over the past 2 decades to estimate the depth of sources of anomaly [7, 8].

Spectral analysis has its theoretical basis in fast Fourier transform (FFT) [14]. FFT yields identification of the energy in the high-frequency band and enables better resolution. This method was applied to digitise magnetic data in profile form to obtain the differential magnetic response of each source ensemble that lies at certain depths. The airborne magnetic data along each profile, regarded as a set of equally spaced potential intensity data, was transformed into the frequency domain using Fourier transformation. The Fourier transform integral of the function is expressed as Equation 1.

$$F(q)=\int_{-\infty}^{\infty} F(x)\cdot e^{-qx}\,dx \tag{1}$$

where *F(x)* is the value of the function at a point *x*, and *F(q)* is the transform at a wave number *q*. Considering the behaviour of the transform, the amplitude or the spectrum energy is given as A·*(f)* or E·*(f)*, respectively. The amplitude and energy spectra are given as in Equation (2).

$$A(f)=\sqrt{R_C^2+R_S^2} \tag{2}$$

The spectral depth method has its basis on the principle that a magnetic field measured at the surface can therefore be considered the integral of the magnetic signature from all depths [15]. The power spectrum of a surface field can be used to identify the average depths of the source ensembles [7]; hence, the spectral analysis method is good in providing the average depth value to the top of the statistical ensemble of blocks of anomalous bodies. These anomalous sources can be interpreted in terms of subsurface structures. The method of computing depth involves Fourier analysis of the anomalies and computation of parameters through the operations on the FFT.

In 1970, Spector and Grant [7] generalised the expression by assuming that the anomalies on the aeromagnetic map are due to an ensemble of vertical prisms. The energy spectrum ⟨$E(r, \theta)$⟩ in polar coordinates is given as Equation (3):

$$\langle E(r,\theta)\rangle=|F_T|^2=4\pi^2 J^2\langle e^{-2hr}\rangle\langle(1-e^{-ir})^2\rangle \langle S^2(r,\theta)\rangle\langle R_p^2(\theta)\rangle\langle R_G^2\rangle \tag{3}$$

where ⟨ ⟩ indicates the expected value, F_T is the Fourier transform of the aeromagnetic anomaly, $r = (u^2+v^2)^{½}$ magnitude of the frequency vector, $\theta = \tan^{-1}\left(\frac{u}{v}\right)$ = direction of the frequency vector, J = magnetic moment/unit depth and thus, $^J/_{(4ab)}$ = moment/unit of the body, h = depth to top of the prism, t = thickness of the prism, $S(r, \theta) = \frac{\sin(\mathrm{arccos}\theta)}{\mathrm{arccos}\theta}, \frac{\sin(br\cos\theta)}{br\cos\theta}$ = factor for the horizontal size of the prism, $R_p(\theta)$ = factor for the magnetisation of the prism = $\left[n^2 + (l\cos\theta + m\sin\theta)^2\right]^{½}$, $R_G(\theta)$ = factor for the geomagnetic field direction = $\left[N^2 + (L\cos\theta + M\sin\theta)^2\right]^{½}$, where in these last two factors, I and M, denote directional cosines of the respective magnetisations.

For the power spectrum,

$$\langle E(r,\theta)\rangle = |F_{TL}|^2 \\ = 4\pi^2 J^2 \langle e^{-2hr}\rangle \langle (1-e^{-ir})^2\rangle \langle S^2(r)\rangle \tag{4}$$

The average ensemble depth h is observed in the factor e^{-2hr}.

Thus, the scaling factor (depth factor) can therefore be expressed as Equation (5):

$$\langle e^{-2hr}\rangle = \frac{\sinh(2r\Delta h)}{4r\Delta h} \tag{5}$$

The anomaly magnetic field intensity values are used to obtain the 2D FFT, from which the spectrum of the magnetic data is extracted. The average spectrum of the partial waves falling within the frequency is calculated, and the resulting values together constitute the radial spectrum of the anomalous field[8]. The logarithms of the energy spectrum are plotted against the wave number and the linear segments identified on each plots. Each linear segment has a group of points due to anomalies caused by bodies occurring within a particular depth. If z is the mean depth of the layer, the depth factor for this ensemble of anomalies is $e^{(-2Z)}$.

Thus, the logarithmic plot of the radial spectrum gives a linear graph whose slope is $2Z$. The mean depth of the buried ensemble is obtained as in Equation (10) [16].

$$Z = -\frac{Slope}{2} \tag{6}$$

The results of the plot of logarithm of the energy spectrum against the wave number are shown in Figures 8a–8f and 9a–9f. Evaluating the slopes of the graphs, the average depths to the magnetic basement for each of the 25 blocks are calculated using Equation 10, and the results are presented in Table 1. The values of Zt (Table 1) represent the shallow depth, while Zb represents the deep depth to the magnetic basement.

Table 1: *Spectral depths for the 25 blocks*

Block	Deep depth (km)	Shallow depth (km)
1	3.325	0.212
2	3.134	0.123
3	3.024	0.103
4	2.836	0.181
5	3.447	0.182
6	3.142	0.122
7	2.813	0.174
8	2.827	0.178
9	2.996	0.25
10	3.121	0.126
11	3.112	0.201
12	3.118	0.144
13	3.121	0.28
14	2.818	0.174
15	2.739	0.138
16	2.819	0.173
17	3.293	0.177
18	2.808	0.17
19	3.108	0.199
20	2.982	0.284
21	3.109	0.199
22	3.292	0.203
23	3.12	0.202
24	3.039	0.2
25	2.984	0.124

Results and discussion

Quantitative interpretation was adopted for the interpretation of airborne magnetic data in Abeokuta with the aim of establishing depth to

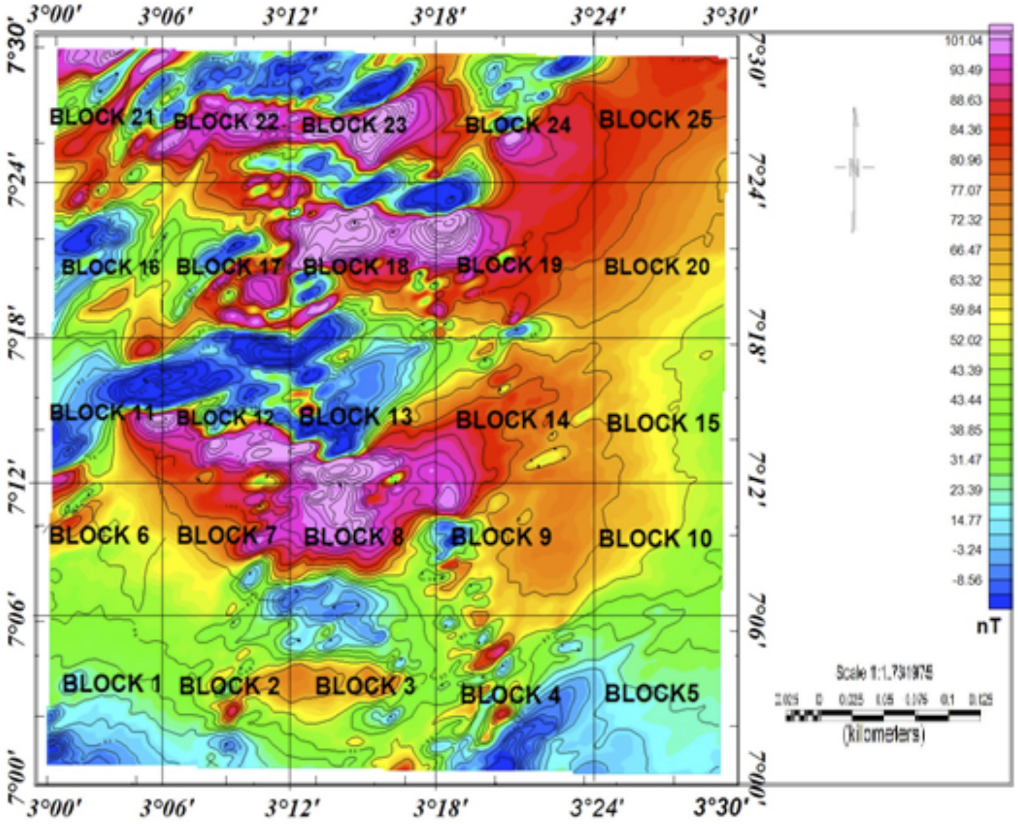

Figure 6: *Total magnetic intensity map of Abeokuta area showing the blocks.*

the basement within different blocks. Generally, the variations in the magnitude of the earth's magnetic field are presented in Figure 6. These maps display the variation in the magnetic intensity, which reflects the susceptibility of the different rocks across the terrain.

The variations in the magnitude of the earth's magnetic field, as shown in Figure 6, are reflections of local changes in the properties of the underlying geological materials and also show that there are sizeable quantities of different magnetic deposits at the location.

According to Dobrin and Savit [17], the main use of any aeromagnetic survey and its derivative maps in mineral prospecting is to make geological deductions from them. Figure 6 shows that the magnetic signature ranges from −8.6 nT to 101 nT, with clusters of short-wavelength anomalies in the northeastern- and northwestern- trending parts. The short-wavelength components are attributed to shallow magnetic sources associated with intrusive bodies such as dykes and plutons. The high magnitude of strong-amplitude magnetic anomaly, 101 nT, which was observed in some northwestern- and northeastern- trending parts of the study area could be due to the presence of outcrops of gneiss–migmatite complex or the rocks existing at shallow depths. The magnetic intensity map shows combination of regional, residual and noise signals. Therefore, the total magnetic intensity map of Sheet No. 260 revealed that this area is composed of sedimentary rocks and basement complex. The fault system may have been responsible for this consistent sinusoidal division of the area under consideration into two distinct units.

Average radial analysis of the processed digitised aeromagnetic data of Abeokuta and its environs was carried out by calculating the average power spectrum over a rectangular window. The calculated average radial power spectrum was plotted as the log graph of power spectrum versus spatial wave number, as shown in Figure 7, which delineates two distinct sources identified as of high amplitude with lower wave number and of low amplitude with higher wave number. The plot of the average radial power indicates that the deep structures have relatively large wavelengths than

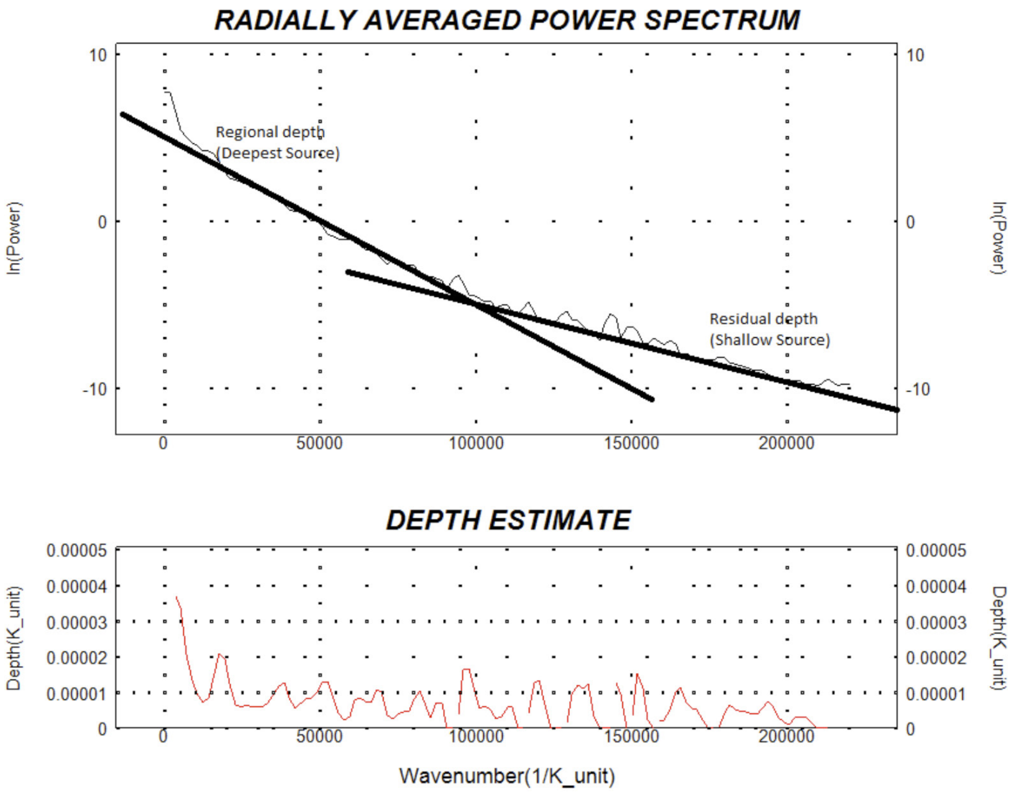

Figure 7: *Radially averaged power spectrum.*

the shallow sources; this observation agreed with field observations.

The results of the plot of logarithm of the energy spectrum versus frequency are shown in Figures 8a–8f and Figures 9a–9f. By evaluating the slopes of the graphs, the average depths to magnetic sources for each of the 25 blocks were calculated using Equation (10), and the results are presented in Table 1. The values of (Table 1) represent the deep magnetic sources, while the values of represent the shallow magnetic sources within the sediments. The value is assumed to represent the basement at various locations (Spector and Grant, 1970; Nabighian, 2005). The graphs of some selected block graphs are shown in Figures 8a–8f and Figures 9a–9f. The gradient of each linear segment was evaluated using Equation 10, which was proposed by Alboral et al. [17]; moreover, it was used to calculate the depths to the causative bodies (deep and shallow sources), where *h* and *m* are the depth and the gradient respectively.

Depth estimates from spectral analysis of the magnetic data along the blocks indicate a two-depth source model, which is shown in Table 1. The depth of the deeper source (maximum depth) ranges from 2.739 to 3.325 km; this could be identified with the basement. The shallow sources (minimum) range from 0.103 to 0.278 km; this could be attributed to near-surface intrusive and local changes in the earth's surface.

The results of this study are in accordance with the earlier work by Kasidi and Ndatuwong [18] on aeromagnetic data over Longituda Plateau and its environment, where the mean depth of the shallow sources was 0.591 and 2.26 km was the depth to deeper magnetic sources. Hassanien [19] used Filon Fourier spectral analysis and obtained the depths of 0.7 km and 6.0 km for the residual and regional anomalies, respectively. However, the study carried out by Nwankwo et al.[20] on sedimentary formation of Northern Nupe Basin found depth to magnetic basement to vary from 0.52 to 4.38 km, while a depth range of 0.24–1.74 km was attributed to shallow sources. Moreover, Onuba et al. [21] evaluated aeromagnetic anomalies over Okigwe area, Southeastern Nigeria, using the half-

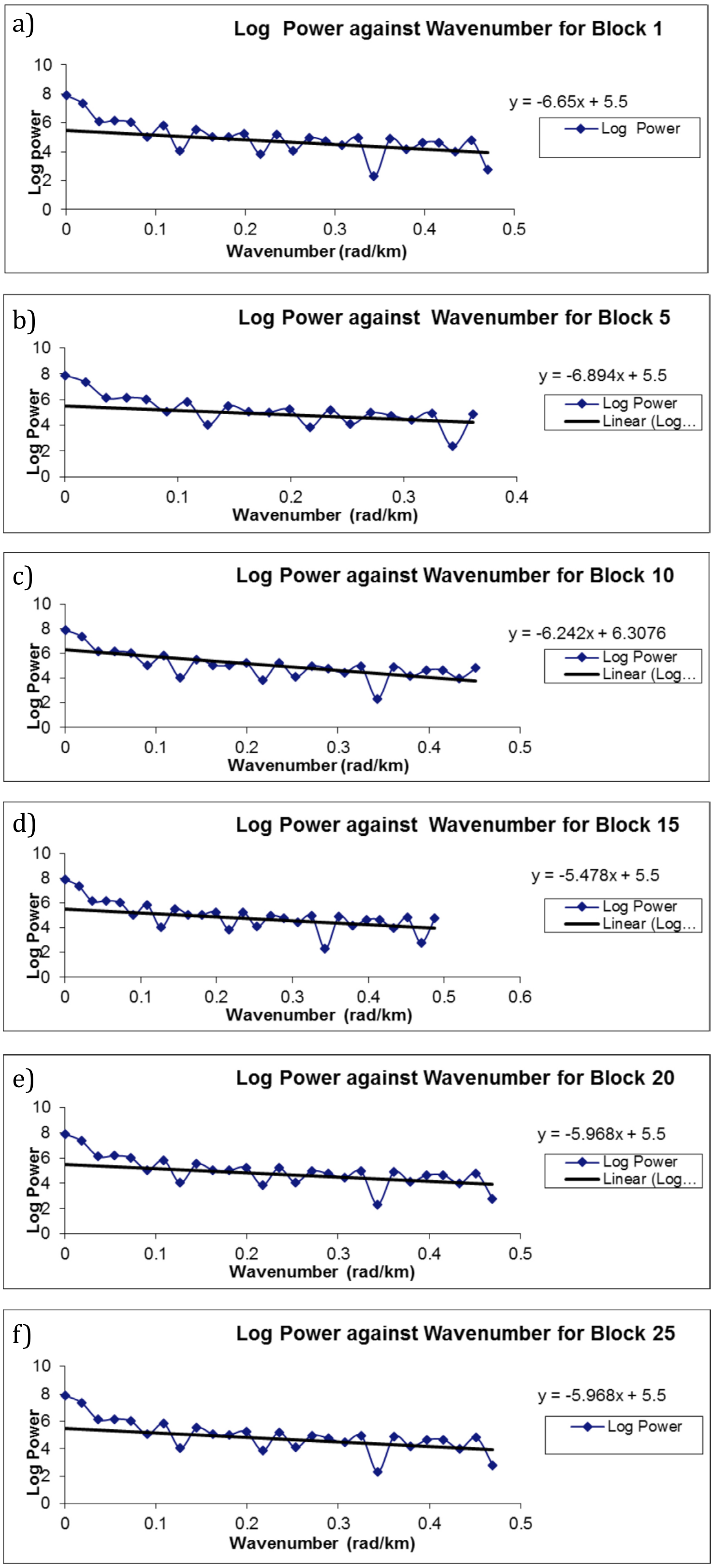

Figure 8: *a) Graph of deep (regional) component of power spectrum for Block 1; b) Graph of deep (regional) component of power spectrum for Block 5; c) Graph of deep (regional) component of power spectrum for Block 10; d) Graph of deep (regional) component of power spectrum for Block 15; e) Graph of deep (regional) component of power spectrum for Block 20; f) Graph of deep (regional) component of power spectrum for Block 25.*

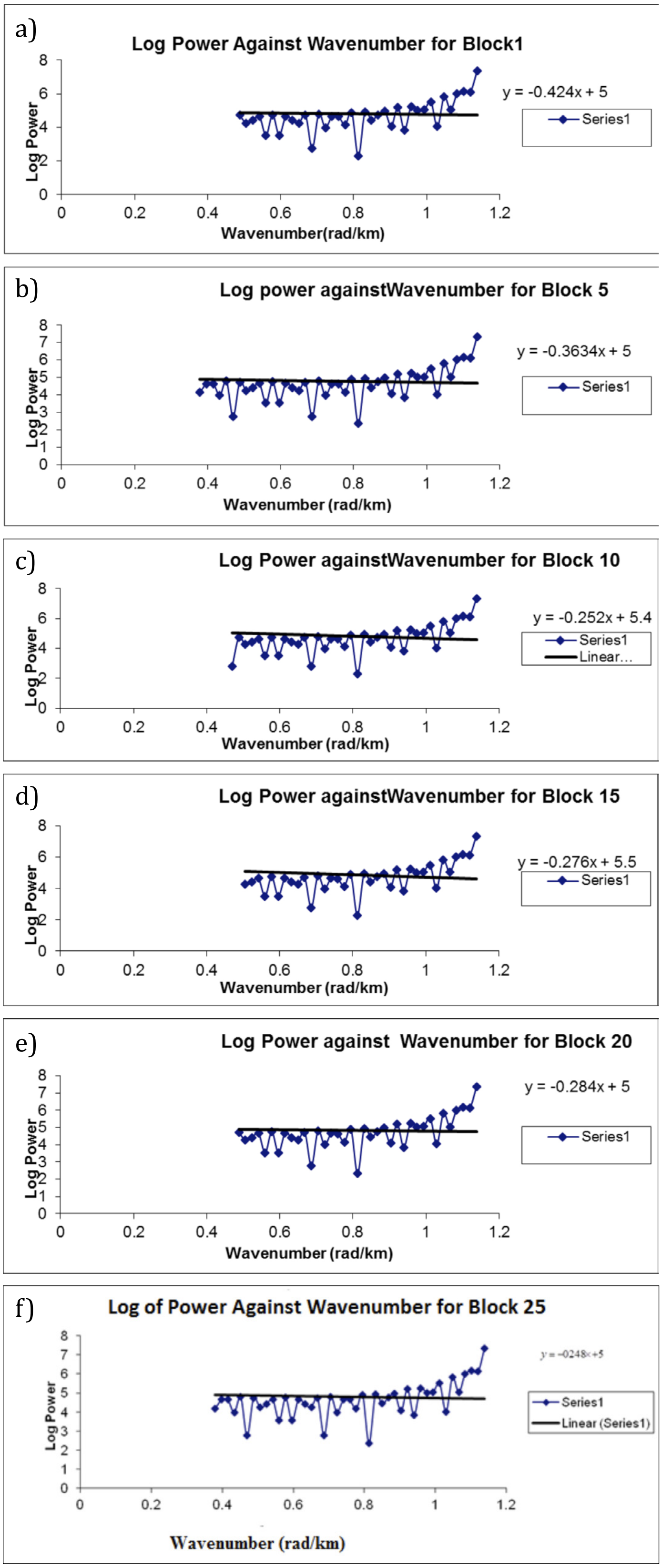

Figure 9: *a) Graph of shallow (residual) component of power spectrum for Block 1; b) Graph of shallow (residual) component of power spectrum for Block 5; c) Graph of shallow (residual) component of power spectrum for Block 10; d) Graph of shallow (residual) component of power spectrum for Block 15; e) Graph of shallow (residual) component of power spectrum for Block 20; f) Graph of shallow (residual) component of power spectrum for Block 25.*

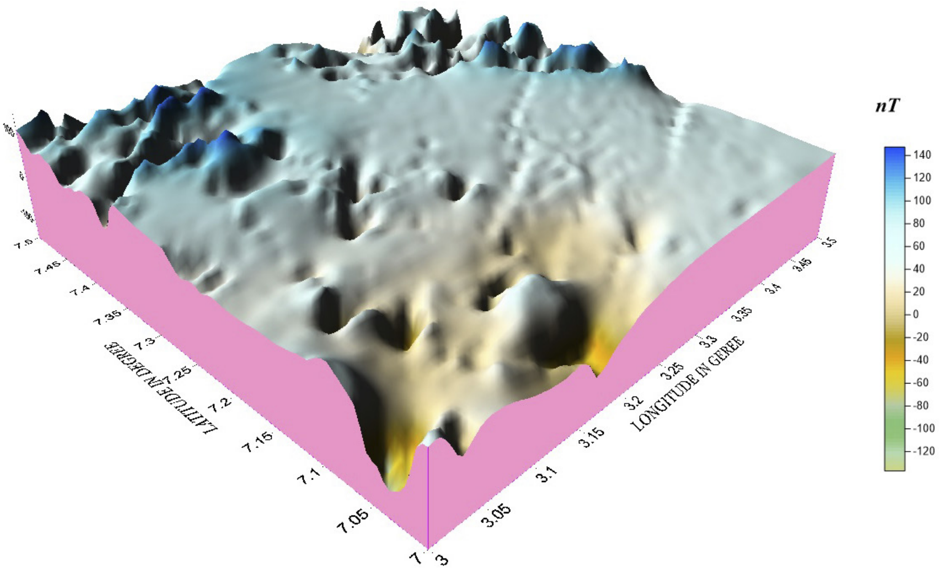

Figure 10: *3-D Surface map of aeromagnetic grid of Abeokuta area showing anomaly spikes.*

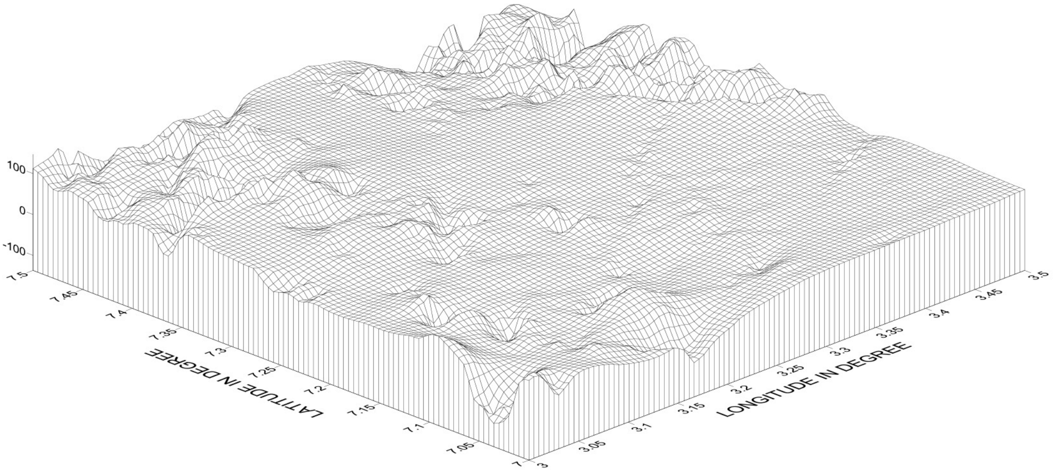

Figure 11: *Wire frame map of Abeokuta.*

slope method to obtain an average depth of the deeper magnetic sources ranging from 2.0 to 4.99 km, while the shallow magnetic sources ranged from 0.4 to 1.99 km. In 2013, Igwesi and Umego [22] interpreted aeromagnetic anomalies over some parts of Lower Benue Trough using the spectral technique to estimate that the average depth to the deeper and depth to the shallow sources ranged from 1.16 to 6.13 km and 0.06 to 0.37 km, respectively.

The surface distribution of the magnetite mineral in the locality was studied using the mapping software SURFER 12, as presented in Figures 10 and 11. Figures 10 and 11 reveal the signal generated by the presence of the magnetic minerals, which relate to a large extent to the depth and geometry of the buried body whether at the near-surface or deep-seated regions of the geologic unit of the basement complex. A generalised depth-to-magnetic basement map (Figure 12) produced from the results of the spectral analysis over the study area reveals a basement depth with average depth of 3.03 km, and Figure 13 reveals a depth in accordance with the average depth of the shallow magnetic sources.

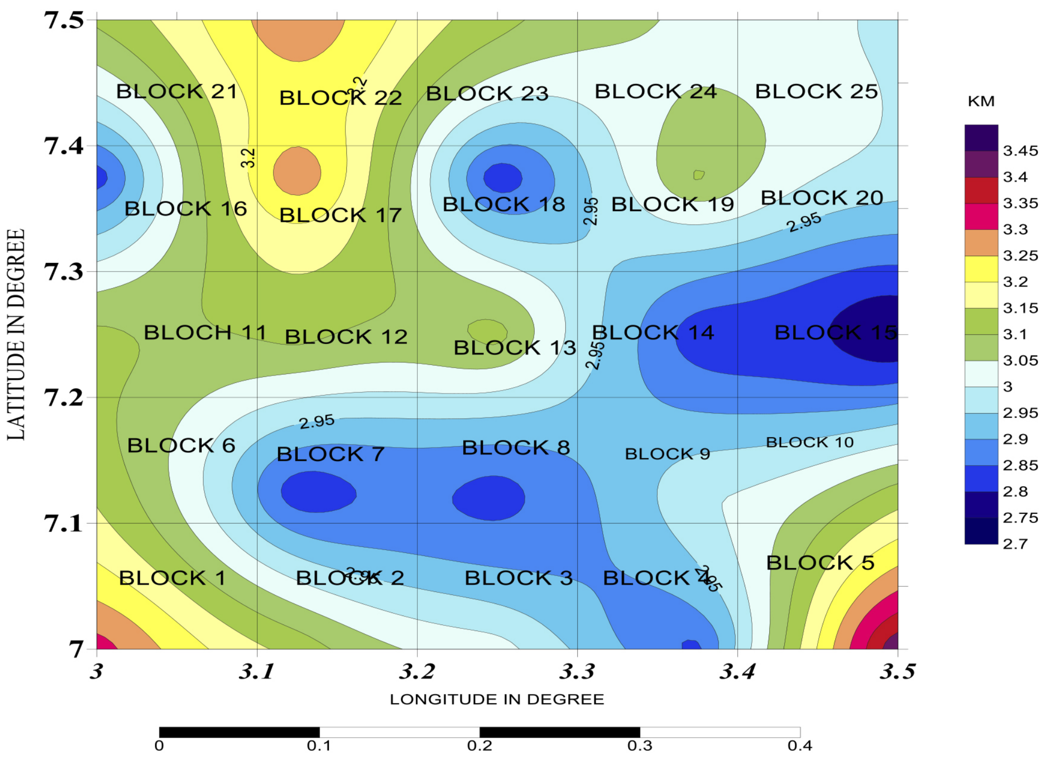

Figure 12: *Contour map of the deep magnetic source depth.*

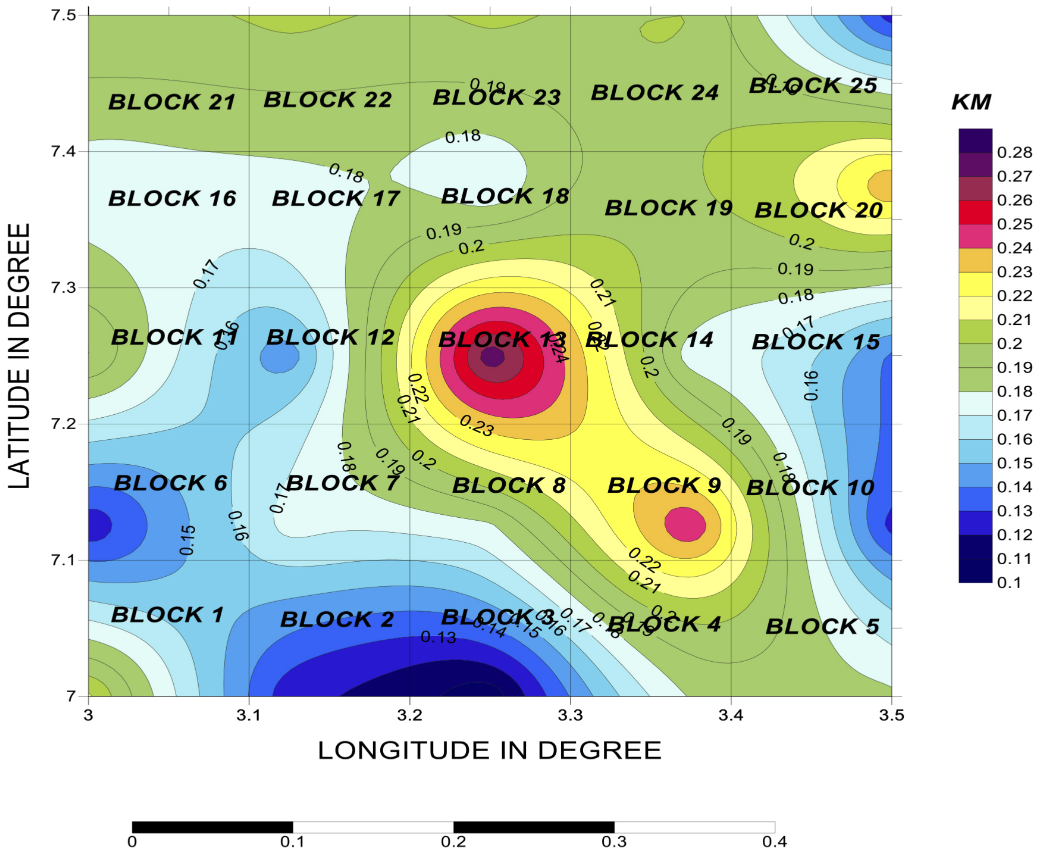

Figure 13: *Contour map of the shallow magnetic source depth.*

Conclusion

An airborne geophysical study is utilised to delineate the subsurface structure that controls the anomalous mineralisation zones of the studied area. In this study, power spectral method was applied to analyse airborne magnetic data with the purpose of estimating depth to the basement in the area under consideration. The results of this spectral analysis show clearly the variation along the profiles in the surface of the magnetic basement across the study area. The depth of the deeper sources ranges from 2.739 to 3.325 km and is believed to correspond to the surface of the magnetic basement in the study area. The shallower depth, ranging from 0.103 to 0.278 km, might refer to some major magnetic units, to uplifted basement surface or to some local magnetic features. These results therefore demonstrate the applicability of the spectral method of magnetic interpretation in estimating the depth to the surface of the magnetic basement in a basement complex.

Acknowledgement

The authors are grateful to the Nigerian Geological Survey Agency for the release of the aeromagnetic data of Sheet Number 260, used in this study.

References

[1] Revees, C. (2007): Aeromagnetic Surveys: principle, practice and interpretation. Geosoft INC.

[2] Essam, A., Ahmed, S., and Keisuke, U. (2003): Interpretation of geomagnetic data of Gabel El-Zeit Area, Gulf of Suez, Egypt using magnetic gradient techniques. Memoirs of the Faculty of Engineering, Kyushu University; 63(3), 139–149.

[3] Nabighian, M.N., Grauch, V.J.S., Hansen, R.O., Lafehr, T.R., Li, Y., Peirce, J.W., Phillips, J.D., Ruder, M.E. (2005): The historical development of the magnetic method in exploration; 75th anniversary. Geophysics; 70(6), 33–6.

[4] Rahaman, M.A. (1976): Review of the Basement Geology of South-Western Nigeria in Kogbe, C. (ed); Geology of Nigeria, Elizabethan, Publishing Lagos.

[5] Jones, H.A. and Hockey, R.D. (1964): The geology of parts of southwestern Nigeria, Lagos. Geological Survey of Nigeria Bulleting; 31, 101.

[6] Obaje, N.G. (2009): Geology and Mineral Resources of Nigeria. Lecture Note in Earth Science Series; 120.

[7] Spector, A. and Grant, F. (1970): Statistical models for interpreting aeromagnetic data: Geophysics; 35, 293–302.

[8] Hann, A., Kind, G. and Mishra, D.C. (1976): Depth estimation of magnetic Source by means of Fourier amplitude spectral. Geophysical Prospecting; 24, 287–305.

[9] Connard, G., Couch, R. and Gemperle, M. (1983): Analysis of aeromagnetic measurements from the Cascade Range in central Oregon, Geophysics; 48, 376–390.

[10] Garcia-Abdeslem, J. and Ness, G.E. (1994): Inversion of power spectrum from Magnetic anomaly, Geophysics; 59, 381–401.

[11] Okubo, Y. and Matsunaga, T. (1994): Curie point depth in northeast Japan and its Correlation with regional thermal structure and seismicity, Journal of Geophysics Research; 99, 22363–22371.

[12] Shuey, R.T., Schellinger, D.K., Tripp, A.C. and Alley, L.B. (1977): Curie depth determination from aeromagnetic spectra, Geophysical Journal of the Royal Astronomical Society, 50, 75–101.

[13] Blakely, R.J. (1988): Curie temperature isotherm analysis and tectonic implicationsof aeromagnetic data from Nevada, Journal of Geophysics Research; 93, 11817–11832.

[14] Sadek H.S. (1978): Profile frequency analysis of potential field data using Filon Fourier transform, with Basic software, In: Andreas Vogel (ed), Geophysical Data Inversion Methodsand Applications, Theory and Practice of Applied Geophysics: Model Optimization in ExplorationGeophysics; 2, 155–177.

[15] TahaRabel (2009): Prospecting for the ferromagnetic mineral accumulations using the magnetic method at Easter desert, Egypt. Geophysics Engineering; 6, 401–411.

[16] Albora, A.M. and Osman, N.V. (2008): Gravity Anomaly separation using 2-D wavelet approach and average depth calculation. Geophysics; 58, 395–404.

[17] Dobrin, M.B. and Savit, C.H. (1988): Introduction to geophysical prospecting. McGraw-Hill Book Co. Inc. New York; pp. 152–190, pp. 498–578, pp. 691–745.

[18] Kasidi, S. and Ndatuwong, L.G. (2008): Spectral Analysis of Aeromagnetic Data over Longuda Plateau and Environs, North-Eastern Nigeria. Continental Journal Earth Sciences; 3, 28–32.

[19] Hassanein, H.I. E. (2011): Using Filon Fourier Spectral Analysis technique for filtering of Aeromagnetic Data and Outlining subsurface structures of Helma–Madrakah Area, Kingdom of Saudi Arabia. Journal of King Abdulaziz University; 12, 105–125.

[20] Nwankwo, L.I., Olashinde, P.I. and Akosile, C.O. (2008): Spectral Analysis of Aeromagnetic Anomalies of the Northern Nupe Basin, West Central Nigeria. Global Journal of Pure and Applied Sciences; 14(2), 247–252.

[21] Onuba, L.N., Anudu, G.K., Chiaghanam, O.I. and Anakwuba, E.K. (2011): Evaluation of Aeromagnetic Anomalies over Okigwe Area, South-Eastern Nigeria. Research Journal of Environmental and Earth Sciences; 3(5), 498–507.

[22] Igwesi D.I and Umego M.N. (2013): Interpretation of aeromagnetic anomalies over some parts of Lower Benue Trough using spectral analysis technique. International of Scientific and Technology Research; 2(8), 153–165.