International Journal of Geosciences, 2022, 13, 557-575
https://www.scirp.org/journal/ijg
ISSN Online: 2156-8367
ISSN Print: 2156-8359

Evaluation of Structural Framework and Depth Estimates Using High Resolution Airborne Magnetic Data over Some Parts of Middle Benue Trough, Nigeria

Nasir Naeem Abdulsalam[1], Ene Kate Ogoh[1], Oluwatoyin Ologe[2*]

[1]Department of Physics, Faculty of Science, University of Abuja, Abuja, Nigeria
[2]Department of Applied Geophysics, Faculty of Science, Federal University Birnin Kebbi, Birnin Kebbi, Nigeria
Email: *oluwtoyin.ologe@fubk.edu.ng

How to cite this paper: Abdulsalam, N.N., Ogoh, E.K. and Ologe, O. (2022) Evaluation of Structural Framework and Depth Estimates Using High Resolution Airborne Magnetic Data over Some Parts of Middle Benue Trough, Nigeria. *International Journal of Geosciences*, **13**, 557-575.
https://doi.org/10.4236/ijg.2022.137030

Received: March 20, 2022
Accepted: July 26, 2022
Published: July 29, 2022

Abstract

High-resolution aeromagnetic data of parts of Middle Benue Trough, Nigeria (sheets 212, 213, 233 and 234) was interpreted by applying source Parameter Imaging (SPI) and Spectral Depth analysis with the aim of mapping out the magnetic lineaments and analysing magnetic signals coming from different sources. The results from the derivatives maps show major and minor lineaments trends in the NE-SW and NW-SE directions respectively. Results from SPI show the maximum sedimentary thickness of about −4546.7 m (−4.5467 km) around the region of Awe, Aman, Langtang south, Gassol and the north-eastern part of Donga. Minimum depth of −167.9 m (−0.1679 km) around the region of north of Shendam, north of Wase, north-eastern part of Aman, Bantaji, Donga, Ibi and Bali. The residual map was divided into twenty-five sections. Spectral Depth was run for each of these twenty-five sections, the result shows that the depth to the deep magnetic source ranges between −0.65 km and −3.35 km. The depth to the shallow magnetic sources ranges between −0.03 km and −0.44 km showing the presence of magnetic intrusive bodies within the sediments. Since the sedimentary thickness of 3.0 km and above is only sufficient for hydrocarbon maturation and accumulation, then the results from this present study show that the study area might be sufficient enough for hydrocarbon maturation and accumulation.

Keywords

Hydrocarbon, Magnetic Sources, Derivatives Maps, Anomaly, Sedimentary Thickness, Maturation

1. Introduction

The study of the earth's magnetism is the oldest branch of the subject of geophysics [1]. To carry out geophysical investigation of the earth's subsurface, signals are sent into the earth and measurements are taken. As the signals propagate through the earth's interior, they are influenced by the internal distribution of the earth's physical properties. The physical properties of the earth's interior within sedimentary formation vary vertically and laterally from the measurement and analysis of signal signatures. This analysis provides useful information about the basement and intra-sedimentary structures on intermediate and regional scale [2] [3] [4]. The aim of a Magnetic survey is to investigate subsurface geology on the basis of the anomalies in the earth's magnetic field resulting from magnetic properties of the underlying rocks. The methodology for acquiring and compiling data appears to be keeping pace with modern technology, presently the magnetic method is by far the most widely used of all geophysical survey, both in terms of line-kilometers surveyed annually and in total line kilometers. This study aimed at delineating the location, depth and extent of compositional boundaries and fundamental structures for possible hydrocarbon maturation and accumulation in which digital tools were applied to digitised total field aeromagnetic anomaly data over parts of Middle Benue Trough (sheets 212, 213, 233 and 234).

Location and Study Area Geology

The study area is located in the Middle Benue Trough, Nigeria (**Figure 1**), it lies

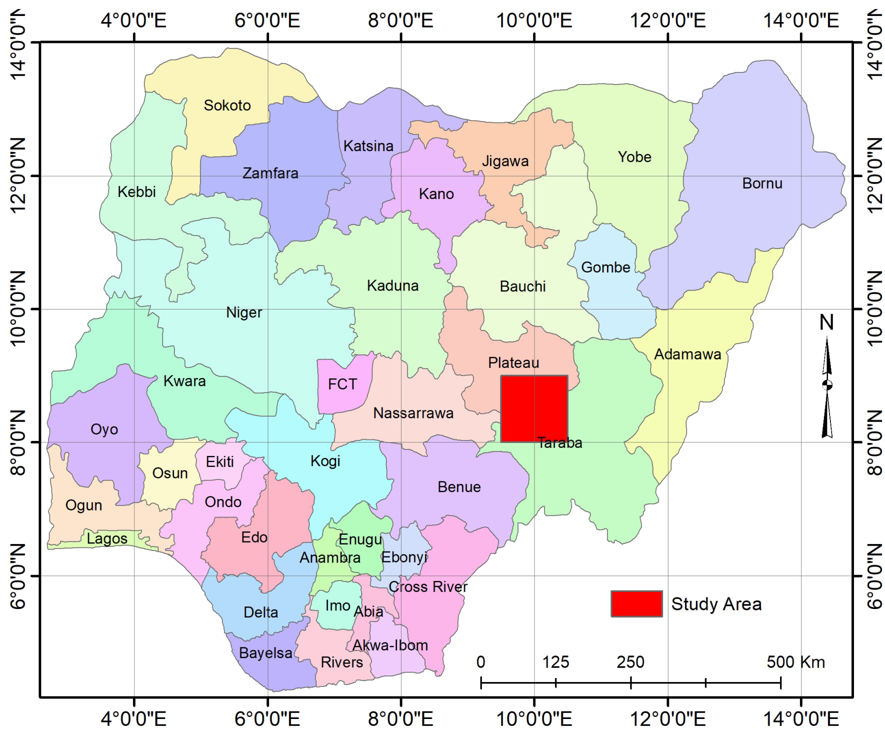

Figure 1. Location map of middle Benue trough.

between Latitude 08.00˚N and 09.00˚N and Longitude 09.30˚E and 10.30˚E. The study area covers four sheets: Shandam 212, Aman 213, Ibi 233 and Bantaji 234, which were digitally merged into one composite map, giving a data matrix size of 110*110.

The Benue Trough of Nigeria is a rift basin in central West Africa that extends NNE-SSW for about 800 km in length and 150 km in width [5]. The southern limit is the northern boundary of the Niger Delta (**Figure 2**), while the northern

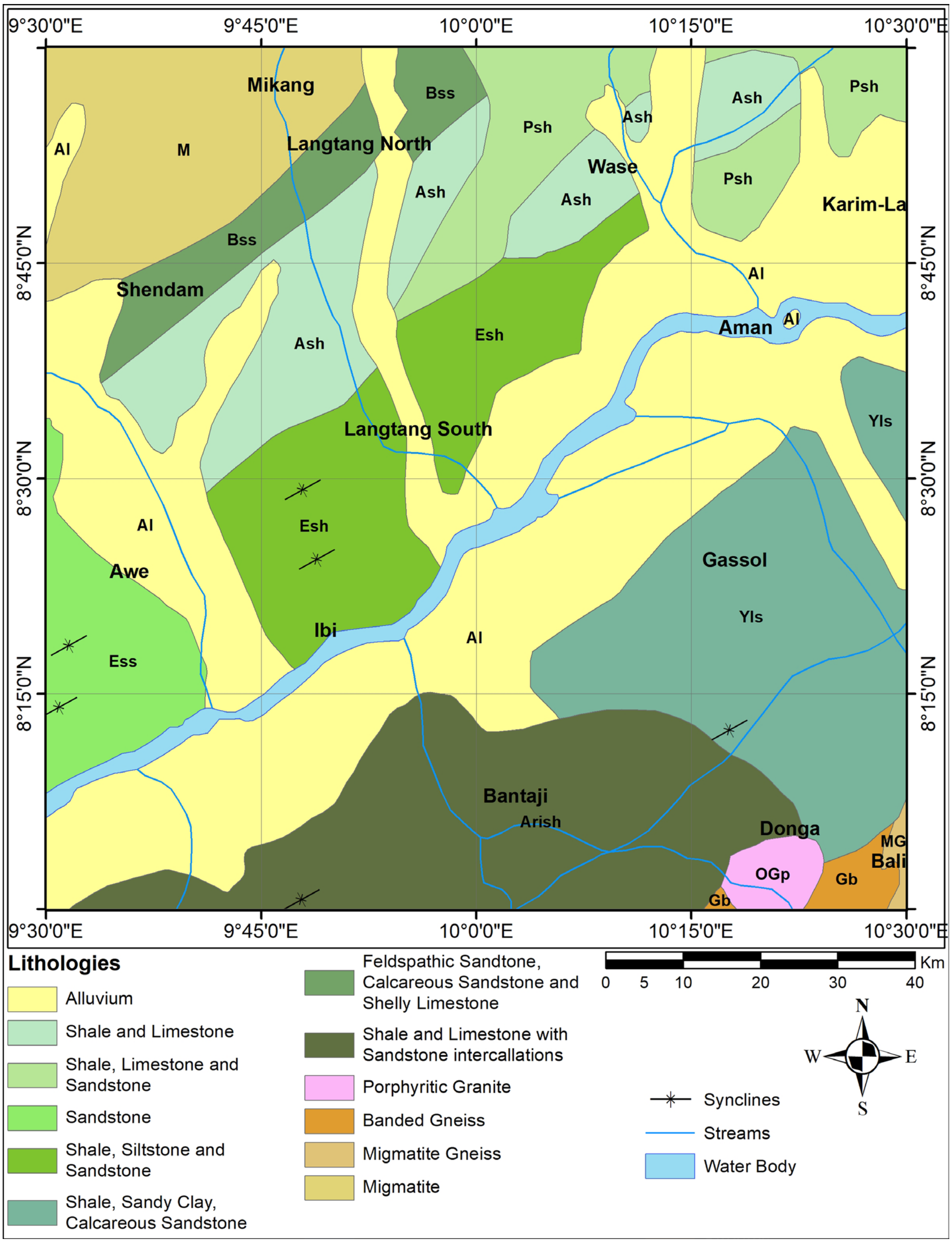

Figure 2. Geological map of the study area.

limit is the southern boundary of the Chad Basin. [6] categorized this trough into three different zones which include; the Lower Benue Trough at the southern part, the Middle Benue Trough at the center and the Upper Benue Trough at the Northern part. This trough which is highly tectonized with compressionally folded, faulted, and uplifted in several places predating the mid-Santonian contains up to 6000 m of Cretaceous-Tertiary sediments (**Figure 2**). The Middle Benue Trough comprises the areas from Makurdi through Yandev, Lafia, Obi, and Jangwa to Wukari. The Middle Benue Trough is characterized by the presence of thick sedimentary cover of varied composition whose age ranges from Albian to Maastrichtian [7]. The age order of sediment deposition in this area followed a descending order starting from Asu-River Group of marine origin, Ezeaku Formation, Keana/Awe Formation, Awgu Formation and Lafia Sandstone [7].

2. Materials and Methodology

The Aeromagnetic data used for this research is secondary data sourced from the Nigerian Geological Survey Agency (NGSA). Four high resolution aeromagnetic maps with sheet numbers 212, 213, 233, 234 and their respective locations Shendam, Aman, Ibi and Bantaji, which covers some part of the Middle Benue Trough, were acquired.

Methodology

Aeromagnetic survey Data Acquisition, Analysis and Interpretation

The aeromagnetic data was acquired by Fuguro as part of a nationwide aeromagnetic survey sponsored by the Nigeria Geologic Survey Agency (NGSA) between the years 2003 and 2009. The survey was carried out along a series of NNW-SSE profile with spacing of 500 m and 80 m mean terrain clearance [8].

Upward Continuation

This technique is a low pass filter employed in magnetic interpretation to determine the form of regional magnetic variation over a survey area, since the regional field is assumed to originate from relatively deep-seated structures [9]. The data was upward continued to different height values so as to be able to monitor the effect and anomaly variation from deep sources at different depth.

Vertical derivatives

[10] preferentially amplify a vertical gradient filter as a short-wavelength component of the field at the expense of longer wavelengths. Vertical derivative filters are generally applied to gridded data using Fast Fourier Transform (FFT) filters and computed by multiplying the amplitude spectra of the field by a factor of the form:

$$\frac{1}{n}\left[\left(u^2+v^2\right)^{\frac{1}{2}}\right]$$

where n is the order of the vertical derivative, (u, v) is the wavenumber corresponding to the (x, y) directions respectively.

Horizontal Derivative/Gradient Method (HGM)

The method is based on the principle that a near-vertical, fault-like boundary produces a magnetic anomaly whose horizontal gradient is largest directly over the top edge of the boundary [11]. If $F(x, y)$ is the magnetic field and $\frac{dF}{dx}$ and $\frac{dF}{dy}$ are derivatives in the -x and –y directions, then the HGM of field F is define as

$$\text{HGM} = \sqrt{\left(\frac{\partial F}{\partial x}\right)^2 + \left(\frac{\partial F}{\partial y}\right)^2}$$

where x and y represent the orthogonal coordinate system of the gridded data and the HGM is computed at each grid point.

3. Results and Discussion

The total magnetic intensity map (**Figure 3**) shows variation of highs and lows in magnetic signature. The pink colorations depict high magnetic signatures while the blue depicts low magnetic signatures and yellow indicates intermediary. The total magnetic intensity (TMI) level in the area ranges from −54.2 to 134.1 nT (**Figure 3**). The negative values imply areas that are magnetically subdued while the positive values are magnetically responsive. The parts of the study area that are magnetically subdued have magnetic low and magnetic high regions that are magnetically responsive, these features are typical of a sedimentary terrain which are assumed to be due to the likely presence of outcrops of crystalline igneous or metamorphic rocks or even crustal boundaries.

Upward Continuation Filtering Process

As the continuation distance is increased, the effects of smaller, narrower and thinner magnetic bodies progressively disappear relative to the effects of larger magnetic bodies of considerable depth extent (**Figure 4**). As a result, upward-continuation maps give the indications of the main tectonic and crustal blocks in an area, as there is attenuation of high wave number anomalies associated with shallow seated bodies.

Quantitative Interpretation

The configurations, depth and magnetisation of the magnetic sources estimates are been done through quantitative interpretation sources which rely on the notion that simple geometric bodies, whose anomaly can be calculated approximate magnetic complex bodies. This is categorised as curve matching, forward modelling or inversion. The purpose of quantitative analysis in this study is to obtain the subsurface configuration of the magnetic interface of the study region.

Techniques used In this study are Source Parameter Imaging (SPI) which was used to estimate the depth to the magnetic source and the spectral Analytical method was used to construct the basement shape underlying the basin, while the First vertical, second vertical, the Total Horizontal derivatives and the Analytical signal method were used to map out the magnetic lineaments in the study area and to analyse the magnetic signals coming from different sources.

First Vertical Derivatives

In order to properly analyse the spatial distribution of lineaments extracted from aeromagnetic images according to their length and orientation, the first vertical derivative filter was applied to the residual grid. The colour and grey scale vertical gradient images of the residual magnetic intensity (Figure 5 and Figure 6) enhanced the map by showing major structural and lithological detail which was not obvious in RTE map (Figure 3).

Lineaments were extracted from the first vertical derivatives map as shown in Figure 5. The rose (azimuth-frequency) diagram of the lineaments (Figure 7)

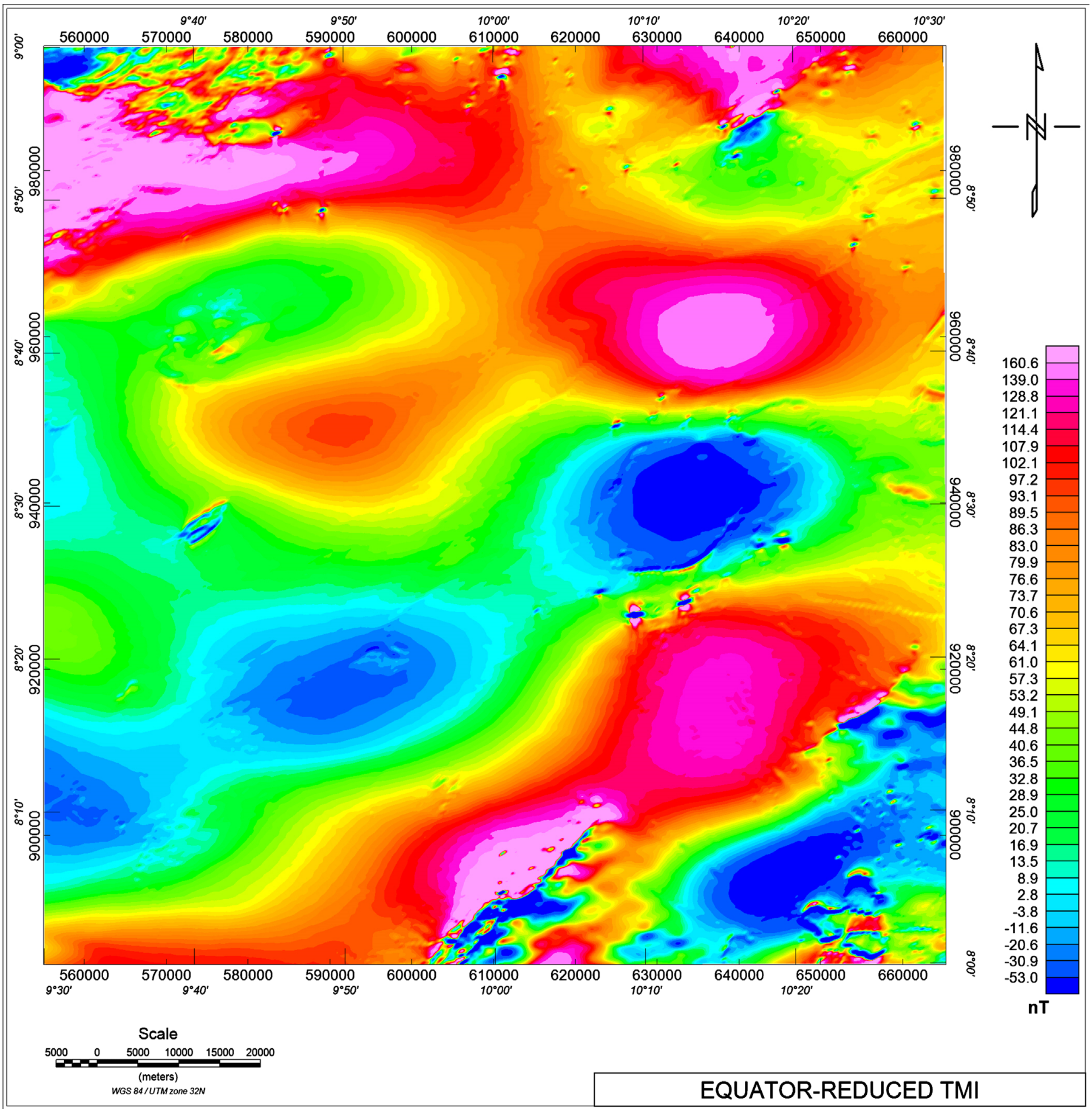

Figure 3. Total Magnetic Intensity (TMI) map reduces to the Magnetic equator (RTE) of the Area.

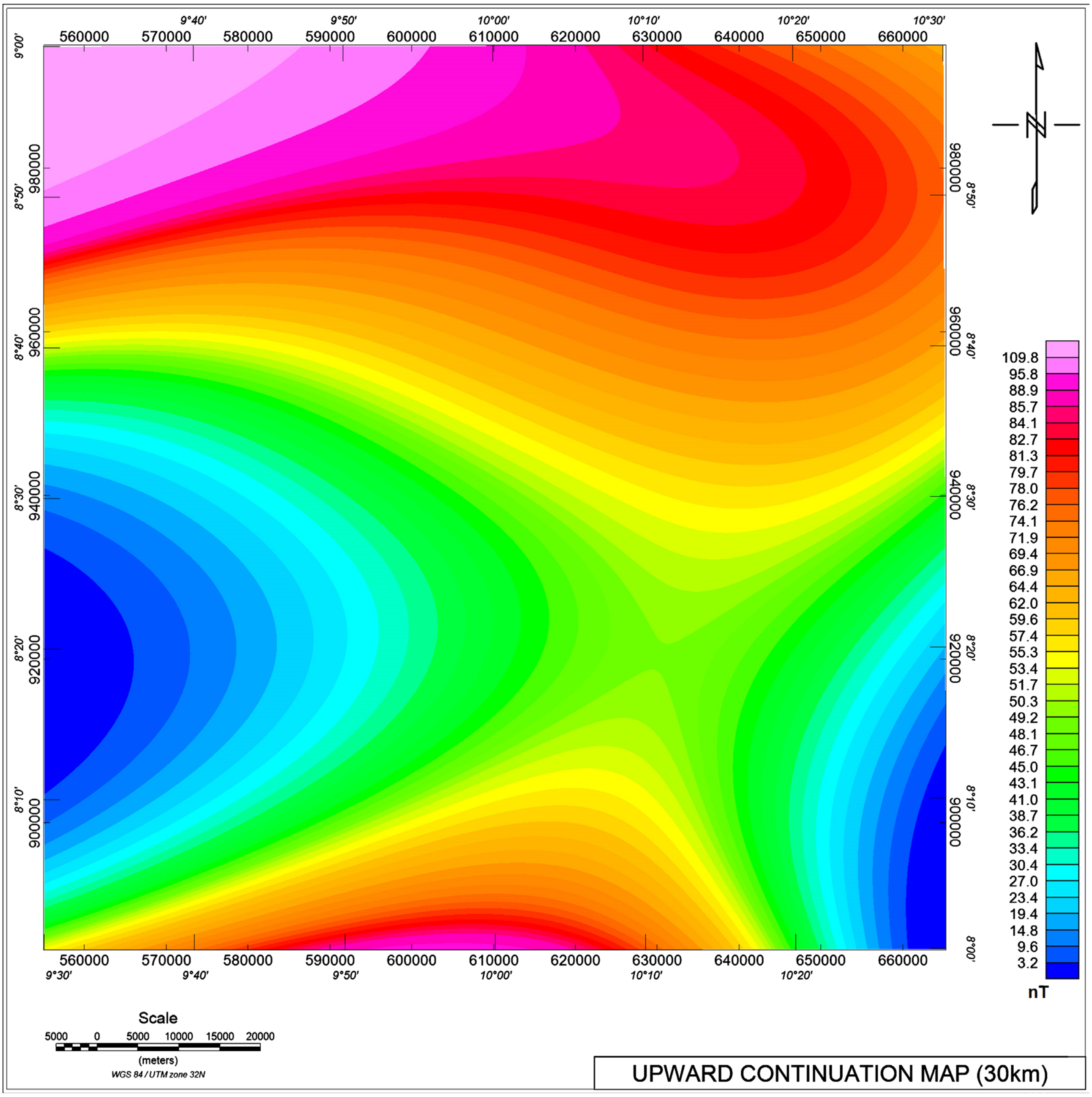

Figure 4. Upward continuation at a height of 30 km above flight level.

prepared from the extracted lineaments shows trends in NE-SW and NW-SE directions. The NE-SW directions are the major trends in area.

Horizontal Gradient Magnitude Map (HGM)

The horizontal gradient magnitude (HGM) map was gotten after the analysis of the residual map. The resulting HGM map (Figure 8) reveals some interesting geological features/structures (supposedly faults and contacts), these features/structures appear to be coming from a near surface sources due to the strong and prominent edge signal indication, as seen in the colour shaded map (Figure 8). These structures have already been mapped using the first vertical derivatives

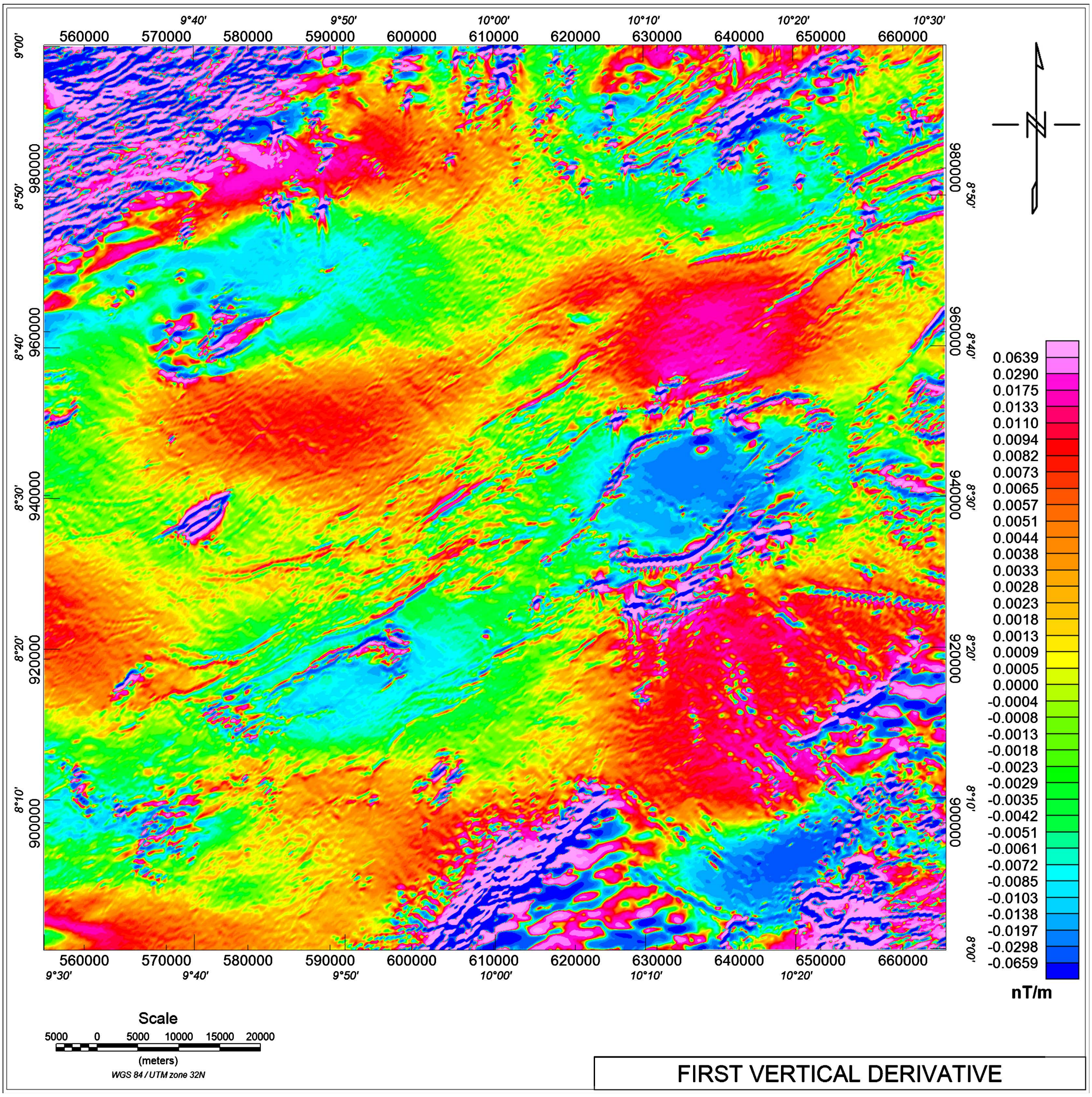

Figure 5. First vertical derivative map of the study area.

and their orientation determined.

Analytical Signal (AS)

The analytical signal map (**Figure 9**) shows high amplitude that runs in an approximately NE-SW direction, with a very prominent signal observed in some part of the North-western part, the South, south-eastern part and some part of the north-eastern side. Three major magnetic zones which are the high signals zones, the intermediate and the weak signal zone, were observed. The high signal zone are observed in the deep purple to pink coloration, the intermediate zones are observed in the yellow to reddish coloration while the very weak signals

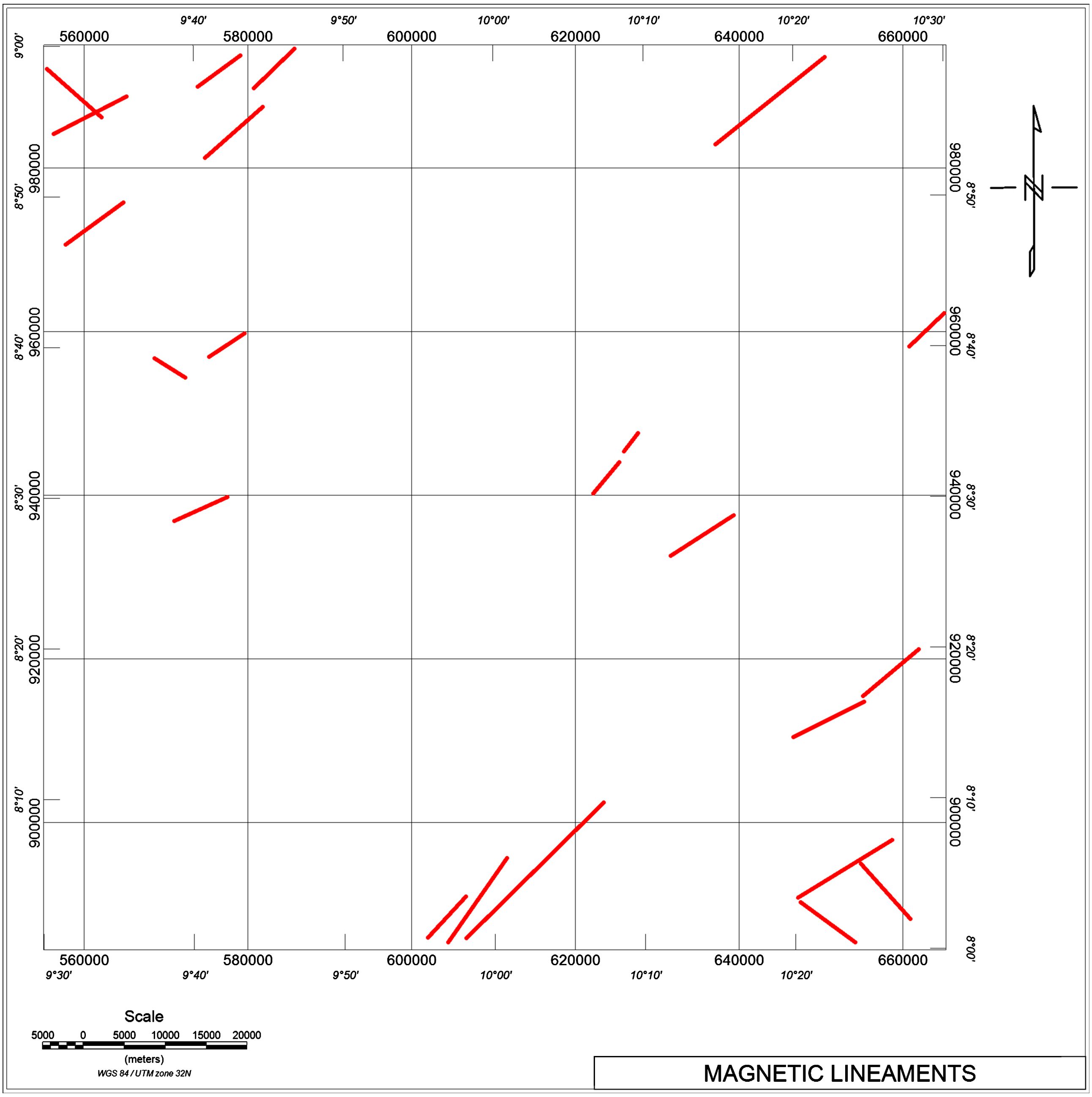

Figure 6. Magnetic lineaments extracted from the first vertical derivatives map.

zones are observed in the greenish to blueish coloration (**Figure 9**). The results from this analysis appear to be in consistency with the result gotten from the HGM edge detection method and the First vertical derivatives.

Depth to basement Estimation

The depth to the magnetic source in the area was estimated using two methods, the Source parameter imaging and the Spectral analysis.

Result from the Source Parameter Imaging

The Source parameter imaging technique was employed to estimate the depth to the magnetic sources in the area. This technique was chosen because it produces

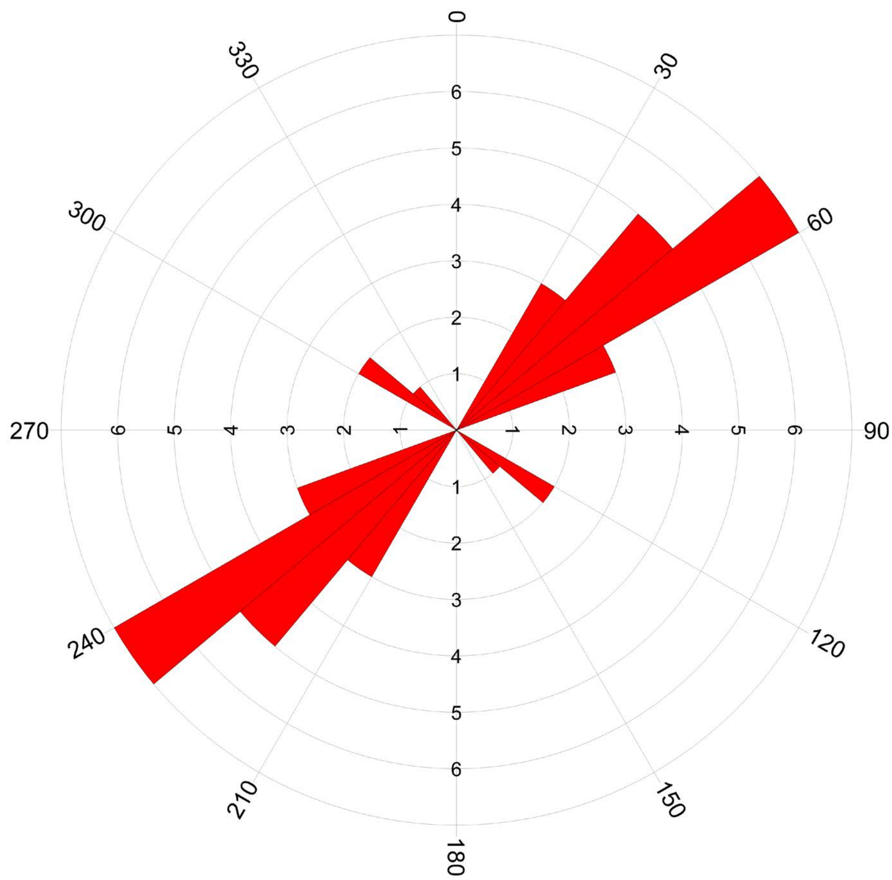

Figure 7. Rose diagram generated from the magnetic lineament map extracted from the first vertical derivatives map.

reliable results and also makes the interpretation of magnetic data significantly easier [12]. Depth estimate was done by dividing into Spectral cells and Windowing in which the residual map was subdivided into 25 overlapping spectral cells of 36.8^2 km each in order to have more data points and more accurate depth representation (**Figure 10**). Radial energy spectrum was generated using digital signal processing software (OASIS MONTAJ) program which employed the fast Fourier transform technique used to transform the residual magnetic data into the radial energy spectrum for each block. [13] affirmed that the calculation of average radial power spectrum can be displayed in a semi-log figure of amplitude versus frequency which has a linear gradient whose magnitude is dependent upon the depth of the source Graphs of logarithm of the spectral energy against frequencies for the 25 spectral cells was plotted and shown in **Figure 11**. The depth estimates were obtained and the result shows that the depth estimates of the various magnetic sources in the area vary from −167.9 m (−0.1679 km) to the depth of −4546.7 m (−4.5467 km). The shallow basement depths occurs within the regions of the north of Shendam, north of Wase, the north-eastern part of Aman, Bantaji, Donga, Ibi and Bali areas, while the deep basement depths occurs within the regions of Awe, Aman, Langtang, south Gassol and the north-eastern part of Donga (**Figure 12**). In comparison with the analytical signal

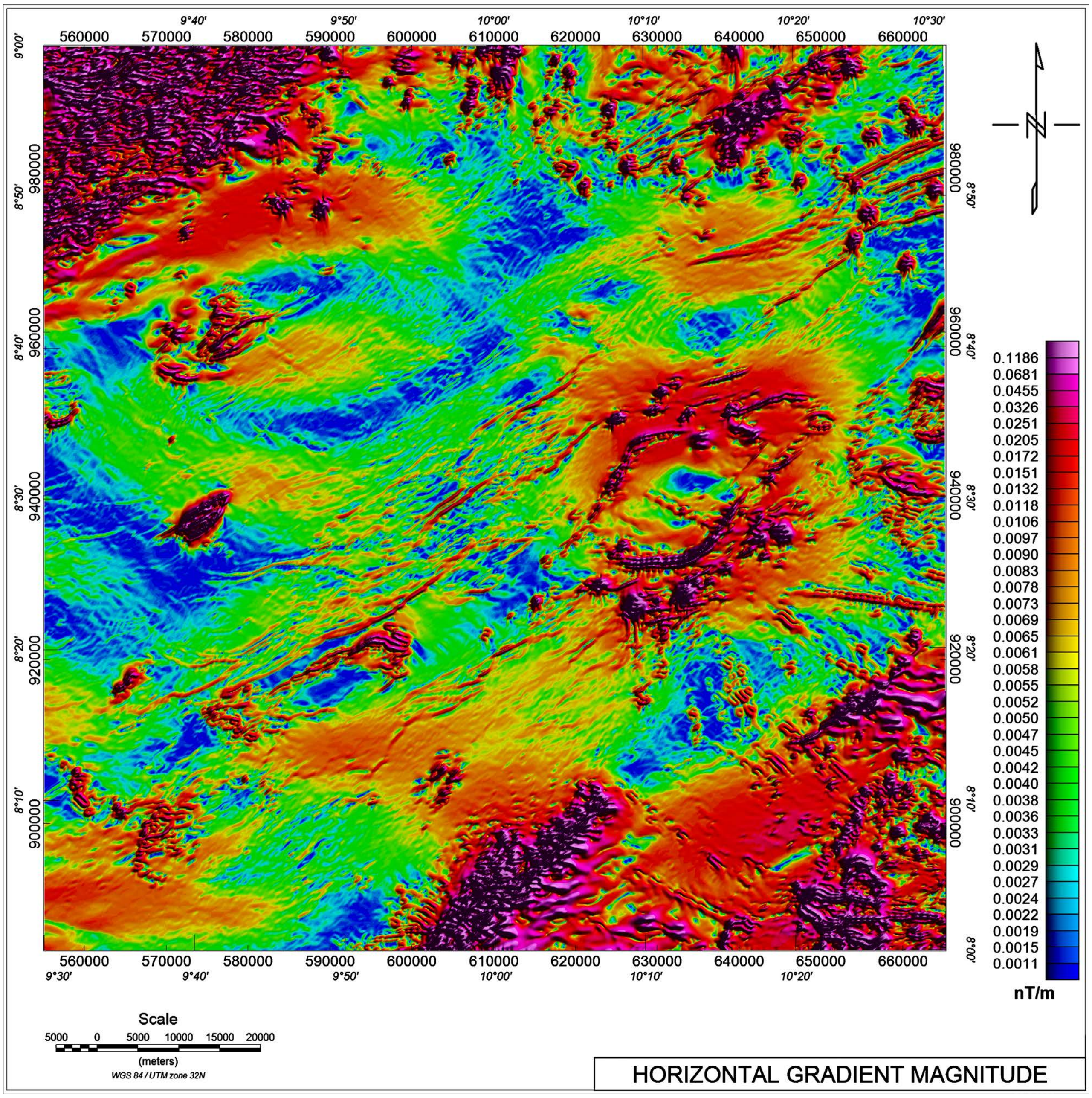

Figure 8. Color shaded-relief image of the HGM of the study area with strong edge signals (purple coloration) from a near surface features/structures.

map of the study area (**Figure 9**), we could see that the SPI method confirms the depth of the Anomaly signals sources are from a shallow region.

Depth to basement from spectrum power

The results of this study were grouped into two intervals (or two main sources depth), which are the deeper sources (Z1)) and the shallow sources (Z2) (**Table 1**). The deeper sources are the first segment of the spectrum plot and this reflect the Precambrian basemen. The shallow horizons are from near surface magnetic intrusion into the sedimentary terrain. The computed depth to basement for the deep sources (Z1) ranges from −0.65 km to −3.35 km (**Table 1**). This result is

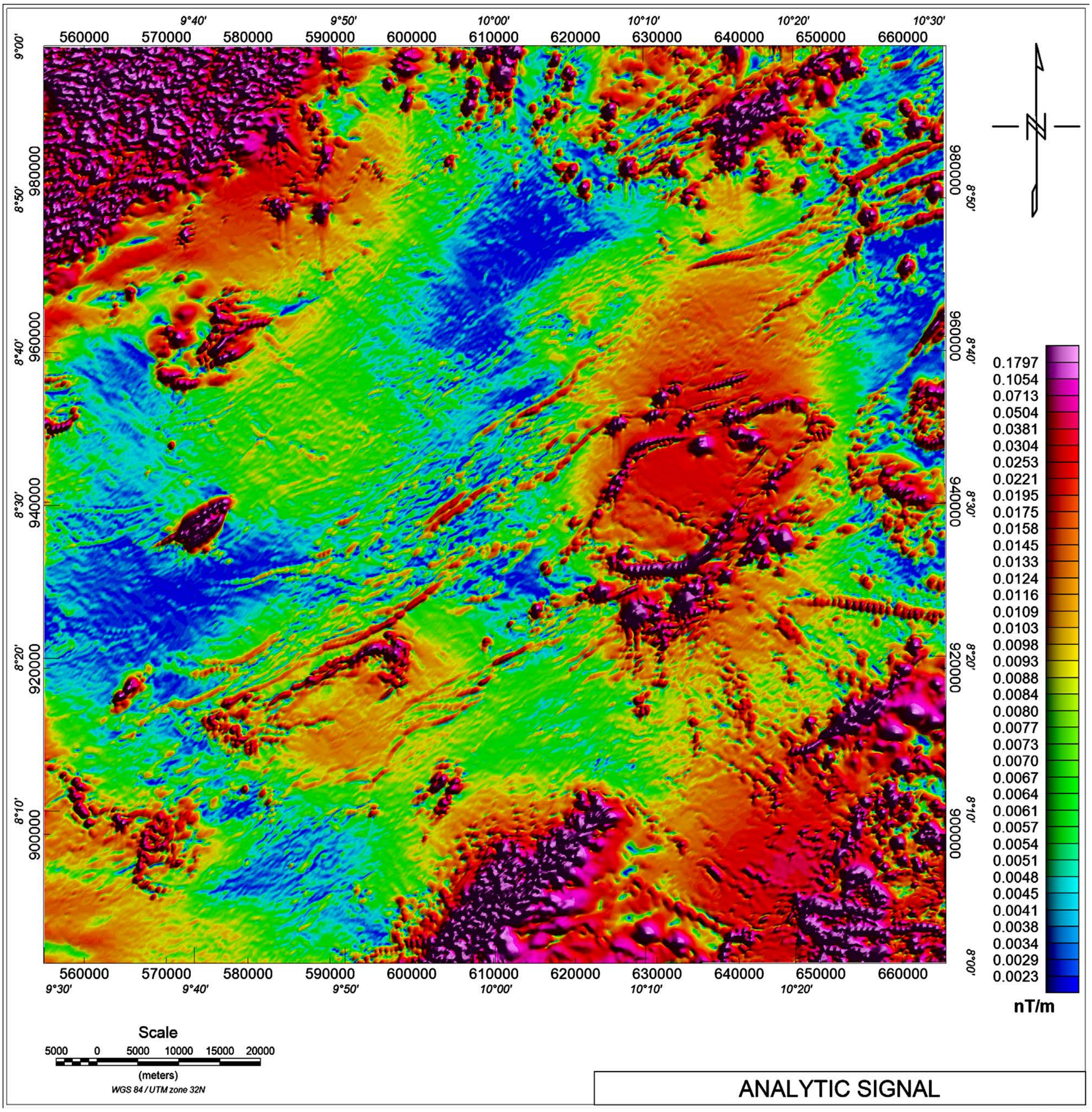

Figure 9. Color shaded-relief image of the analytical signal showing the variations in magnetic amplitude signals from various magnetic sources. (High signal sources in deep purple to pink coloration).

Table 1. Estimated depth to various magnetic sources from the Spectral analysis for deep depth source (Z1) and shallow depth source (Z2).

Block No.	X_UTM (m)	Y_UTM(m)	Depth Z1 (km)	Depth Z2 (km)
1	573462.9	903179.3	−2.92177	−0.03697
2	591826.9	903179.3	−1.47392	−0.06378
3	610262.9	903179.3	−0.64712	−0.04109
4	625662.9	903179.3	−1.43739	−0.07789

Continued

5	647062.9	903179.3	−1.42829	−0.07153
6	573462.9	921579.3	−1.46601	−0.06377
7	591826.9	921579.3	−3.34747	0.44351
8	610262.9	921579.3	−1.62474	−0.04107
9	625662.9	921579.3	−1.35083	−0.0697
10	647062.9	921579.3	−2.43857	−0.05906
11	573462.9	939979.3	−2.22629	−0.04445
12	591826.9	939979.3	−1.22344	−0.04461
13	610262.9	939979.3	−1.17489	0.221586
14	625662.9	939979.3	−2.42515	−0.05255
15	647062.9	939979.3	−0.89401	−0.04376
16	573462.9	958379.3	−3.14601	−0.04986
17	591826.9	958379.3	−2.34477	−0.04745
18	610262.9	958379.3	−2.43248	−0.06423
19	625662.9	958379.3	−2.90682	−0.04053
20	647062.9	958379.3	−3.22132	−0.04241
21	573462.9	976779.3	−1.5663	−0.03575
22	591826.9	976779.3	−1.52781	−0.05887
23	610262.9	976779.3	−2.49055	−0.05692
24	625662.9	976779.3	−1.38482	−0.03172
25	647062.9	976779.3	−2.09694	−0.27963

consistent with the results gotten from the SPI depth to source (**Figure 12**) and it's an indication of the area being a sedimentary terrain. The undulating nature of the basement of the study area is displayed in **Figure 13** and **Figure 14** with the 3-D view in **Figure 15**.

4. Conclusions

High resolution aeromagnetic data of Middle Benue Trough (sheets 212, 213, 233 and 234) Nigeria has been interpreted using SPI, Spectral Depth analysis. The qualitative and quantitative interpretation results from this research corroborated the findings derived from the works of [14] [15]. Source parameter imaging and spectral depth analysis were applied to determine the depth of the magnetic source for hydrocarbon potential. The result of the two methods adopted agrees with each other having a maximum sedimentary thickness of −4.54 km and −3.35 km, respectively.

For any area to be viable for hydrocarbon accumulation the thickness of the

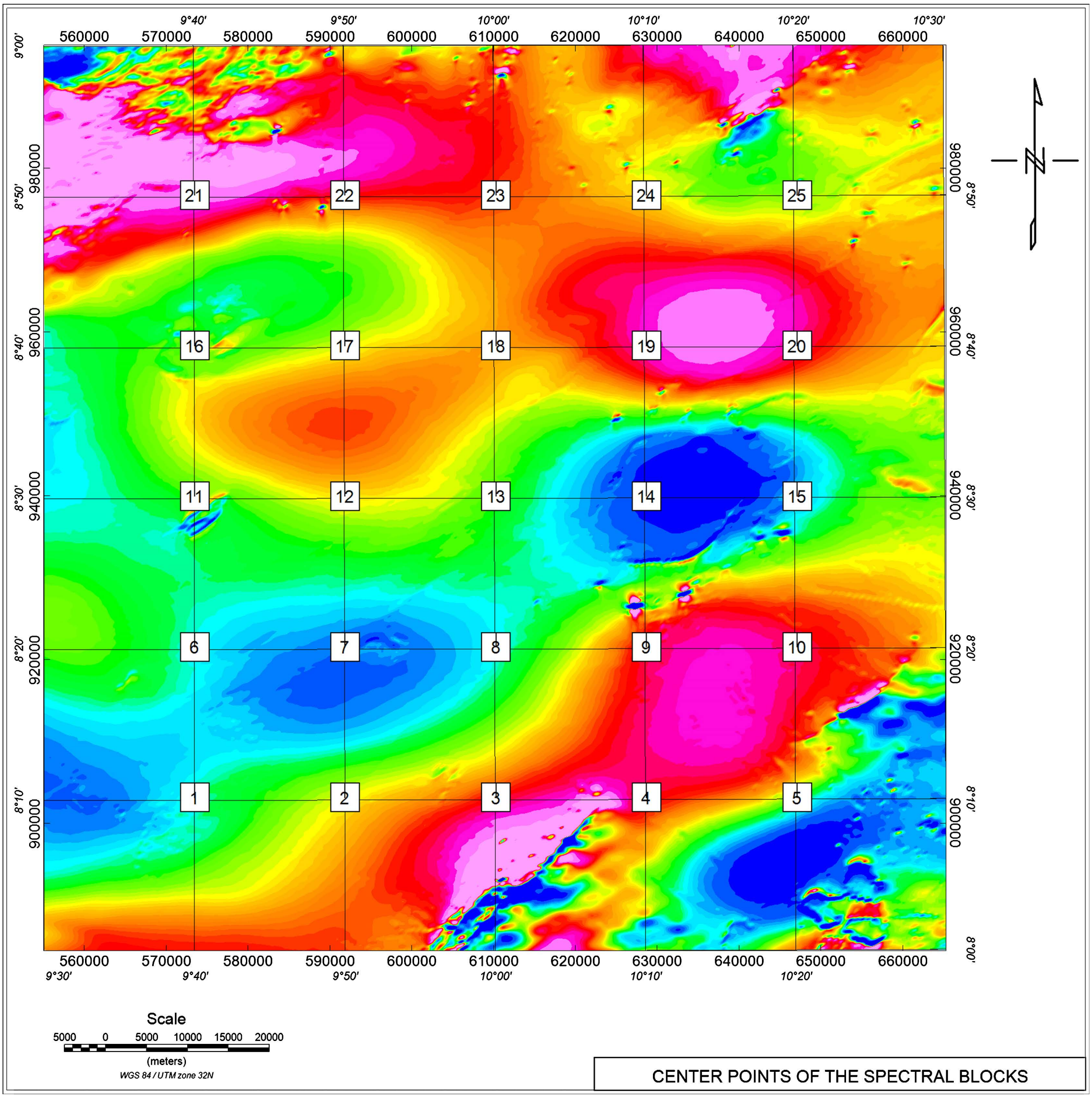

Figure 10. Schematics of the 25 overlapping spectral blocks labelled 1 to 25.

sediment must be up to 3.0 km as well as other conditions necessary for hydrocarbon maturation such as good quality source rocks, good reservoir and seal lithologies, favourable regional pathways and trapping mechanisms should be present.

The result from the source parameter imaging and the spectral analysis over part of the Middle Benue is an indication that hydrocarbon prospecting should be intensified in this area since the sediment over the area is sufficiently thick to

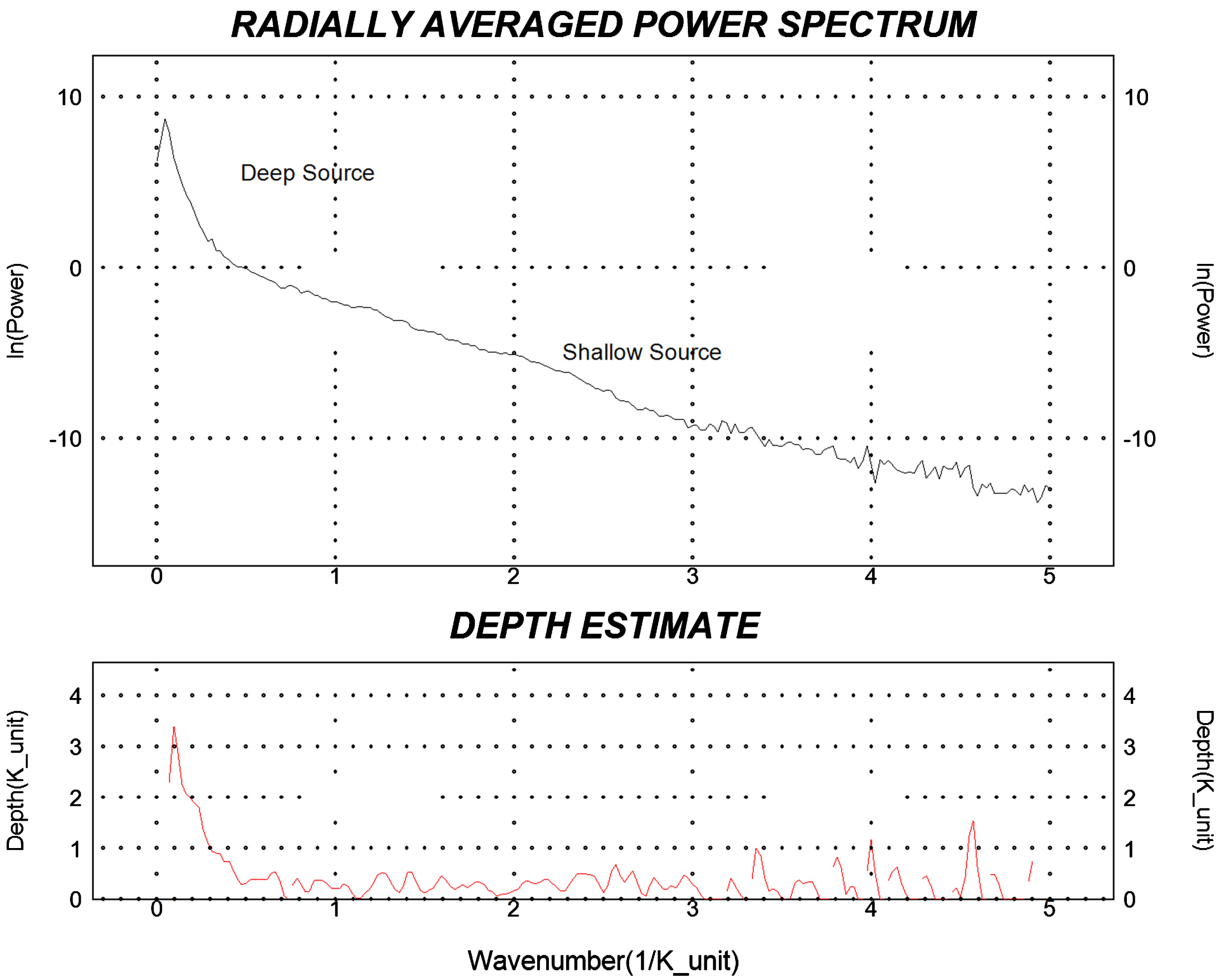

Figure 11. Radially averaged Power Spectrum for Block 1.

generate hydrocarbon.

It can therefore be concluded that, the application of aeromagnetic survey is a powerful tool in the determination of structural settings, depth estimation to basement, sediments thickness estimation and basement topography modelling especially in the sedimentary basins. Based on this study, the following recommendations are made:

1) Ground thrusting is highly recommended to confirm the delineated structure, Ground geophysical and geological drilling surveys are recommended where possible to validate airborne geophysical measure since they have better depth and lateral resolutions.

2) The hydrocarbon prospect of the field should be examined due to the thickness of the sediments observed within the basin is probable for hydrocarbon generation, other factors should be considered such as presence of source

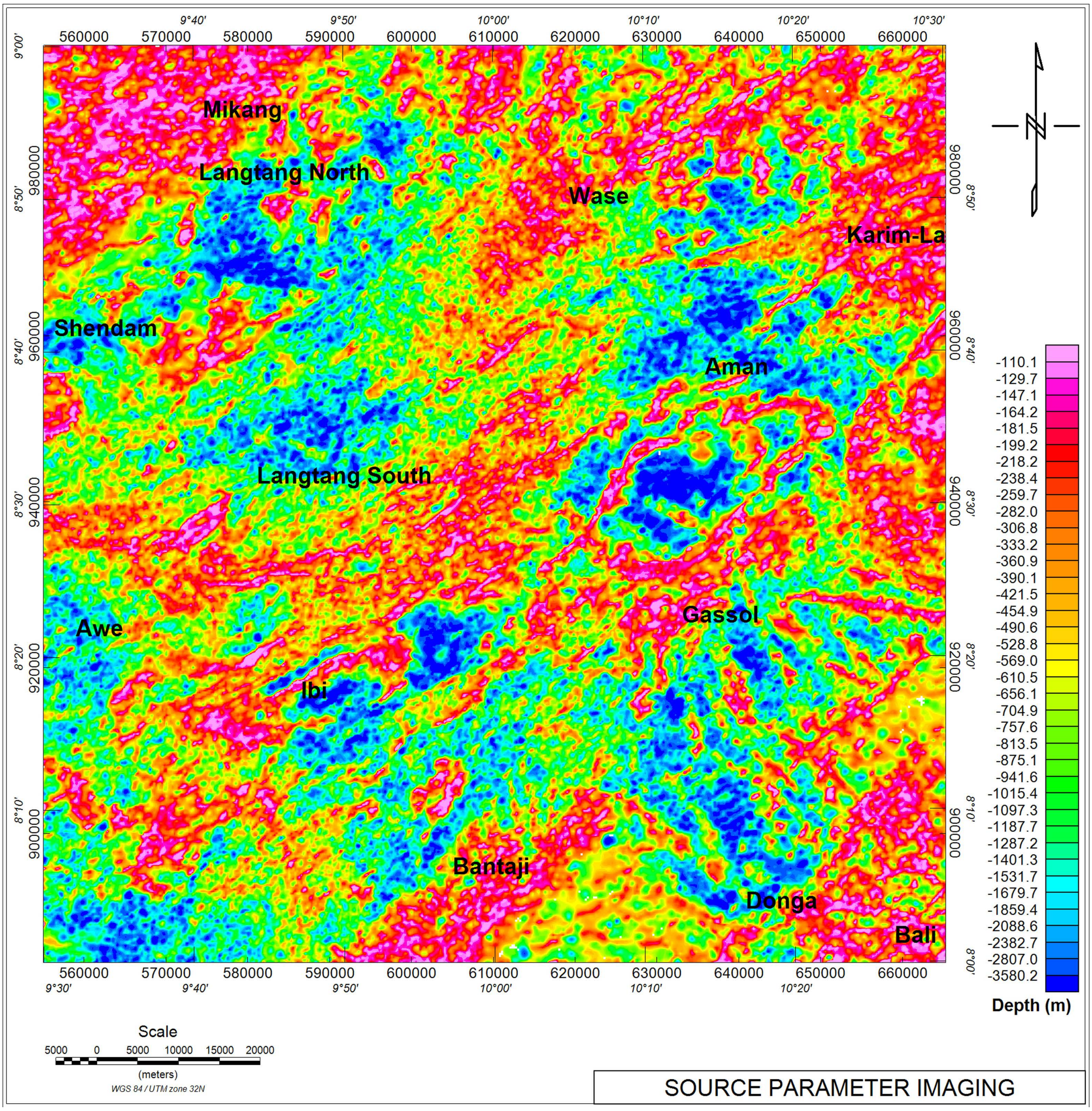

Figure 12. Source Parameter Imaging (SPI) map showing the various depth to magnetic sources in the study area.

rock, reservoir rock, trap and seals, then the temperature of maturity, Total organic content (TOC), and so on should be examined, this can be done through a thorough and detailed geochemical analysis of the sediments in the area.

3) It is also recommended that Aeromagnetic method should be employed more in other parts of the basins so as to determine the thickness of the sediments and to determine the hydrocarbon prospect in the area.

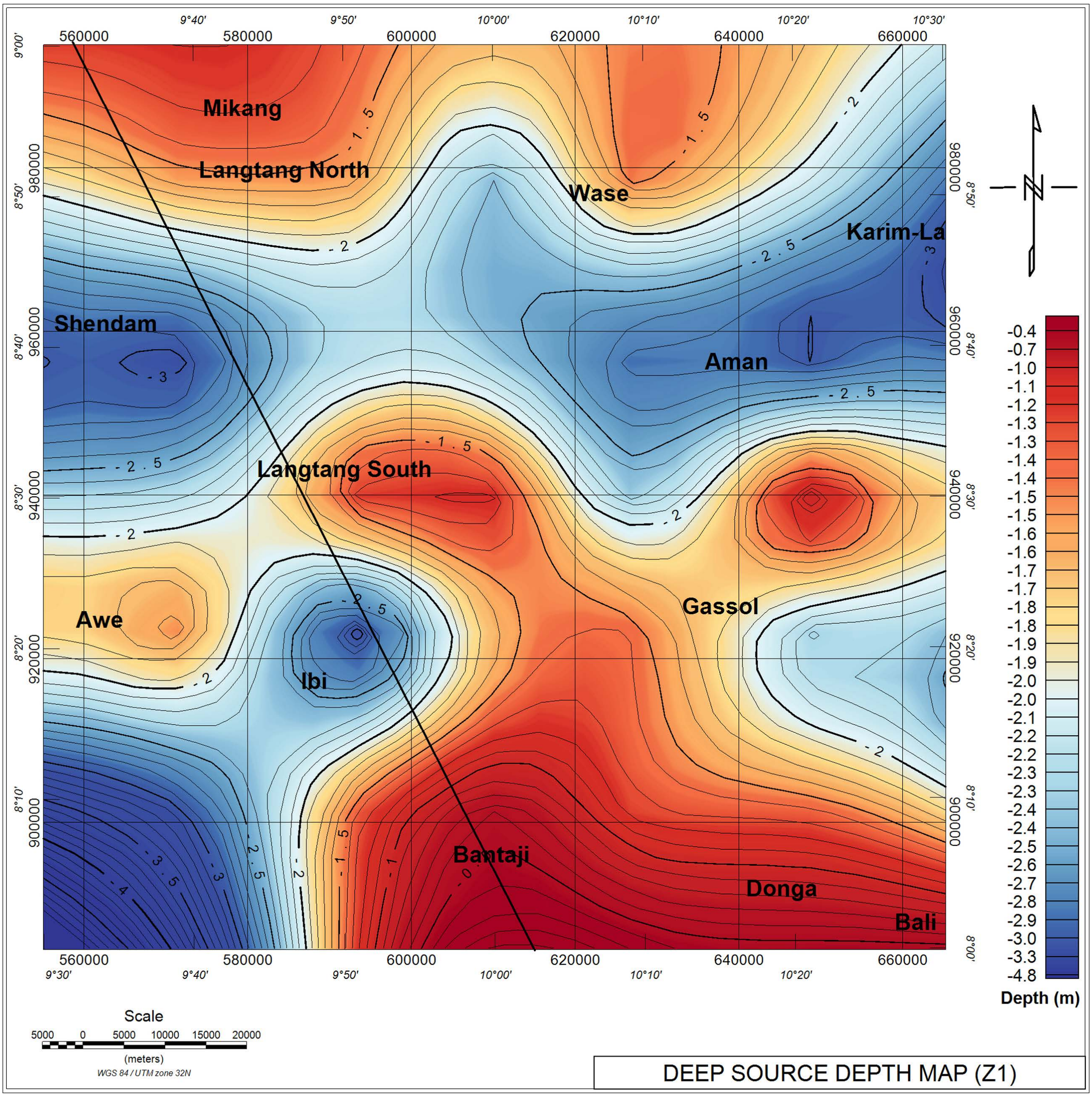

Figure 13. Map of deep source depth (Z1) to basement of the study area.

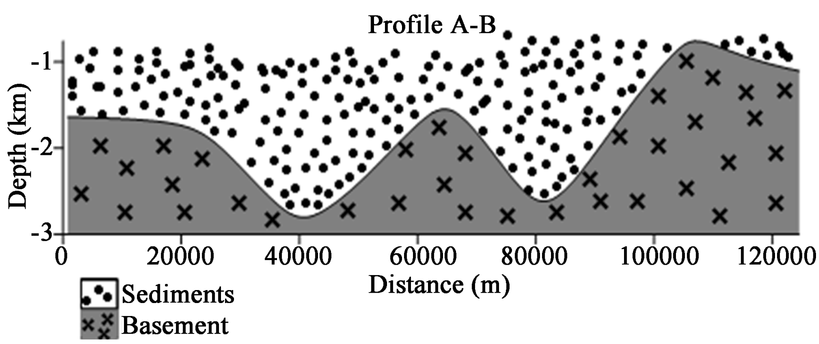

Figure 14. Cross section A-B of the above map.

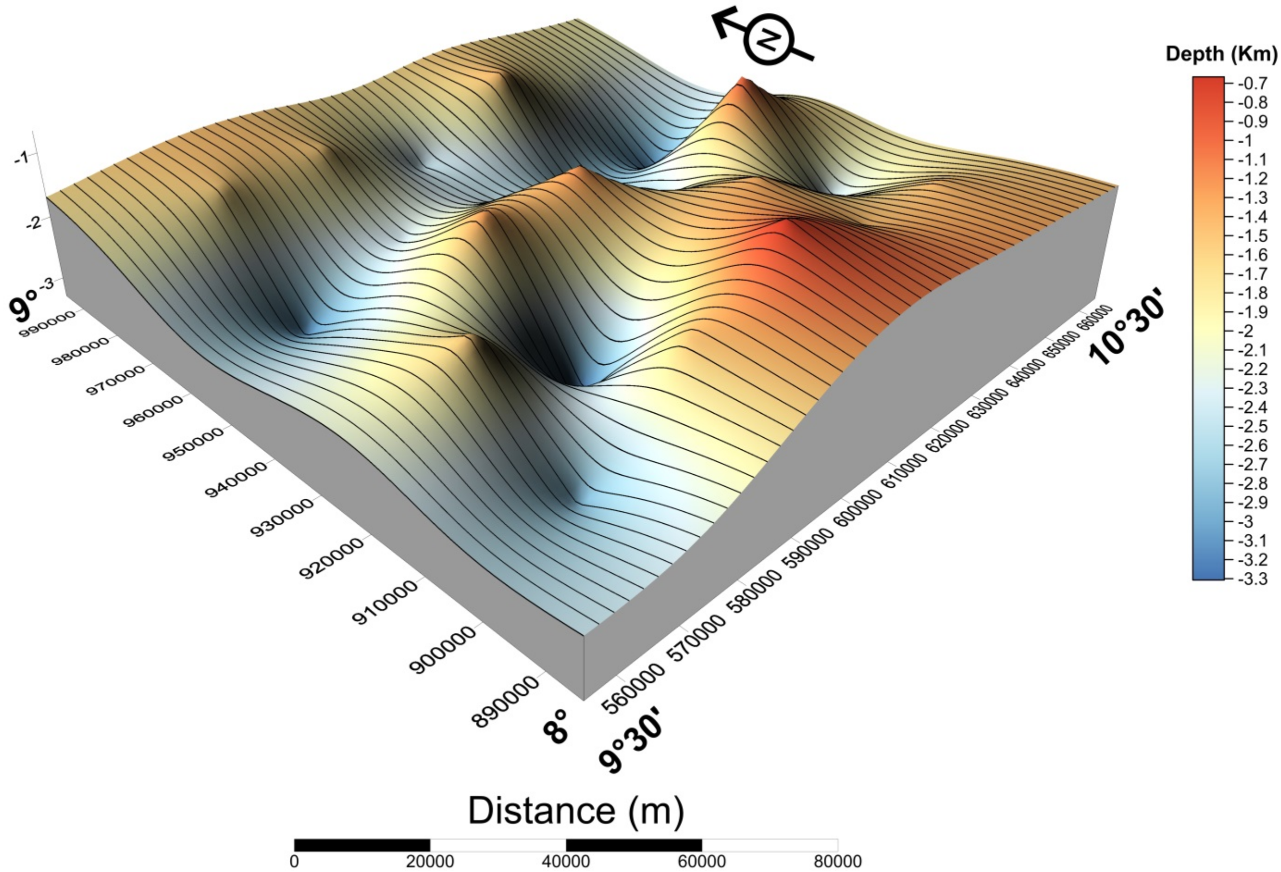

Figure 15. 3D Surface Plot for the basement topography of the study area from the deep anomaly depth source (Z_1).

Acknowledgements

We will like to acknowledge the Department of Physics, University of Abuja for providing the enabling environment to carry out the interpretation and analysis of this research.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Reford, M.S. (1980) Magnetic Method. *Geophysics*, **45**, 1640-1658. https://doi.org/10.1190/1.1441055

[2] Kearey, P. and Brooks, M. (2002) An Introduction to Geophysical Exploration. Blackwell Scientific Publications, Hoboken.

[3] Olurin, O.T., Olowofela, J.A., Akinyemi, O.D., Badmus, B.S., Idowu, O.A. and Ganiyu, S.A. (2015) Matched Filtering Analysis of Airborne Magnetic Data over Idogo Area, Nigeria. *The African Review of Physics*, **10**, 383-393.

[4] Augie, A.I. and Ridwan, M.M. (2021) Delineation of Potential Mineral Zones from Aeromagnetic Data over Eastern Part of Zamfara. *Savanna Journal of Basic and*

Applied Sciences, **3**, 60-66.

[5] Benkhelil, J. (1989) The Origin and Evolution of the Cretaceous Benue Trough (Nigeria). *Journal of African Earth Sciences* (*and the Middle East*), **8**, 251-282. https://doi.org/10.1016/S0899-5362(89)80028-4

[6] Offodile, M.E. (1976) The Geology of the Middle Benue Trough, Nigeria. The Palaeontological Institution of the University of Uppsala, Uppsala.

[7] Obaje, N.G. (2004) Geology and Mineral Resources of Nigeria. Springer, Berlin, 10-30.

[8] Reford, S.W., Kwan, K., Nyakaana, J., Katumwehe, A. and Wane, O. (2009) Airborne Geophysics as a Tool to Promote Mineral İnvestment in Africa. *ASEG Extended Abstracts*, **2009**, 1-8. https://doi.org/10.1071/ASEG2009ab077

[9] Adewum, T. and Salako, K.A. (2018) Delineation of Mineral Potential Zone Using High Resolution Aeromagnetic Data over Part of Nasarawa State, North Central, Nigeria. *Egyptian Journal of Petroleum*, **27**, 759-767. https://doi.org/10.1016/j.ejpe.2017.11.002

[10] Telford, W.M., Geldart, L.P. and Sheriff, R.E. (1990) Applied Geophysics. 2nd Edition, Cambridge University Press, Cambridge, 770. https://doi.org/10.1017/CBO9781139167932

[11] Hildenbrand, T.G. (1983) A Filtering Program Based on Two Dimensional Fourier Analysis. Open-File Report 83-237. U.S. Geological Survey, Reston, 4-10.

[12] Spector, A. and Grant, F.S. (1970) Statistical Models for Interpreting Aeromagnetic Data. *Geophysics*, **35**, 293-302. https://doi.org/10.1190/1.1440092

[13] Thompson, D.T. (1982) A New Technique for Making Computer-Assisted Depth Estimates from Magnetic Data. *Geophysics*, **47**, 31-37. https://doi.org/10.1190/1.1441278

[14] Amigun, J.O., Afolabi, O. and Ako, B.D. (2012) Euler 3-D Deconvolution of Analytical Signal of Magnetic Anomalies over Iron Ore Deposit in Okene. *Nigeria Journal of Earth Sciences*, **2**, 1-9.

[15] Abbass, A.A. and Mallam, A. (2013) Estimating the Thickness of Sedimentation within Lower Benue Basin and Upper Anambra Basin, Nigeria, Using Both Spectral Depth Determination and Source Parameter Imaging. *International Scholarly Research Notices*, **2013**, Article ID: 124706. https://doi.org/10.1155/2013/124706