PHYSICS MEMOIR
Available online @ https://physicsmemoir.online

Phys. Memoir 3 (2021) 25–37

Journal of Theoretical & Applied Physics

Original Research

Delineation of Horizontal Locations and Estimation of Depth to Magnetic Source Geometries of Dubumbali, North-East Nigeria

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Abstract

Identification of magnetic source geometries of causative bodies is an important procedure when prospecting for hydrocarbon signatures from aeromagnetic data. In order to achieve this purpose, three methods namely Wavelet transform technique (WT-T), Fourier transform technique (FTT) and Euler deconvolution technique (EDT) were applied to the reduced to equator (RTE) magnetic data. The WTT applied to the data is based on Morlet wavelet to determine the horizontal locations of magnetic source distribution in the potential field anomalies. These anomalies are always superimposed upon one another in frequency and space domain making it difficult to identify magnetic sources which are of adjacent sources. In view of this, each of the profile data was convoluted with the continuous wavelet transform and the square of coefficients from the convoluted profiles were plotted against the pseudo-wave number. Also, a scaled normalization factor was introduced on the coefficients so that the resolution of various adjacent magnetic sources can be revealed. Depth to magnetic sources was obtained using the FTT, while EDT is used to identify and estimate depth to various magnetic source geometrics with prescribed values of structural indices ranging from 1.0 to 3.0. From this analysis, we have been able to use both WTT and EDT to identify various magnetic source geometries which are attributed to volcanic intrusive rocks found to be predominant in the area while the results of depth estimate using both FTT and EDT ranges from 250 m to 1800 m. The study concluded that the methods are not only useful in the identification and estimation of source geometries due to magnetic anomalies alone, their combinations have served as a tool for identifying hydrocarbon signatures within the study area.

Keywords: Aeromagnetic Data, Wavelet Transform Technique (WTT), Euler Deconvolution Technique (EDT), Fourier Transform Technique (FTT), Magnetic Source Geometrics

Article History:
Received 21 November 2019
Received in revised form 15 May 2020
Accepted for publication 11 June 2020
Published 03 February 2021

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1. Introduction

Magnetic survey has been used extensively in the investigation of subsurface geology on the basis of its anomalies present in the magnetic field of the earth resulting from the properties of susceptibility contrast of the fundamental rocks [1]. This survey is not limited to detections of hidden ore sources in the mineral's investigation only but has also received a nod in reconnaissance survey for studying of faults, geothermal and hydrocarbon signatures. In magnetic data interpretation, part of its objective is to obtain depth to the top of magnetic basement which is equivalent to the thickness of the sediments in the case of an Inland basin and more importantly detection of these sources which may be due to the presence of intrusive bodies which exhibit more magnetic properties than the underlying lava flow [2-3] reported that intrusive rocks reveals high magnetic intensities as a result of the presence of strong magnetic mineral contents and that higher wave number magnetic anomaly are characteristics of low intrusions coming from igneous rock while low wave number anomalies are associated with intrusions covered by thick basins. There are many different mathematical techniques used in analyzing information regarding identification and location of magnetic sources. Some of the techniques were discussed comprehensively in the research work of [3-4]. However, identification of magnetic sources is best analyzed in frequency/wave number domain because the convolution operator is easily changed to multiplication information by the application Fast Fourier technique [5].

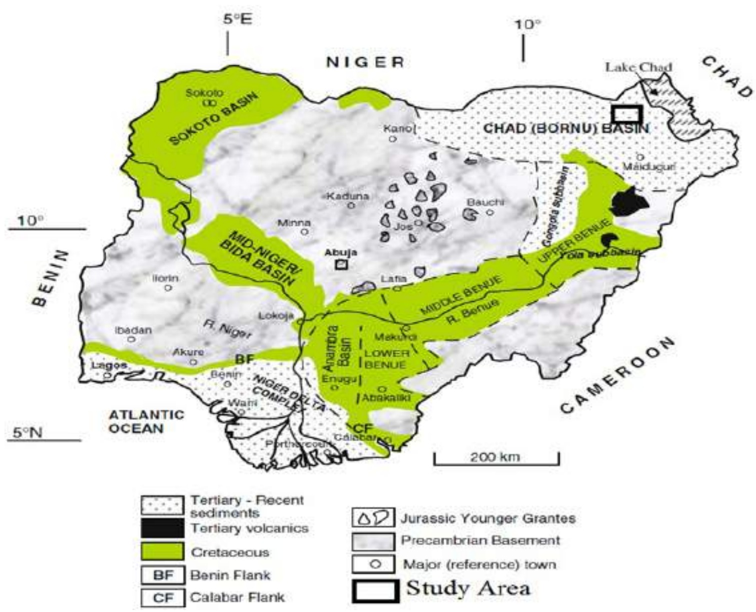

Figure 1. Geological map of the Chad Basin Nigeria (Obaje, 2009)

Among various Spectra technique that are available is traditional Fourier transform, which has been reported by many researchers [3-4,6-16] not to be appropriate in the analysis of spaced or time bound signal such as a gravity of magnetic data because it has complexity in interpreting location of features from the transform coefficients. As a result, the CWT a newly revealed mathematical technique is appropriate for the investigation of magnetic anomalies which shows that the local features which can be regarded as the source geometrics present in the data. Several applications of CWT wavelet transform on the analysis and interpretation of potential field data have been made; this can be found in the work of [16]. We have applied the scaled normalized CWT on the effect of the resolution of magnetic anomaly data using Morlet as a daughter wavelet to identify and determine the horizontal locations of source distribution in the magnetic field anomalies.

2. Geology of the Study Area

The study area which lies within the North-eastern part Nigerian has been described by many authors [17], [18] to be an inland basin that occupies the Nigerian sector of Chad basin of the country (Fig. 1). This basin is part of

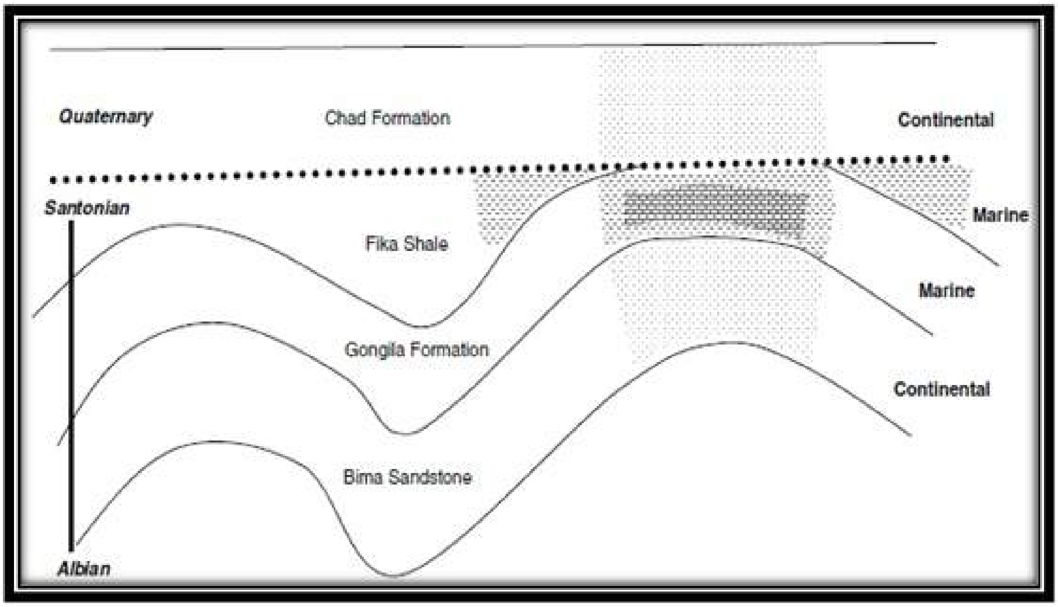

Figure 2. Stratigraphic sequence of the study area (Obaje, 2009)

the African Phanerozoic sedimentary basins whose source is linked to the active process of plate difference because tectonically, some fractures, faults and lineaments were formed around the basin for the period of the Pan African crustal consolidation. The intrusives produced antecedent directions for basin rift in the future [19]. Information about the stratigraphic sequence of this region revealed that there are five of them and they include the Bima Sandstone which found at the underneath, the Gongila Formation which is next to it, the Fika Shale, the Keri–Keri and Chad Formations, all of which can be found in Fig. 2.

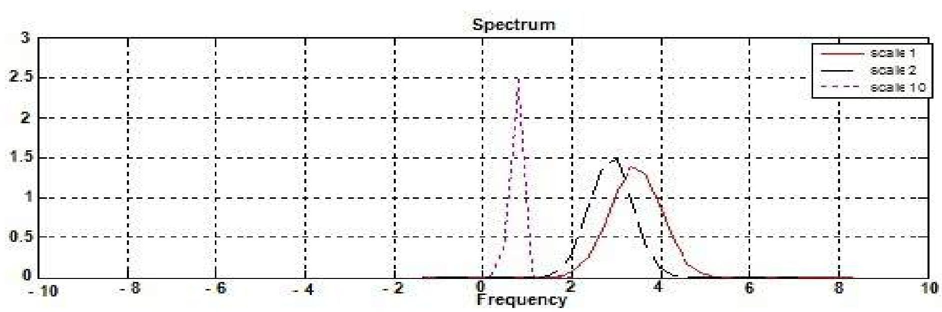

Figure 3. Fourier spectrum of Morlet wavelet function ($k_0 = 5$) for different scales

3. Methodology

3.1. Theories of Continuous Wavelet Transform (CWT)

The theories of CWT as reported in the work of [3] and [16], is defined as

$$W_v(a,t) = \sum_{v-0}^{k-1} X_v \bar{\psi}_{a,t}(v) \; a > 0 \tag{1}$$

$$\psi_{a,t}(v) = \frac{1}{\sqrt{a}}\psi\left(\frac{v-t}{a}\right) \tag{2}$$

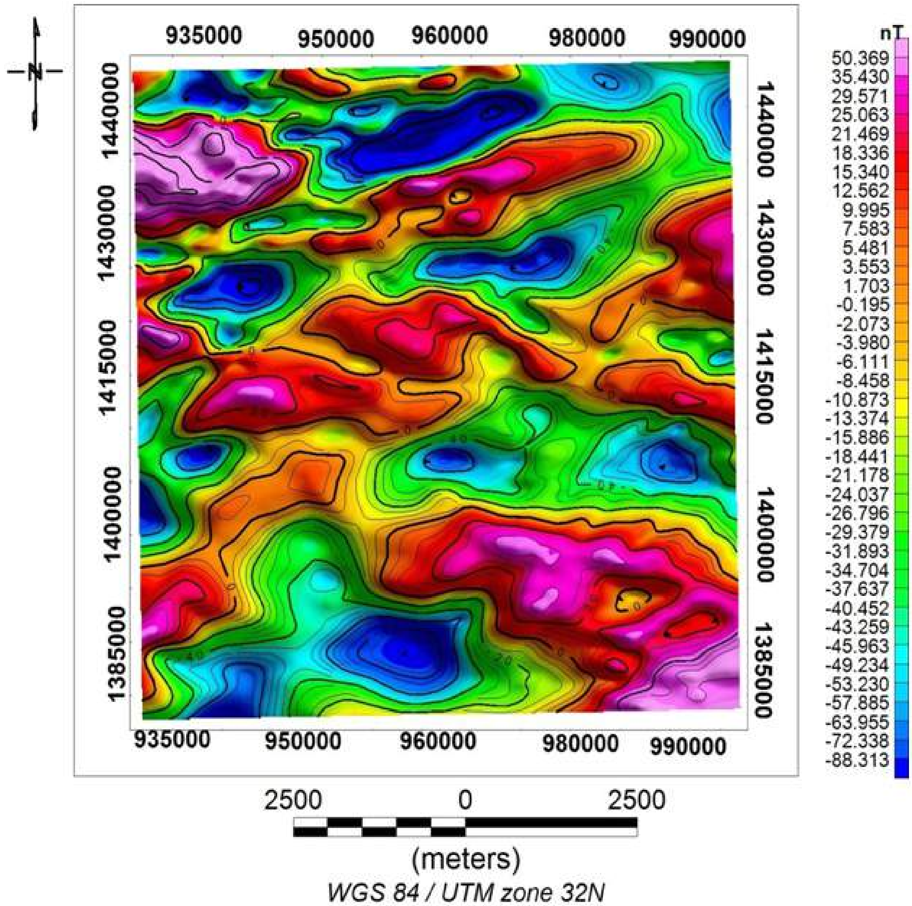

Figure 4. Magnetic data acquired for the study area (sheet index 45. NGSA)

Where $\psi_{a,t}(v)$ is the mother wavelet function, $a > 0$ is the scale factor, t is the translation parameter, and $\bar{\psi}_{a,t}(v)$ is the complex conjugate of $\psi_{a,t}(v)$. Although the Wavelet Transform (WT) of a discrete profile data X_v can be view as the coefficient of the CWT at different scales. But the choice of wavelet function depends on the nature of the data in consideration. Meanwhile to avoid duplication of words on choice of wavelet function, properties of the functions and the choice of scales, all of these have been discussed extensively in the work of [16]. Therefore, whenever a non stationary data such as aeromagnetic or gravity is been considered, Morlet wavelet is used because of its numerous properties such as high resolution in both space and time domain [20]. The Morlet wavelet function can be defined as

$$\bar{\psi}(k) = exp^{-(k-k_o)/2} \tag{3}$$

Where k and k_0 are wave number and center frequency of the wavelet function, also the characteristics spectrum plot of the function is shown in figure 3. The plot shows that Morlet function is nearly equal to zero for wave number less than zero. This will be useful in situations where elimination of interference of negative frequencies are required.

In other to obtain the coefficient of CWT from the application of CWT to aeromagnetic profile data, it is advisable to compute in the frequency domain because it is considerably faster than that of space domain [21]. Therefore, coefficients of these profile data were computed in frequency domain and their implementation step is adapted from the work of [16] and is given below:

(a) Calculate the Fourier transform $T(k)$ of the original signal $t(x)$.
(b) The Fourier transform $T(k)$ is multiplied by Morlet function $\overline{\psi}(k)$ at different scales in other to achieve transform. $G\overline{(k)} = T(\vec{k}) \times \vec{\psi}(k)$
(c) In other to obtain the result of coefficient of wavelet transform $W_v(t)$ in space domain, the inverse Fourier transform of $W\overline{(k)}$ is computed and
(d) The result of the wavelet transform at different scales following steps (ii) and (iii) was obtained using different scales with the dilated wavelet basis.

Using the implementation steps listed above, i.e from (a) to (d), the square of absolute values (which is the same thing as Scalogram) of the results obtained from the implementation (d) was computed and this plot only shows scaling values and the energy levels of the transformed coefficients. These coefficients reveal maxima associated with larger anomalies in the Scalogram plot. But, the Scalogram plot does not gives a direct interpretation pseudo-wave number response of magnetic sources [3]. In view of this, a scale a, is stretched to an equivalent pseudo-wave number K_a and the relationship between K_a and a is given in equation (5).

$$K_a = \frac{K_c}{a\Delta} \tag{4}$$

where K_a is the pseudo-wave number of wavelet transform at Scale a, Δ is the sampling interval and K_c is the center frequency of the Morlet function.

[1] observed that in view of the fact that magnetic anomalies are results of superposition of numerous mechanisms of rocks connecting to sources that belongs to diverse positions and extents which is a problem in the identification of magnetic sources resulting from strong obstructions, then a scale normalization parameter was applied to the coefficients of the wavelet transform. This scale normalization factor therefore increases the resolution of numerous intrusive sources in the Scalogram plots [20].

3.2. Theories of Fourier Transform (FT)

According to [22] that showed the contributions from the depth, width and thickness of magnetic source ensembles affect the shape of power spectrum and the power spectrum is related by the equation:

$$1n\left[P_{\Delta T}(|k|)^{1/2}\right] = 1n\ A_1 - |k|Z_t \tag{5}$$

where $P_{\Delta T}$ is the average power spectrum, k is the wave number, A_1 is a constant, Z_t depth to the top of magnetic source which can be obtained by fitting a straight line through the high wave number region of a radially average power spectrum of the magnetic anomaly.

3.3. Theories of Euler Deconvolution (ED)

The Euler's 3D homogeneity relation as related to magnetic field data is of the form [23]

$$(x - x_o)\frac{\partial T}{\partial x} + (y - y_o)\frac{\partial T}{\partial y} + (z - z_o)\frac{\partial T}{\partial z} = N(B - T) \tag{6}$$

where (x_o, y_o, z_o) is the location of a magnetic source, whose total field magnetic anomaly at the point, (x, y, z) is T and B is the regional field. N is a measure of the rate of change of a field with distance and assumes different values for different types of magnetic source (called structural index). Equation (6) is solved by calculating or measuring the anomaly gradients for various areas of the anomaly and selecting a value for N. For a homogeneous point source N = 3, a linear source (line of dipoles or poles, and for a homogeneous cylinder, rod, etc.) N = 2, for extrusive bodies (thin layer, dike, etc.) N = 1, for a contact, vertex of a block and a pyramid with a big height N = 0.

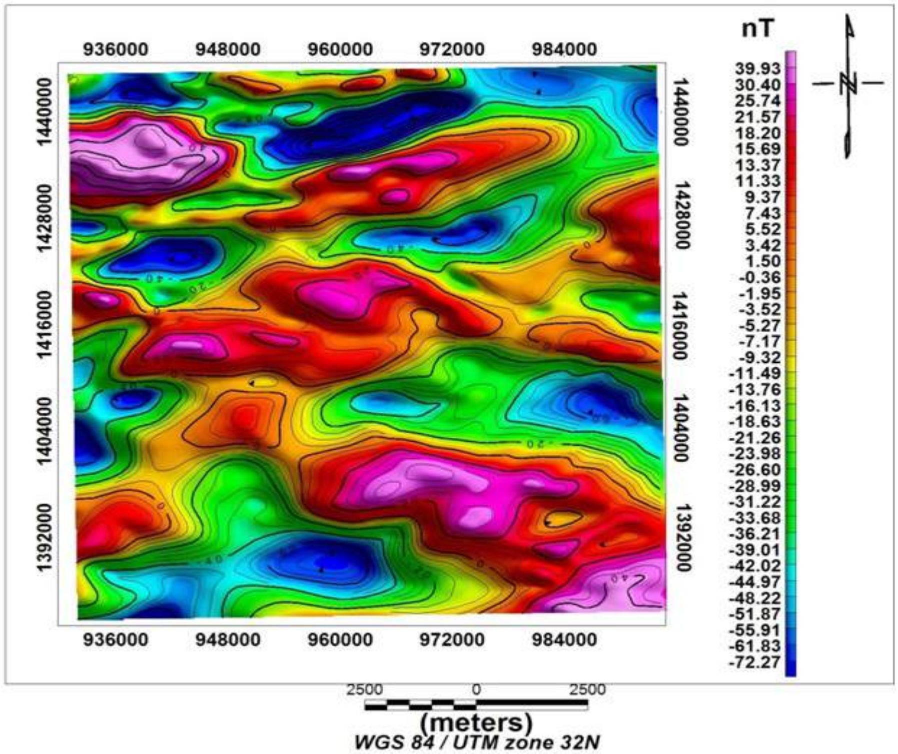

Figure 5. Reduced to Equator (RTE) Aeromagnetic data of the study area

3.4. Application of CWT, Fourier Transform and Euler Deconvolution to RTE Aeromagnetic Data

Aeromagnetic data used in this study was acquired from the Geological Survey Agency of Nigeria (GSAN) bounded with the Universal Transverse Meridian coordinate 1300000 mN and 1440000 mN and 930000 mE and 990000 mE and the data was windowed from the sheet index which can only be accessed using a software called Oasis montaj (Fig. 4).

In order to identify and determine the nature of intrusive sources present in the study area, the RTE aeromagnetic data was cautiously gridded using an interval value 0.875 km [16] and this yield eleven (11) profiles that cut across the acquired data (Figure 5). The implementation steps listed above (i.e. from (a) to (d)) were subjected to all the 11 profiles and Scalogram was plotted for each of the profiles.

For the depth estimate, Fourier transform was applied to the profile data and Z_t is estimated by fitting a straight line through the low wave number parts of the power spectrum (Fig. 12).

Also, in order to determine the location and estimate the depth of causative anomalous bodies for various magnetic sources, Euler deconvolution technique was applied to the RTE magnetic data by using a window size of 2000 m width and Structural index (S.I) of 1.0 to 3.0 were used (Fig. 13 – 15).

4. Results and Discussion

The results of CWT applied to the profiled magnetic data are presented from Fig. 7 to Fig. 11. Earlier in Fig. 4, it was observed that the RTE aeromagnetic map is made up of regions of high (pink colors 1.7 to 42.4 nT), low (-37.6 to -0.2 nT) and very low (-88.3 to –40.5 nT) magnetic values. The high magnetic values are found to be less predominant across the study area and this can be attributed to an indication of certain hidden intrusives and magnetic sources while low and very low magnetic values which are more predominant spreading across the study area are reflections of down-faulted blocks in the basement complex which has been filled with sediments or possibly represents sets of tectonic trends on the basement complex which controls the overlying sediments of the

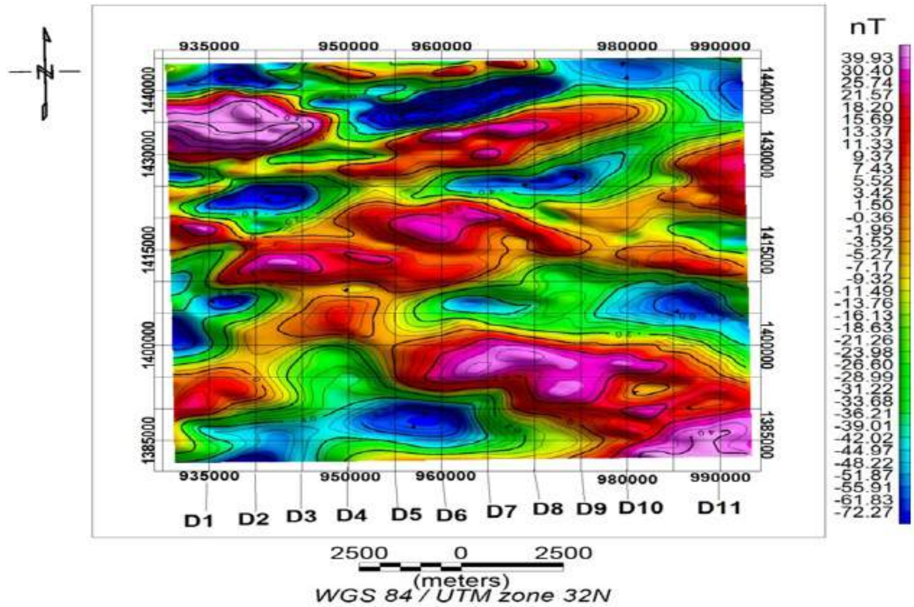

Figure 6. Aeromagnetic map gridded from profile (D1) to (D11)

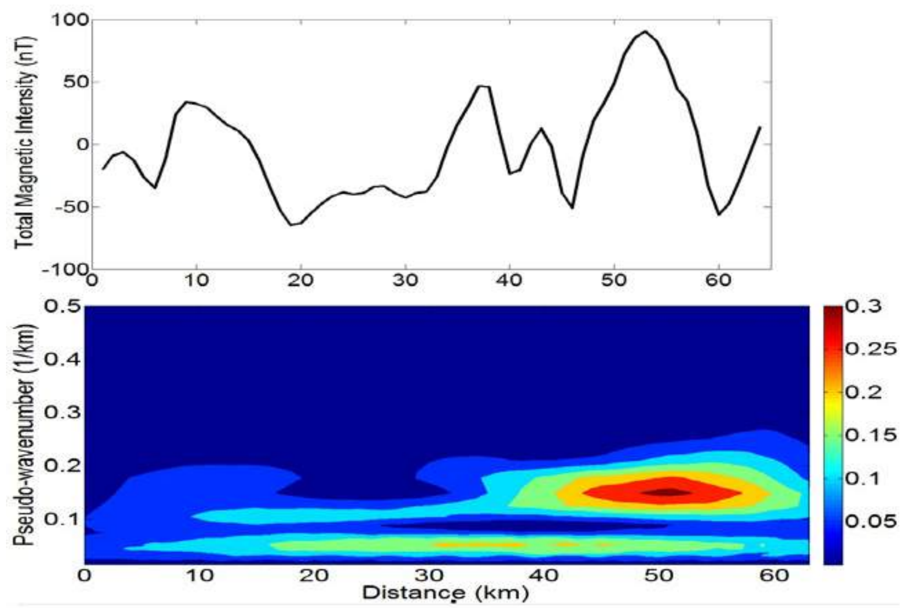

Figure 7. Profile D1 and its scalogram plot

area. Meanwhile, from the gridded aeromagnetic map (Figure 5), it will be noticed that the profiles cut across both regions of higher, low and very magnetic values. Therefore, some of the results obtained from the convoluted profiled magnetic data are profile D1, D4, D5, D6, D9 and D10 with the profiled aeromagnetic data at the top and Scalogram plot (i.e. the scaled pseudo-wave number against distance) is blow. From all the Scalogram plots presented, it will be observed that each profile revealed pronounced (deep brown) and least (blue) energy values. The pronounced energy values which are found in the low pseudo-wave number portion of the vertical axis plots are of different geometrical shapes (e.g. spheres, horizontal dykes, circles, vertical dykes). These geometric shapes correspond to deep seated

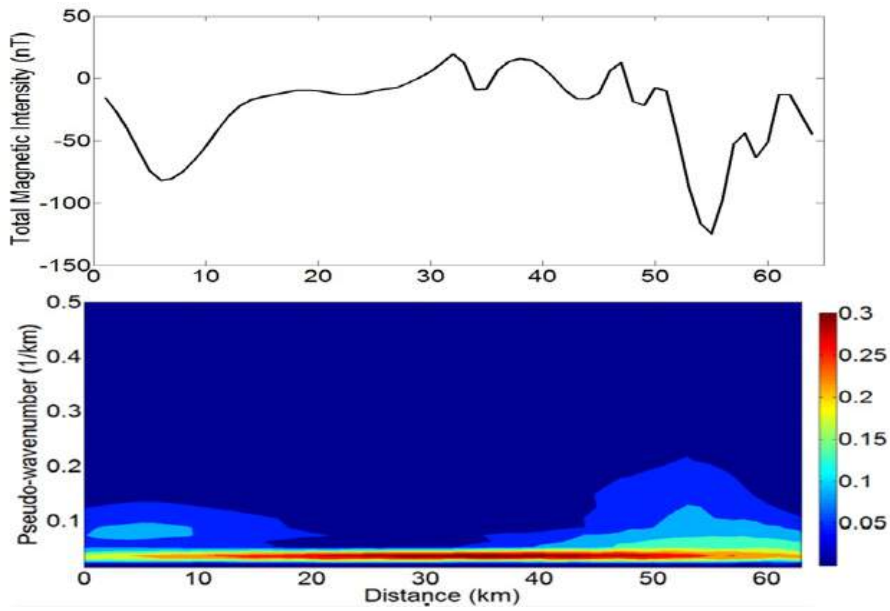

Figure 8. Profile D4 and its scalogram plot

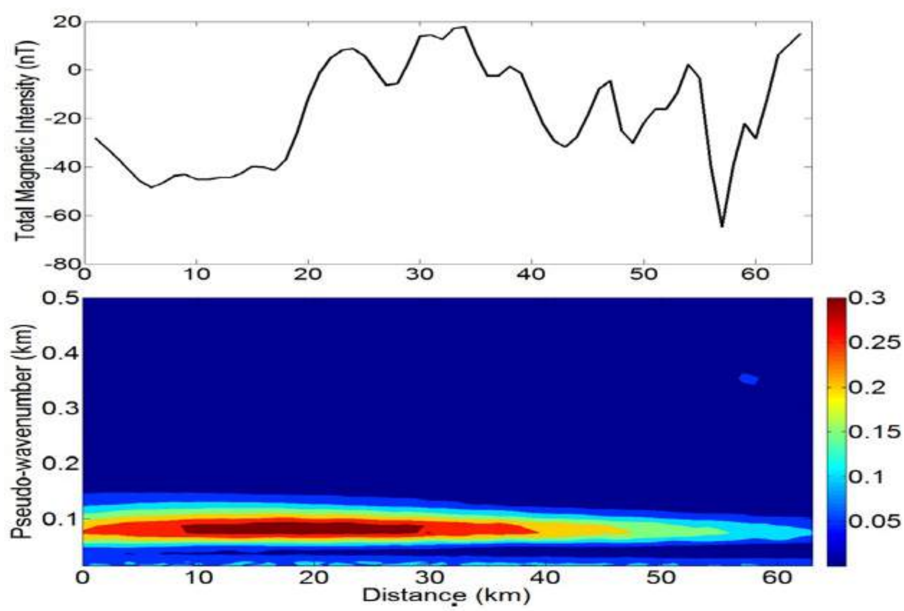

Figure 9. Profile D5 and its scalogram plot

intrusive magnetic sources and this is analogous to various depth estimation to magnetic sources carried out by many researchers using conventional Fourier transform techniques [22,24-27].

For profile D1, D6, D5 and D10 they revealed a sphere like geometrical shape with pseudo-wave numbers ranging from 0.10 to 0.15 km^{-1} with horizontal distance of 50 to 52 km for D1, 0.20 to 0.30 km^{-1} with horizontal distance ranging from 50 to 60 km for D6, 0.05 to 0.10 km^{-1} with horizontal distance of 10 to 30 km for D5 and 0.10 to 0.15 km^{-1} with horizontal distance ranging from 45 to 53 km for D10 respectively. More so, profile D4 and D9 possess a dyke like geometrical shape with pseudo-wave numbers ranging from 0.05 to 0.10 km^{-1} with horizontal distance of

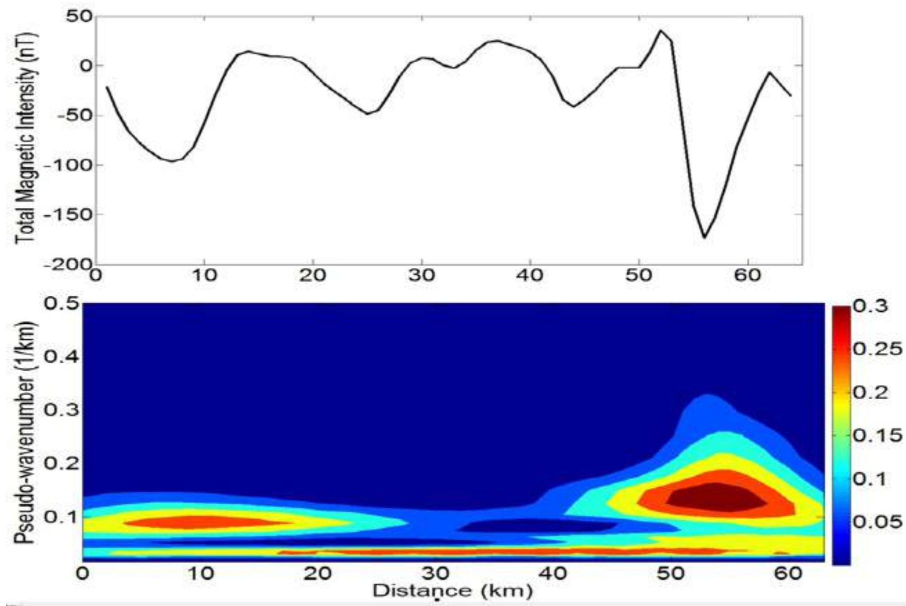

Figure 10. Profile D6 and its scalogram plot

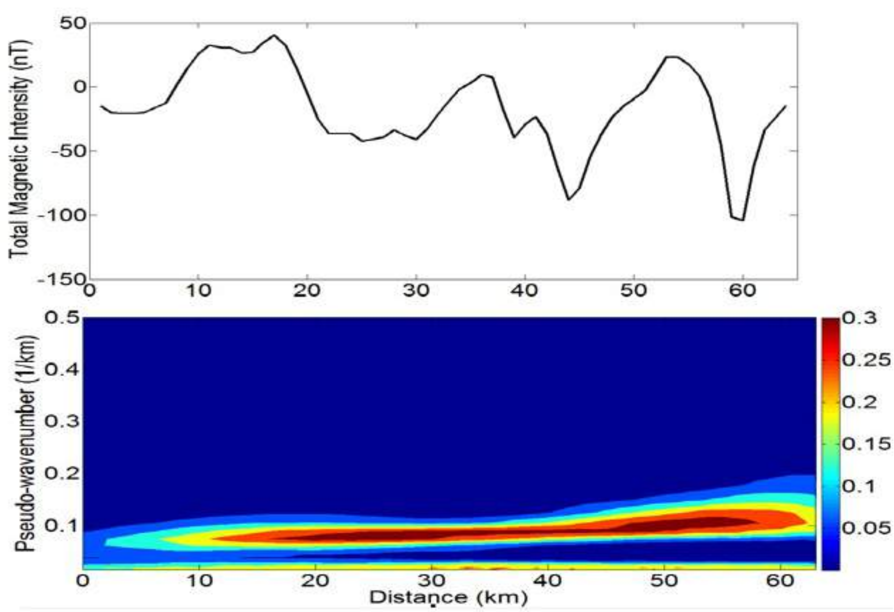

Figure 11. Profile D9 and its scalogram plot

20 to 50 and 20 to 40 km respectively.

The result of Fourier transform technique reveals a depth estimate of 1.87 km by fitting a straight line through the low wave number parts of the power spectrum and this is analogous to the results obtained from the Wavelet transform technique applied to the RTE magnetic data profiles where identification of various source geometrics were made from the plot (Figure 9 – 11).

The result of the EDT for S.I of 1.0 to 3.0 is shown in figure 13 to 16 with clustering of various sources but from the EDT plots, it was be observed that the best clustering for source positions N = 3 is an indication of general trends

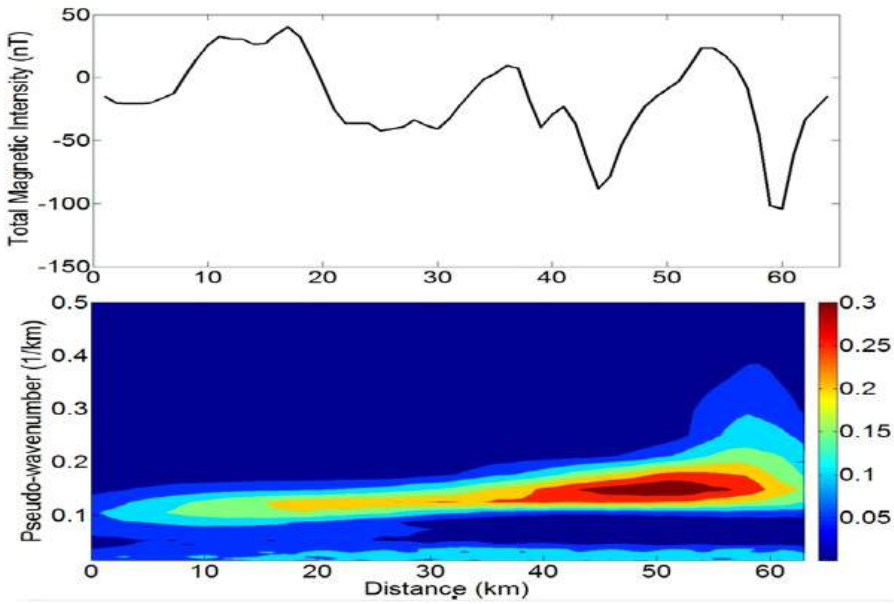

Figure 12. Profile D10 and its scalogram plot

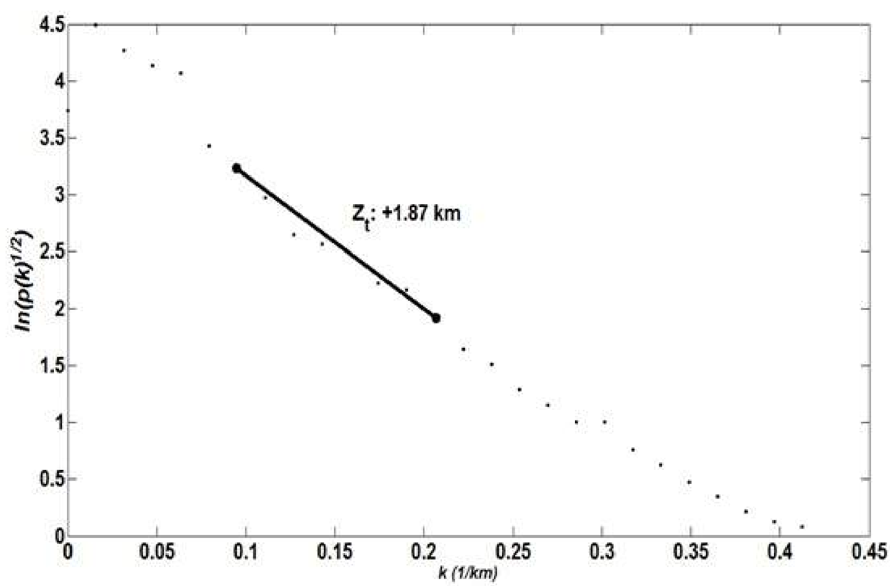

Figure 13. Radially average power spectrum for estimation of depth to magnetic sources from RTE Aeromagnetic map

associated with horizontal location as the case of WTT analysis (Figure 9 – 11) and value of depth obtained using the FTT.

In view of the above, the magnetic source geometries identified from this study is an important signature in hydrocarbon prospecting as reported in the research work of [3] where they applied WTT to the aeromagnetic data of Dagang oil field, China. In the case of this work, it was observed that magnetic sources are hidden at a depth ranging from 1 to 3.5 km with an equivalent pseudo-wave number of between 0.23 – 0.80 km-1. Meanwhile, in some of our earlier work [16] [20] where we estimated depth to the top and bottom of magnetic sources respectively and these depths were obtained from the low pseudo- wave number of the study area (0.05 – 0.19 km^{-1} and 0.09 – 0.25 km^{-1} respectively). A similar research work was also reported by Li et al., 2013 where they applied WTT to Chad lineament, a case study of North-central Africa. The results obtained using WTT tends to be in agreement the two other methods and earlier work published from this area and other part of the world.

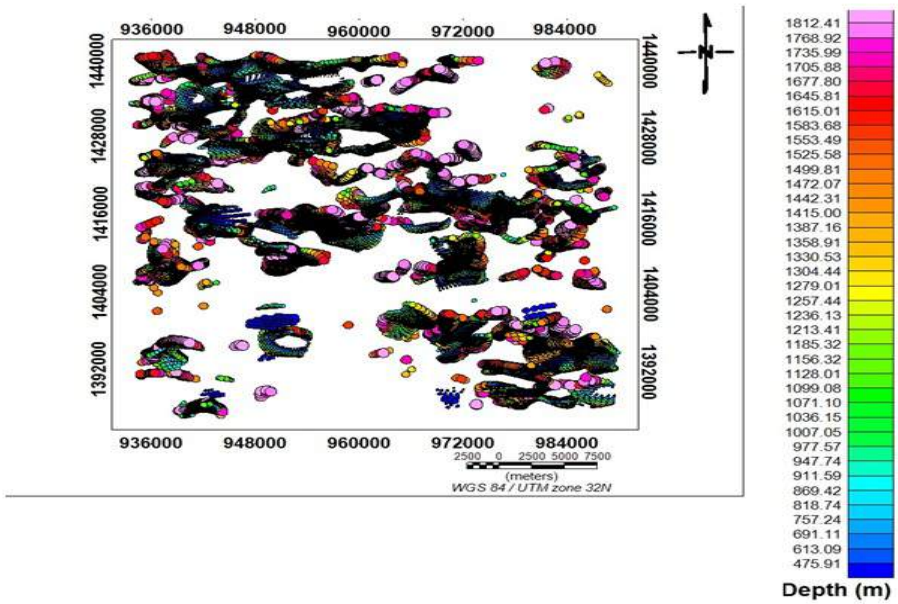

Figure 14. Euler Deconvolution showing the nature and distribution of magnetic sources with depth (S.I = 1.0)

5. Conclusion

We have applied three mathematical techniques to the identification and estimation of source geometries due to magnetic anomalies and these geometries are important in prospecting for hydrocarbon signatures of the area. The techniques were able to identify and estimate depth to magnetic sources. The revelation of pronounced energy values from the WTT corresponds to deep seated magnetic sources and their corresponding pseudo –wave numbers is the same as that of wave number obtained from FTT. Also the identified and estimated depth sources from the EDT are similar to that of WTT while the obtained depth is the same as that of FTT. Some geometrical shapes revealed are sphere and dyke-like in nature which are indication of hydrocarbon signatures in a recognizance survey area. Therefore, further research is necessary to ascertain the effectiveness of the magnetic anomalies as it relates to hydrocarbon exploration in the study area.

Acknowledgments

The authors wish to acknowledge the Nigeria Geological Survey Agency for providing us with the Aeromagnetic data used in this work. Thanks also to the anonymous reviewers whose review has contributed immensely to the improvement of this work.

Funding

This research work did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sector.

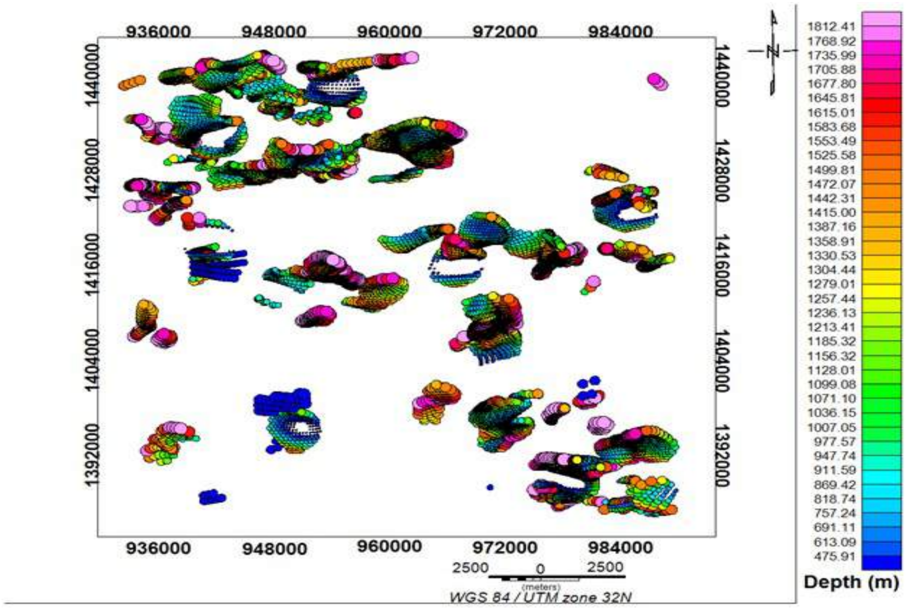

Figure 15. Euler Deconvolution showing the nature and distribution of magnetic sources with depth (S.I = 2.0)

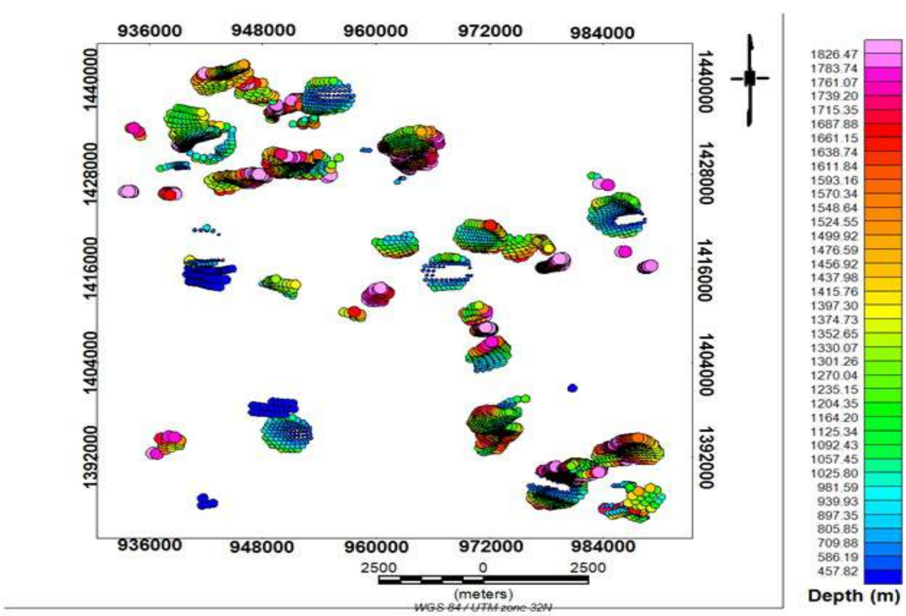

Figure 16. Euler Deconvolution showing the nature and distribution of magnetic sources with depth (S.I = 3.0)

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