Available online at www.elixirpublishers.com (Elixir International Journal)

Earth Science

Elixir Earth Science 123 (2018) 51858-51867

ISSN: 2229-712X

Estimation of Sedimentary Depth of Upper Benue Trough Nigeria using Aeromagnetic Data

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ARTICLE INFO

Article history:
Received: 23 August 2018;
Received in revised form: 20 September 2018;
Accepted: 1 October 2018;

Keywords
Aeromagnetic Data,
Euler Deconvolution,
Spectral Analysis,
Shaded Relief,
Mineralisation.

ABSTRACT
This study is aimed at estimating the sedimentary thickness of the Upper Benue Trough (Nigeria) as revealed by the Aeromagnetic data using the Spectral Analysis and Euler Deconvolution techniques. The area investigated covers from 09^0 00' - 10^0 00'N and from 11^0 30' - 12^0 30'E. An average sediment thickness of 3.98km was estimated which could favour hydrocarbon accumulation and maturation. There is a NE-SW increase in sedimentary thickness which varied from 2.2km to around 5.2km; it is thickest in the NE region. Verification was performed using the Euler deconvolution method which revealed clusters of Euler depth solutions within the low magnetic zones of interest (between 2km and above 3km). Combining both methods implies that a sedimentary depth of up to 4km (to 5km) could be possible especially in the Yola, Mayo Balewa and Bubila regions which thus increase the probability of hydrocarbon maturation and entrapment in these areas.

Introduction

Aeromagnetic survey maps the variation of the geomagnetic field, which occurs due to the changes in the percentage of magnetite in the rock. It reflects the variations in the distribution and type of magnetic minerals below the earth surface. Sedimentary formations are usually non magnetic and consequently have little effect whereas igneous and metamorphic rocks exhibit greater variation and become useful in exploring bedrock geology concealed below and over formations (Alberto and Politecnico, 2005). There has been increase in the use of airborne magnetic survey and gravity in the petroleum exploration industry recently. The early use of potential field methods in petroleum was to map sedimentary basin thickness while high resolution surveys are used to investigate basement trends and intra-formational structures (Nabighian and Grauch, 2005; Grauch *et al,* 2006).

Studies involving the interpretation of aeromagnetic data over the Benue Trough have revealed the existence of block faulting and numerous intrusive bodies (Osazuwa *et al.* 1981; Ajakaiye 1981; Ofoegbu 1984, 1985; Ofoegbu and Mohan 1990; Ofoegbu and Onuoha 1991). Various depth estimate techniques were applied on their data and results obtained showed that the estimates of the thickness of sedimentary rocks obtained by the different authors agree fairly well with each other. For example, Osazuwa *et al.* (1981) obtained a depth range of 0.9 – 4.9 km and 0.9 – 2.2 km in the northern Benue Trough from magnetic and gravity data respectively, while in the southern Benue Trough, Ofoegbu (1984) found that the thickness of sediments vary between 0.5 and 7 km. Ofoegbu and Onuoha (1991) from the results derived from 2D spectral analysis identified the existence of two main source depths in parts of the southern Benue Trough, the deeper source lying at a depth of 1.3 – 2.5 km, while the shallower depths were generally less than 250m.

This study utilized Spectral Analysis and the Standard Euler Deconvolution methods to estimate the thickness of the sedimentary layers in the upper Benue trough.

Geology of Study Area

The Benue Trough is a NE-SW folded rift basin that runs diagonally across Nigeria. It formed simultaneously with the opening of the Gulf of Guinea and the Equatorial Atlantic in Aptian-Albian times, when the Equatorial part of Africa and South America began to separate (Benkhelil 1987). The Trough is an elongate rifted depression in which the sediments reach well over 5000m thickness in places and have been strongly folded, probably by later adjustments along faults in the underlying basement. The Bida Basin is a shallow unfaulted arm of the Benue Trough. The Benue Trough probably provided the major link between the Mediterranean Ocean and Gulf of Guinea via the lullmedden and Chad Basins, during Upper Cretaceous times.

The basal lithic fill in the Benue trough (best exposed in the upper part) are the lower Cretaceous alluvial fan, braided river, Laustrine and deltaic Clastics of Bima Sandstone (Allix and Popoff, 1983) which also extends into the central Benue Trough (Nwajide, 1990). Volcanic and minor intrusive rocks are widespread and there are deposits of lead ores and coal. The trough bifurcates near its northeastern end, and the northern branch continues beneath the Chad Formation as an elongate depression that extends well beyond Lake Chad.

The study area is part of the upper Benue Trough comprising of Yola and its adjoining area and lies within latitude 9^o 00' and 10^o 00'N and longitude 11^o 30' and 12^o 30'E (fig.1).

The Upper Benue is largely referred to as failed rift valley (Cratchly et al., 1984; Nwogbo et al., 1991), and so it is expected that the region should be a major depositional basin and therefore a good site for mineralisation. Upper Benue basin belongs to the genetically and physically related systems of faults and rifts termed the West and Central African Rift System (WCARS).

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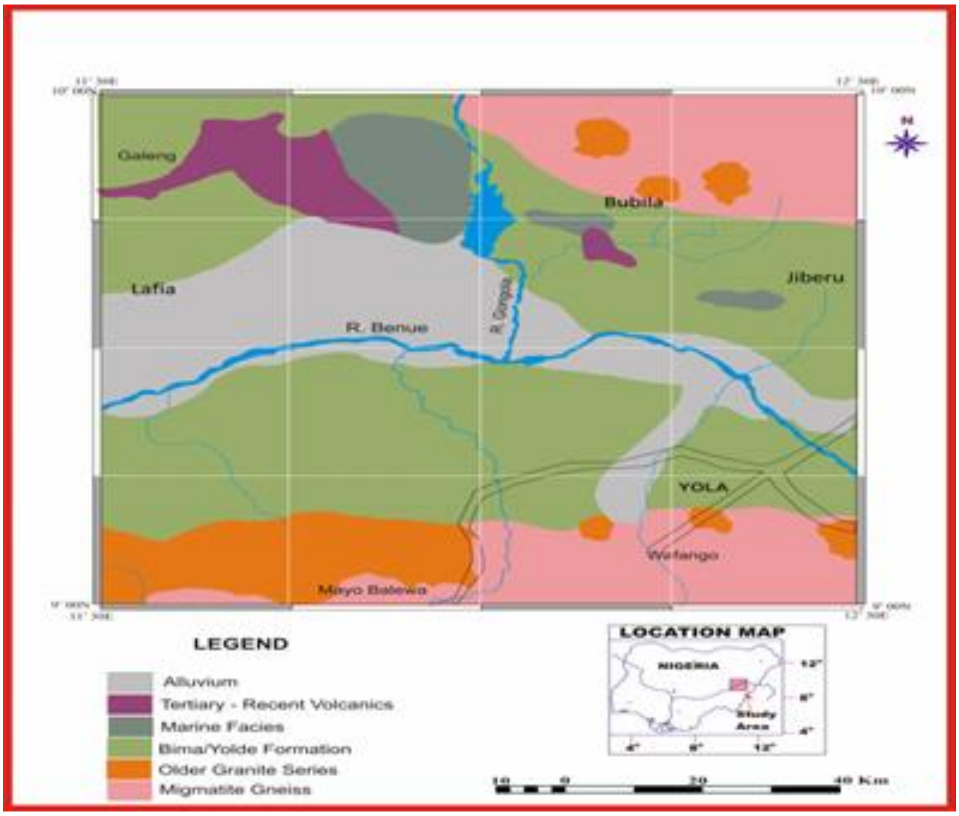

Figure 1. Geological map of study Area.

The system's origin is attributed to the breakup of Gondwanaland and the opening of South Atlantic and Indian Ocean. The Upper Benue – Chad axial trough is believe to be the third and failed arm of a triple junction rift system that preceded the opening of the South Atlantic during the early Cretaceous and subsequent separation of African and South American continent (Adegoke, 2012).

The crystalline basement whose topograph is believed to be irregular (Carter et al., 1963) is exposed in a number of locations in the region. Intruded into the basement is a series of basic, intermediate and acid plutonic rocks referred to as the older Granites. Notable outcrops of the older Granites include the small inliers of biotite granites which are found around Kaltungo, Gombe, Kokuwa, and in the Lafia area (Alagbe and Sunmonu, 2014).

Materials and Method

The aeromagnetic maps used for the study were obtained from the Geological Survey of Nigeria. The nominal flying altitude above the terrain was 500 feet (approximately 152m) with flight line and tile line spacing of 2km and 20km respectively. The regional correction on the maps was based on I.G.R.F. (epoch date, 1st January 1974, using IGRF 1975 model).The maps were digitized 2km along the flight line to produce the corresponding X, Y and the total magnetic field intensity Z as text files which are then analyzed using potential field software like USGS Potential field software version 2.0, Oasis Montaj 8.3. Regional – residual separation was carried out using polynomial fitting – an analytical technique in which matching of the regionals by a polynomial surface of low order exposes the residual features as random errors. The Polynomial residue map was then subject to the Fast Fourier Transformation software (FFTIL) to perform further analysis.

In the interpretation of magnetic anomalies by means of local power spectra, there are three main parameters to be considered. These are depth, thickness and magnetization of the disturbing bodies (Kasidi and Ndatuwong, 2008). It is necessary to define the power spectrum of a magnetic anomaly in relation to the average depth of the disturbing interface. It is also important to point out that the final equations are dependent on the definition of the wavenumber in the Fourier transform. For an anomaly with n data points the solution of Laplace equation in 2D is given as;

$$M(x_j, z) = \sum_{j=0}^{n-1} A_k e^{i2\pi k x_j} \; e^{\pm 2\pi k z} \tag{1}$$

Where k is the wavenumber and A_k are the amplitude coefficients of the spectrum such that;

$$A_k = \sum_{j=0}^{n-1} M(x_{j,} z) e^{-i2\pi k x_j} \; e^{\pm 2\pi k z} \tag{2}$$

When z = 0 (for initial reference) equation (2) can be written as;

$$(A_k)_0 = \sum_{j=0}^{n-1} M(x_j, 0) e^{-i2\pi k x_j} \tag{3}$$

Putting (3) into (2);

$$A_k = (A_k)_0 \, e^{\pm 2\pi k z} \tag{4}$$

Finding the square of both sides of (4) in order to derive the power spectrum;

$$P_k = \quad (A_k)^2 = (A_k)_0^2 \, e^{\pm 4\pi k z} \tag{5}$$

Or

$$P_k = (P_k)_0 \, e^{\pm 4\pi k z} \tag{6}$$

Taking logarithm of both sides,

$$\log_e P_k = \log_e (P_k)_0 \pm 4\pi k z \tag{7}$$

From equation (7), it's obvious that plotting log of the power spectrum ($\log_e P_k$) against the spatial wave number ($k^* \equiv 4\pi k$), reveals the depth (z) as the slope. These depths were established from the slope of the log-power spectrum at the lower end of the wave number band. The method allows an estimate of the depth of an ensemble of magnetized blocks of varying depth, width, thickness and magnetization.

The Euler method utilises the magnetic field strength at any point in terms of the gradient of the total magnetic field, expressed in Cartesian coordinates.

Furthermore, these gradients are related to different magnetic sources by a function termed the Structural Index, (N). Euler's equation is given by equation (8);

$$(x-x_0)\frac{\delta T}{\delta x}+(y-y_0)\frac{\delta T}{\delta y}-z_0\frac{\delta T}{\delta z}=N(B-T) \tag{8}$$

where x_0, y_0, z_0 are the coordinates of a magnetic source whose total field intensity T and regional value B are measured at a point (x,y,z); For two dimensions (x,z), Euler's equation reduces to equation (9);

$$x_0\frac{\delta T}{\delta t}+z_0\frac{\delta T}{\delta z}+NB=x\frac{\delta T}{\delta x}=NT \tag{9}$$

$\frac{\partial T}{\partial y}$ is assumed to be equal to zero, N is assumed between 0 and 3 in incremental interval in other to minimize error due to wrong geologic representation while gradients of T with respect to x and z can be derived from the measured magnetic data; the only unknowns are x_0 and z_0.

The output consists of (after using least-squares procedure) determinations of the depth to the magnetic body (z_0) producing the anomaly which can be plotted on a map as a circle, the increasing size of which indicates greater depth (Reynolds, 2011). This method was used to validate our estimate of depth of sedimentation within the study area.

Results and Interpretation

The total aeromagnetic map of study area is shown in fig.2, from which we could observe high magnetic anomalies in the range of 7800 to 7920 gammas. The 3D aeromagnetic surface (wireframe) map is shown in fig.3 from which we could conspicuously notice the low and high magnetic relief areas. The high areas are in red to pink colours while the low areas are in light- green to deep-blue colours. The low relief areas involve; Yola, Jiberu, and Mayo Balewa hence these areas may occupy pronounced sedimentary thickness

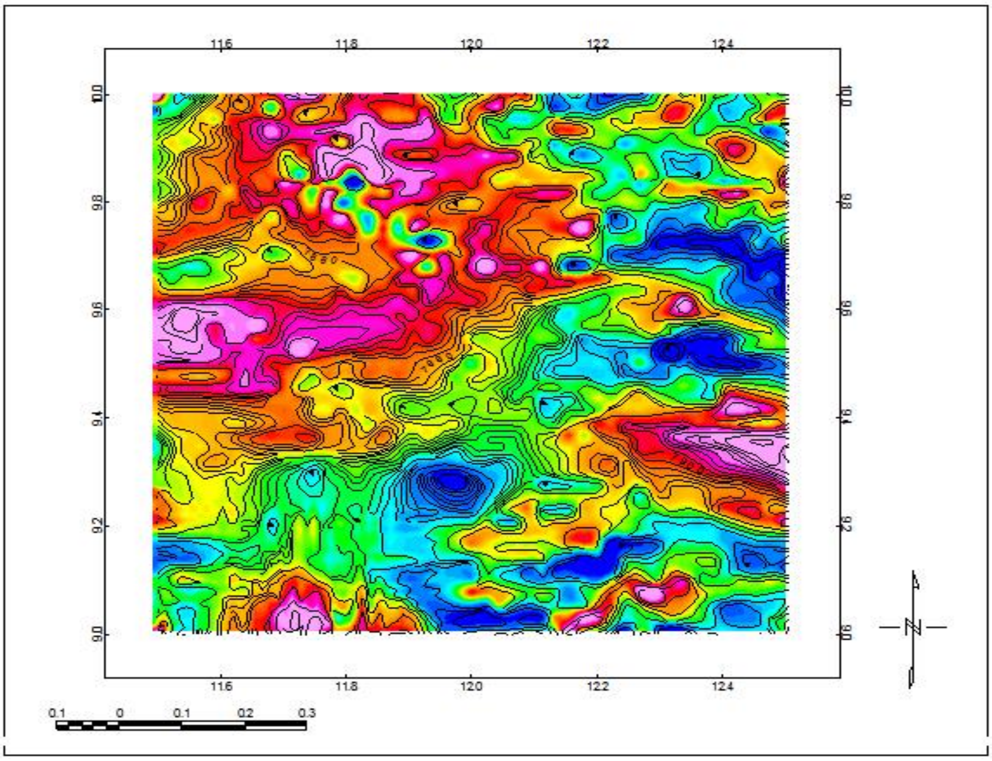

Figure 2. Total Magnetic field map of study area.

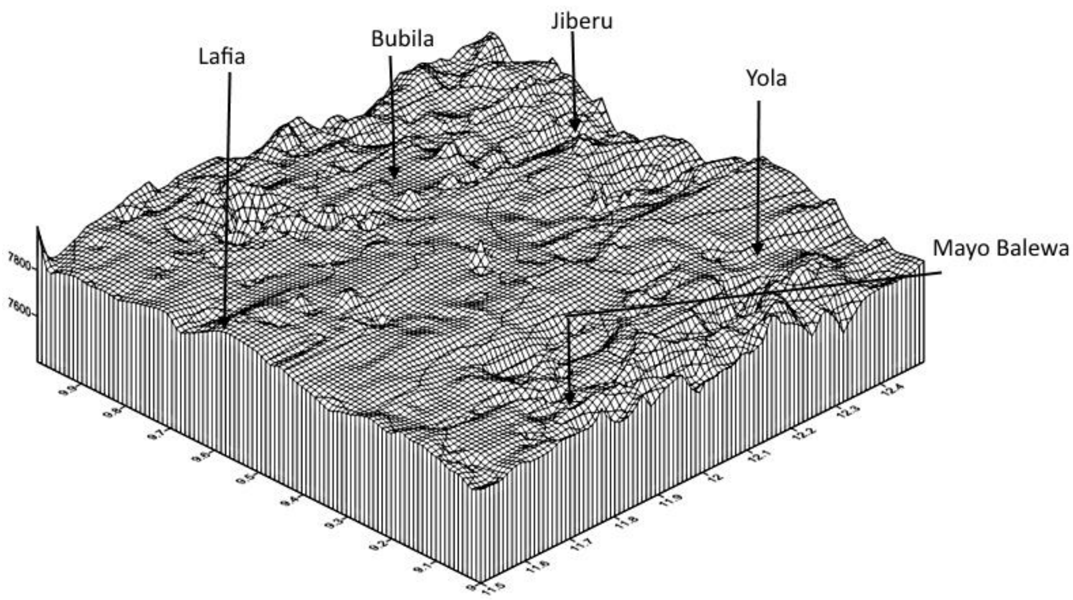

Figure 3. 3D surface aeromagnetic map of study area.

Figures 4 and 5 represent the Reduction to Pole (RTP) aeromagnetic map and the Shaded Relief map respectively. The two are in conformity with the distribution of magnetic highs and lows in the study area. It could be deduced that the entire North West region is magnetically high while about 32% of the South East region is correspondingly high.

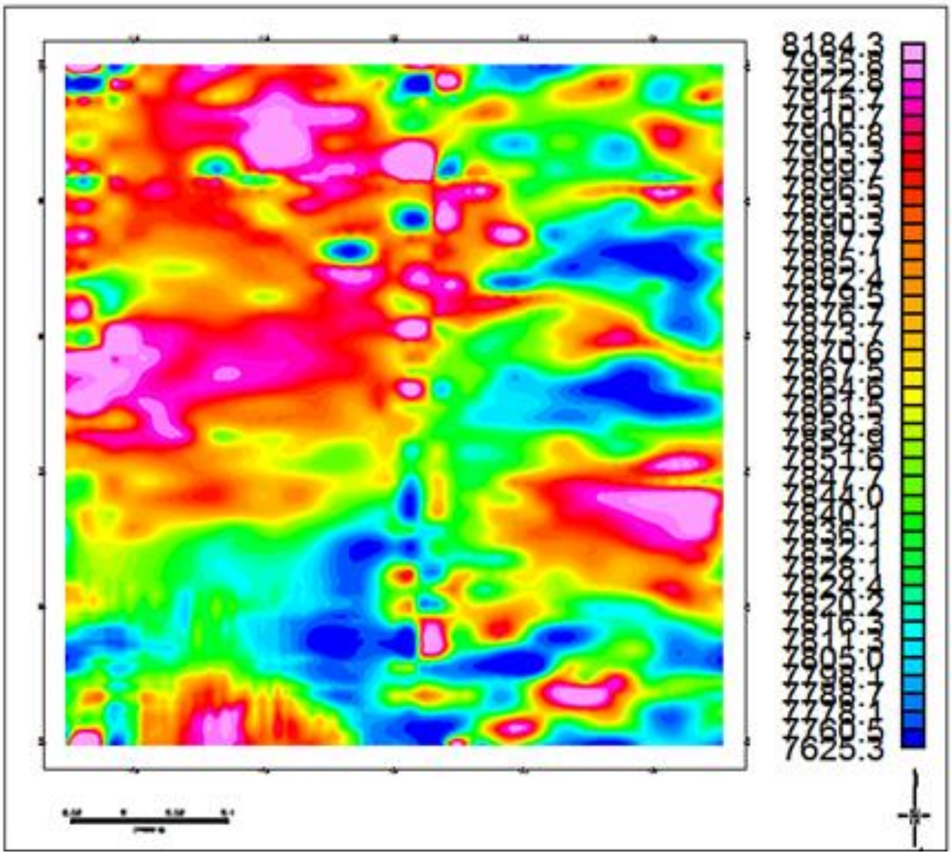

Figure 4. Reduction to Pole map of study area.

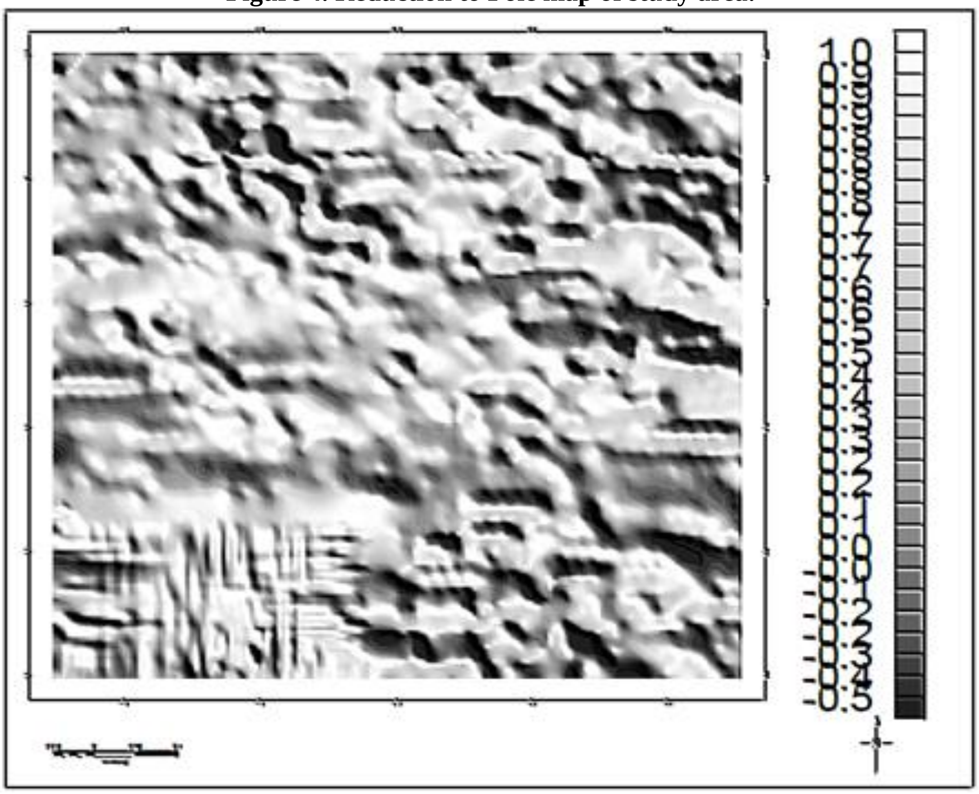

Figure 5. Shaded relief map of study area.

For the Spectral determination of depth to magnetization, the study area was divided into four blocks containing 4 x 4 (A1 to D4) data points as revealed in figures 6 (a – d). The estimated depths to magnetic basements are highlighted as D_1 and D_2 in table 1. The first layer depth (D_1) is from the shallower sources and varies from 0.1km to 1.3km with an average of 0.64km while the second layer depth (D_2) varies from 2.2km to 5.5km with an average of 3.98km.

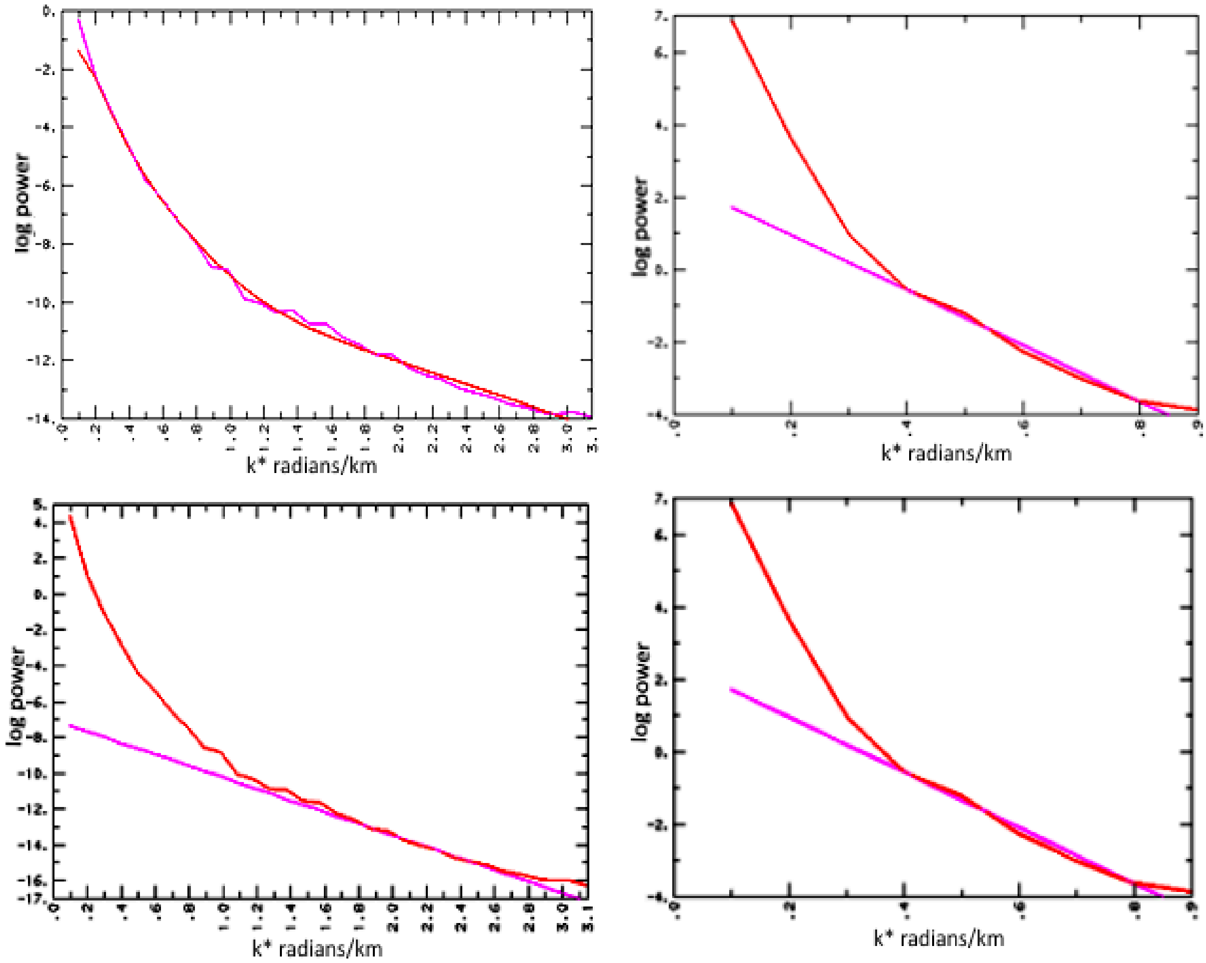

Figure 6a. Spectral plots of block A aeromagnetic sheet.

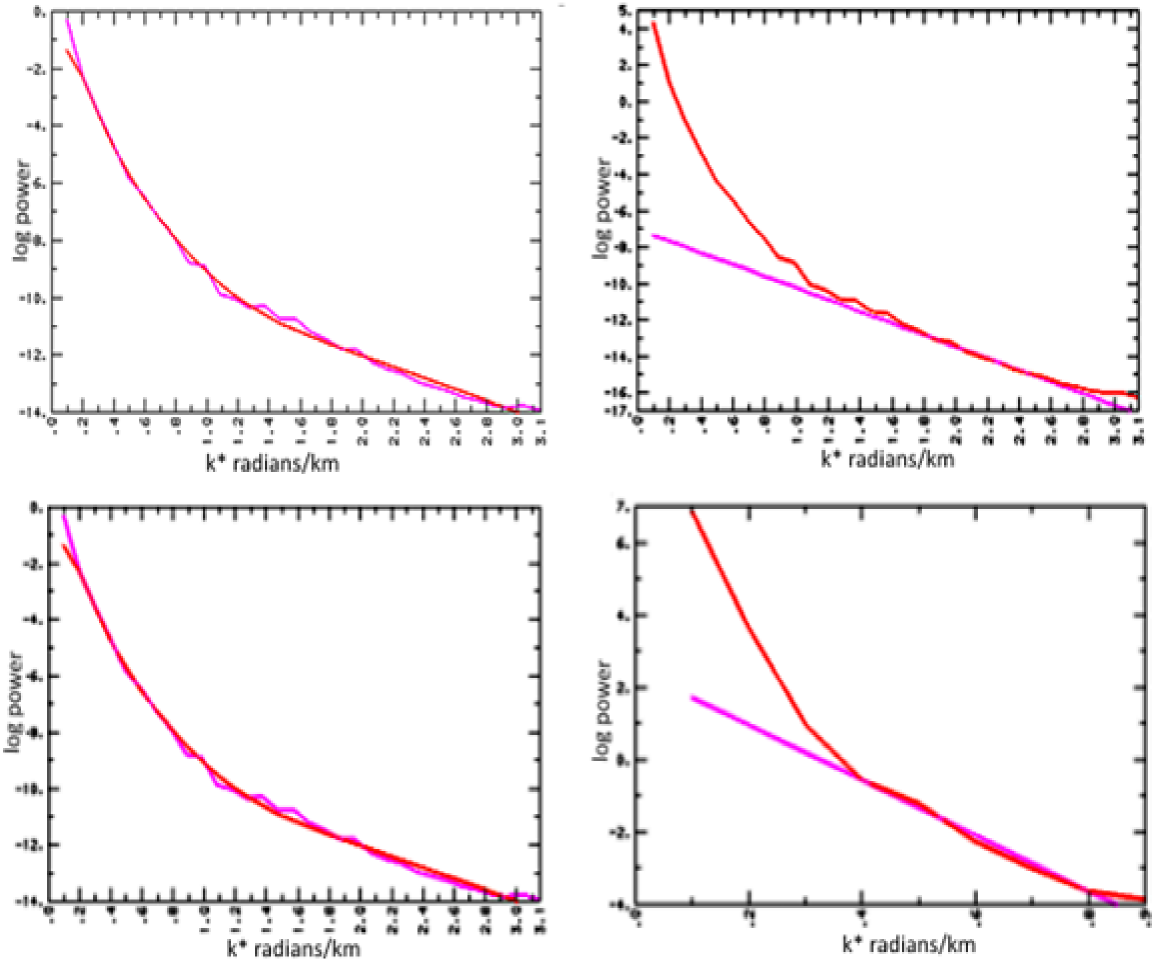

Figure 6b. Spectral plots of block B aeromagnetic sheet.

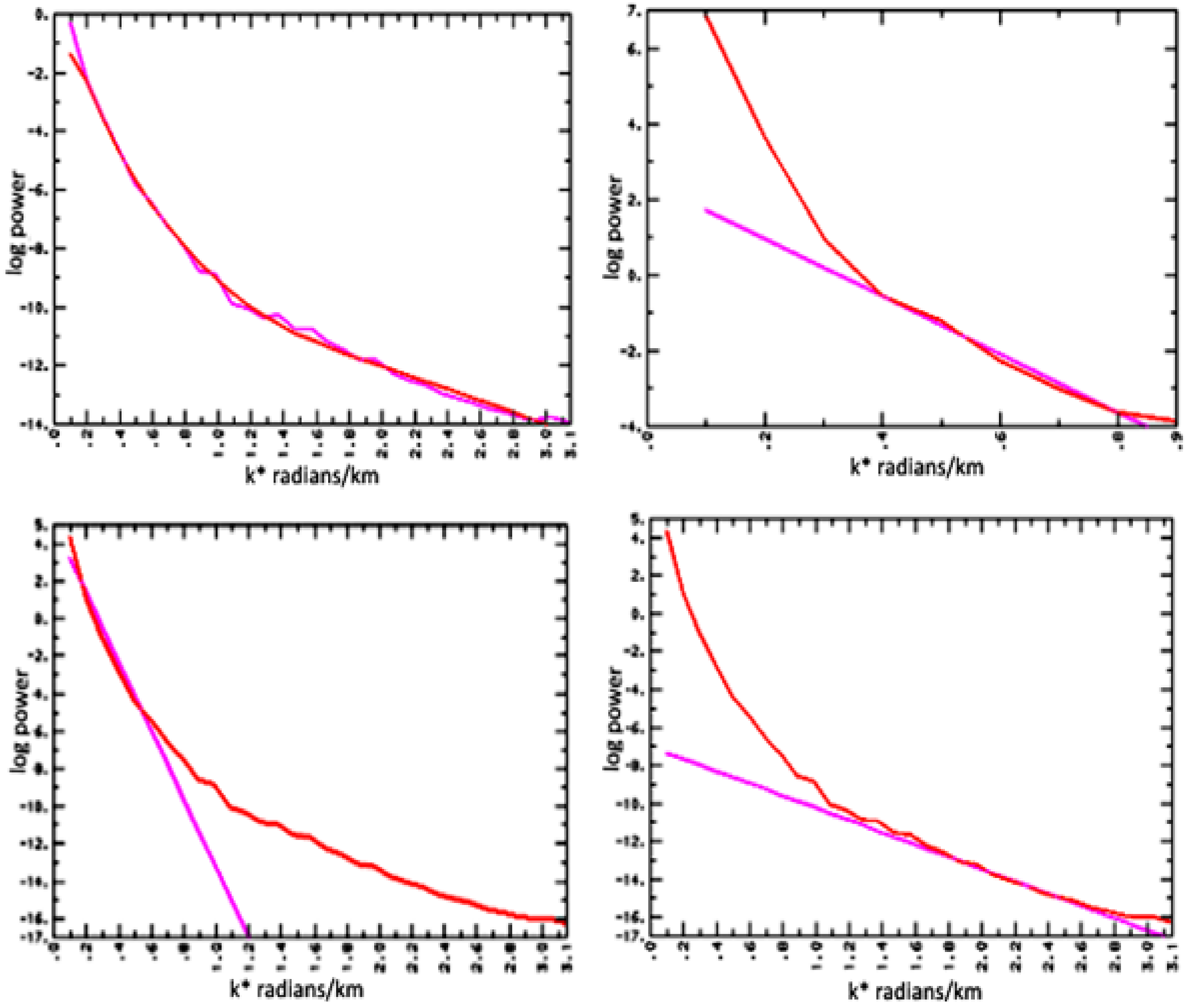

Figure 6c. Spectral plots of block C aeromagnetic sheet.

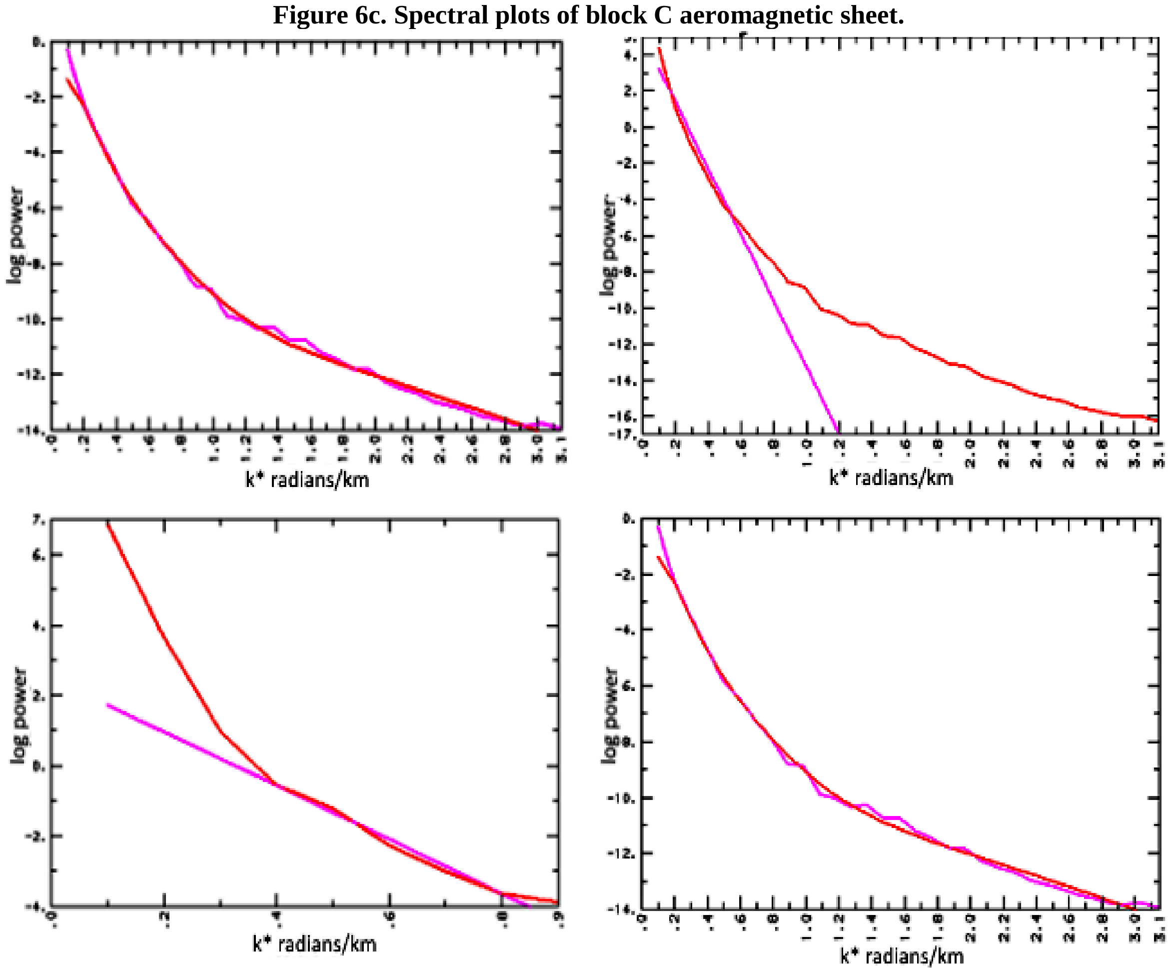

Figure 6d. Spectral plots of block D aeromagnetic sheet.

Table1. Summary of Spectral Estimation of Basement Depths in the Study Area.

SPECTRAL BLOCK	LONGITUDE		LATITUDE		DEPTH (KM)	
	X_1	X_2	Y_1	Y_2	D_1	D_2
A1	11.50	11.75	9.00	9.25	1.2	3.6
A2	11.50	11.75	9.25	9.50	0.6	4.1
A3	11.75	12.00	9.00	9.25	0.9	4.3
A4	11.75	12.00	9.25	9.50	0.5	4.2
B1	11.50	11.75	9.50	9.75	0.9	3.7
B2	11.50	11.75	9.75	10.00	0.8	2.2
B3	11.75	12.00	9.50	9.75	0.2	3.2
B4	11.75	12.00	9.75	10.00	1.1	4.2
C1	12.00	12.25	9.00	9.25	0.7	5.2
C2	12.00	12.25	9.25	9.50	0.9	2.2
C3	12.25	12.50	9.00	9.25	0.7	3.2
C4	12.25	12.50	9.25	9.50	0.5	4.4
D1	12.00	12.25	9.50	9.75	0.4	5.2
D2	12.00	12.25	9.75	10.00	1.3	5.5
D3	12.25	12.50	9.50	9.75	0.1	3.4
D4	12.25	12.50	9.75	10.00	0.5	5.0

The D_1 depth refers to depth to shallow magnetic basement owing to intrusive bodies or near-surface basement rocks probably isolated bodies of ironstones formation concealed within the sedimentary deposits. These depths are contoured to fascilitate interpretation, the result is presented in fig. 7. The D_2 basement depth (sedimentary thickness) contour map of the study area is shown in fig. 8. This is in conformity with the predicted area of sedimentary deposits from Fig. 2 and also in tandem with the stated diagonal depositional sequence that formed the Benue trough (as depicted in the NE-SW increase in sedimentary thickness seen in fig. 8)

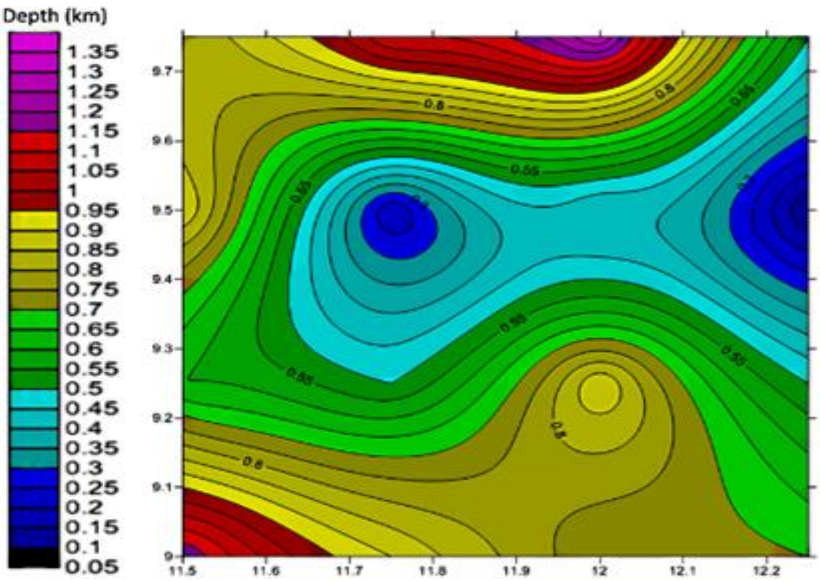

Figure 7. Contour map of D_1 depth values in the study area.

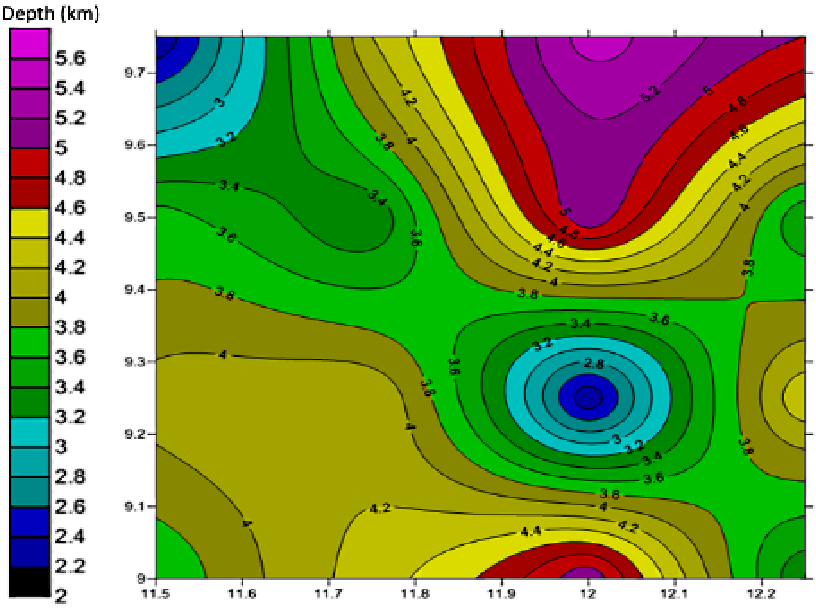

Figure 8. Sedimentary thickness contour map of study area.

The standard Euler deconvolution method of depth solutions was carried out which reveled deep seated magnetic basement rocks, implying thick sedimentary deposits in the range of 2km to 3km as shown in fig. 9(a-c). The circumscribed regions indicate regions of possible sizeable sedimentary thickness while clusters (tiny circles) indicate possible geologic features like faults, joints and massive intrusions. Point/localized clusters are solutions to probable deep seated intrusions (e.gs. points "P") while lengthy clusters (e.gs. points "L") indicate possible faults and joints – as highlighted in fig. 9c.

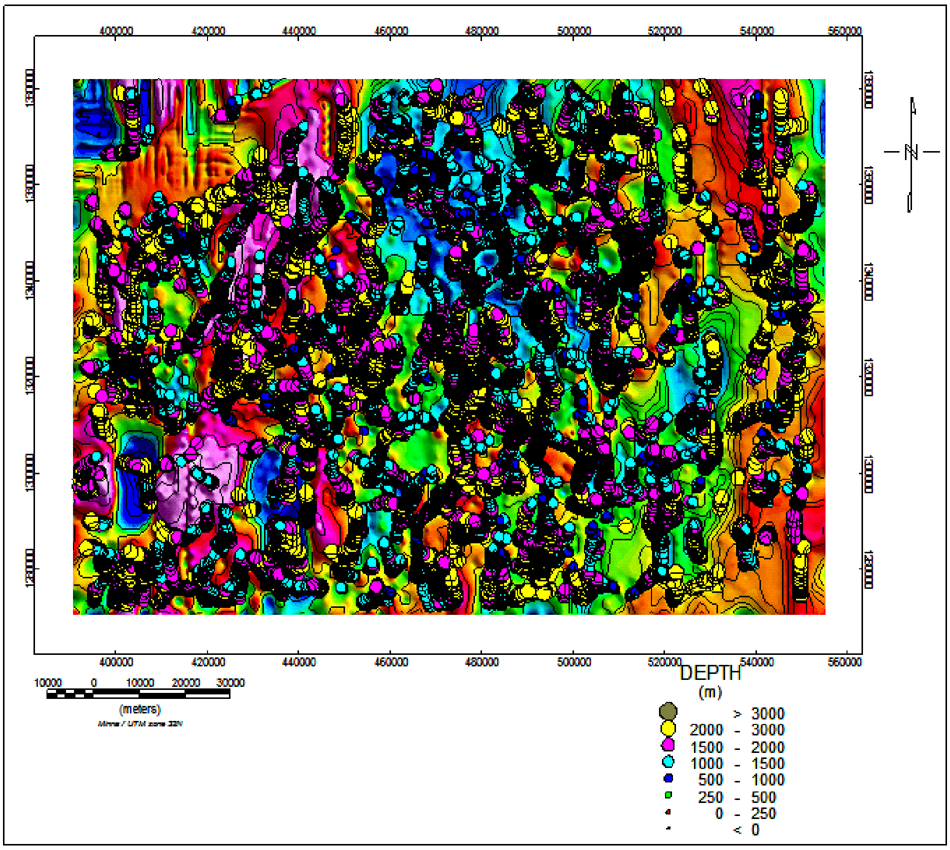

Figure 9a. - Standard Euler map (S.I. = 1) of study area.

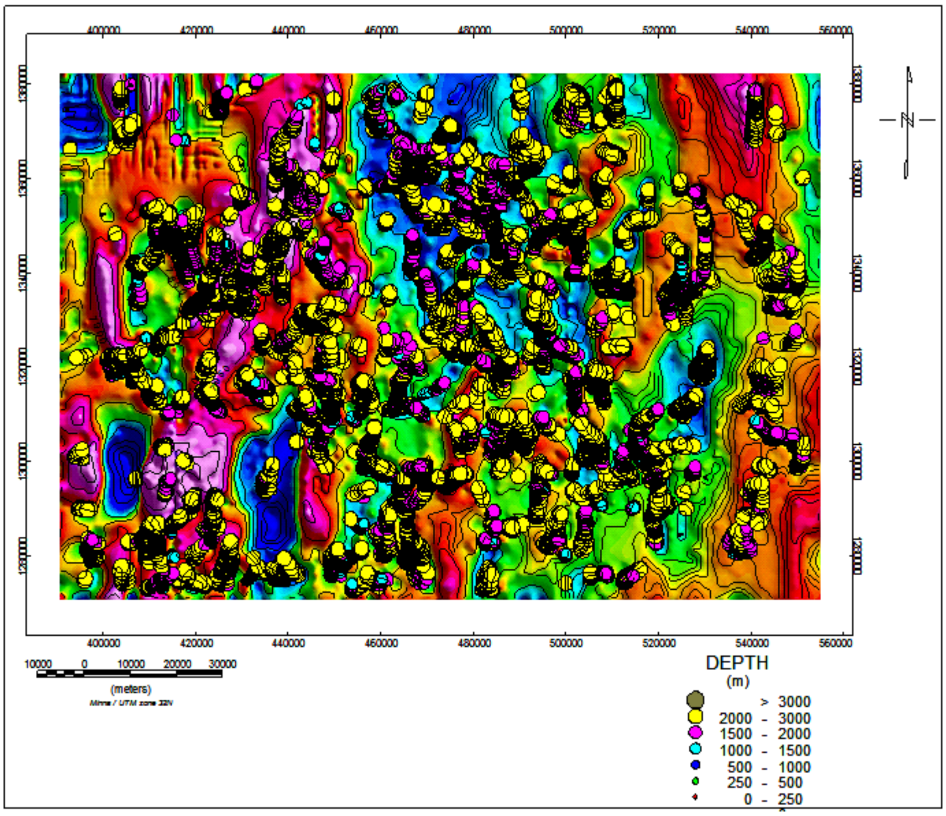

Figure 9b. -Standard Euler map (S.I. = 2) of study area.

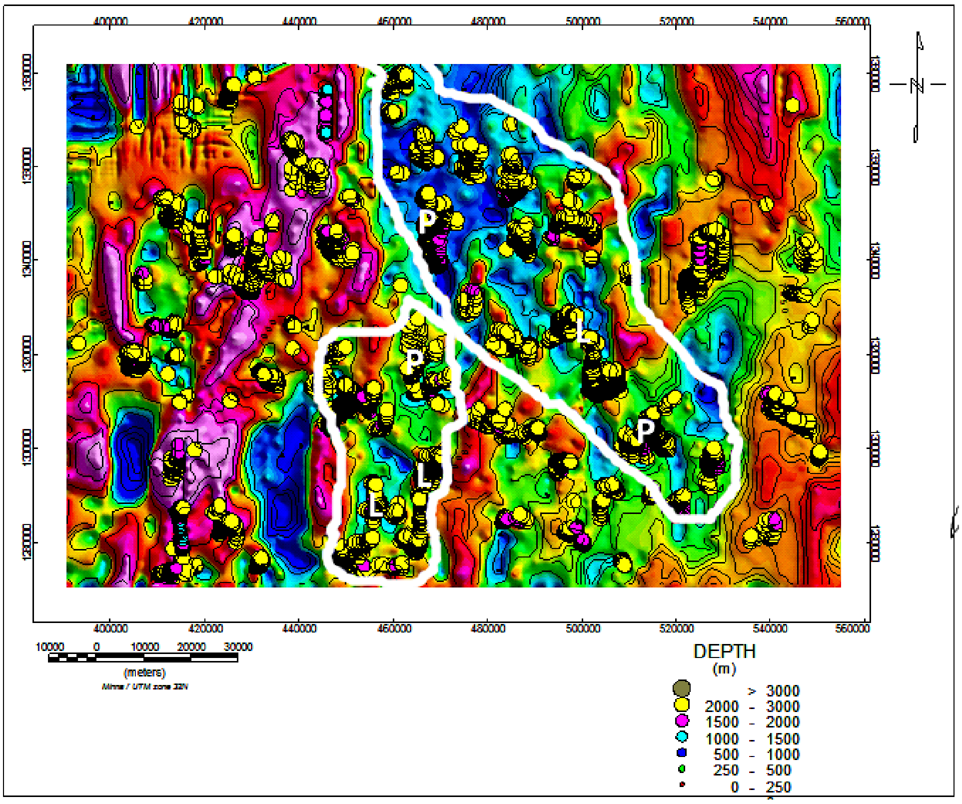

Figure 9c. -Standard Euler map (S.I. = 3) of study area.

Conclusion

The estimation of sedimentary thickness (D_2) that was carried out in this study was performed using Spectral analysis method from which the thickness contour (fig. 8) developed revealed that the sedimentary thickness varies from 2.2km to around 5.2km – see table 1 as well. It is thickest in the NE region but the overall average is 3.98km. A verification was performed using the Euler deconvolution method especially fig. 9c which revealed clusters of Euler depth solutions within the low magnetic zones of interest – suspected to have deep seated igneous basement and hence thick sedimentary deposit. The depth estimate of the clusters is between 2km to above 3km (in agreement with the range from the Spectral analysis approach).

Combining both methods means that a sedimentary depth of up to 4km (to 5km) could be possible which could support petroleum entrapment. It is thus suggested that further geophysical investigations using seismic approach be carried out especially in the Yola, Mayo Balewa and Bubila regions which showed possibility of thick deposits as well as possible geologic features that could support hydrocarbon accumulation.

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