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COMBINED DEPTH ANALYSIS OF NIGER DELTA BASIN USING SPECTRAL METHOD AND 3D EULER DECONVOLUTION OF GRAVITY DATA.

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Abstract: The gravity method is one of the oldest methods of geophysics and still finds relevant use in providing answers to questions about the subsurface. Especially, when gravity data is subjected to filtering, transforming and enhancement techniques. Its usefulness as a reconnaissance tool in the search for oil and gas is still very valid. This study provides the depth to basement estimates of the Niger Delta basin, consequently revealing the extent of sedimentary cover. The volume of this cover in any basin answers pertinent questions regarding the possibility of generation, accumulation and preservation of oil and gas within it. Gravity data obtained from the Nigerian Geologic Survey Agency were subjected to Spectral Depth Analysis and 3D Euler Deconvolution transformation procedures using the 'Oasis Montaj version 8.4' software. Plots obtained from the Spectral analysis were further analyzed by determining slopes of their various portions. Depth maps for deep and shallow sources of the study area were generated from the values eventually obtained. Euler map of the study area was also obtained using a 0.0 structural index. The spectral depth analysis indicates that the depths range from 0.4 to 4.7 km while those obtained from the Euler Analysis suggests that a good portion of the delta are characterized by depths ranging from 5 – 15 km.

Keywords: Basement, Depth, Euler, Gravity and Spectral

1.1 INTRODUCTION

Depth to basement information is useful for hydrogeological studies ([16]; [12]; [1]; [2]), tectonic trends analysis ([6]; [23]; [11]), hydrocarbon exploration ([4]; [22]) and so on. For instance, hydrogeologists need to estimate cover thickness to facilitate the mapping of hydrostratigraphic units of groundwater exploration; it is also useful to produce realistic potential field geophysical models; and the information is important to evaluate the accessibility of rocks with economic potential. Significantly, determining the sedimentary volume in any basin considered for petroleum exploration is an essential first step. The presence and volume of Hydrocarbon within a basin is contingent upon the volume of sediments. Therefore, to answer questions about the economic validity of such a venture and manage exploration risk ([26]), sedimentary volume dependent on depth to basement values must be estimated.

There has been extensive use of both Spectral Analysis and 3D Euler deconvolution for depth determination employing potential data. For example, [9] and [18]. Additionally, combining more than one method is reasonable as this helps to obtain more accurate depth estimates ([13]). These methods are also often used to depict basement undulations when used with a moving window approach.

The control of basement on an overlying sedimentary section is very well known as exemplified in a study by [14]. Two types of basement control including, basement topographic control and reactivated basement faults or shear zones, were identified.

Without a doubt, an imprecise depth value of the Niger Delta basin is put at 9 – 12 km in sedimentary thickness ([10]), if regions beyond the current reservoirs are to be further explored for unknown petroleum systems, a detailed depth analysis is necessary across the delta.

2.1 GEOLOGICAL SETTING

The Niger-Delta Basin shown in Figure 1 of Nigeria is a prolific petroleum producing basin located on the west coast of Central Africa in the gulf of Guinea bounded to the south by the Atlantic. It is located between latitude 4^o and 6^oN, longitude 3^o and 9^oE ([21]). The delta spreads over a land area in excess of 105,000 km ([5]). The cover within this study area is made of synrift clastics of the Late Cretaceous, Paleocene Carbonates, Paleocene to Pliocene marine shales, Early Eocene to Quartenary deltaic deposits and Oligocene to Recent alluvial deposits all otherwise classified into three broad formations, namely, Akata Formation, Agbada Formation and Benin Formation (Fig. 2).

The Benin Formation is at the apex of the sequence and consists essentially of fresh water – bearing continental sands and gravels. Offshore they become thinner and disappear near the shelf – edge ([10]). The Agbada Formation underlies the Benin Formation and consists primarily of sand and shale and is of fluvio-marine origin. It alternates fine and coarse clastics resulting in several reservoir – seal couplets and is the usual limit of wells drilled in the area having a thickness of about 3000m. The Akata Formation is composed of shales, clays and silts at the base of the known delta sequence and it is described as the source rock of the basin ([25]). The Formation contains a few streaks of sand, possibly of turbiditic origin. The thickness of this sequence is not known for certain, but may reach 7000m in the central part of the delta ([25]).

The Agbada formation of the Delta is known as the reservoir formation of the Tertiary petroleum system but recent forays beyond the formation revealed hydrocarbon presence. Suggesting that Late Cretaceous clastics of the system perhaps serve as hydrocarbon habitat. This work is therefore a precursor to better understand the basement topography of the study area and how it favors the possible presence of other petroleum systems.

Both the Spectral Depth Analysis and 3D Euler Deconvolution were applied to the gravity data (Fig. 3) of the Niger Delta Basin to determine the depth to basement, delineate boundaries and calculate source depths within the study area.

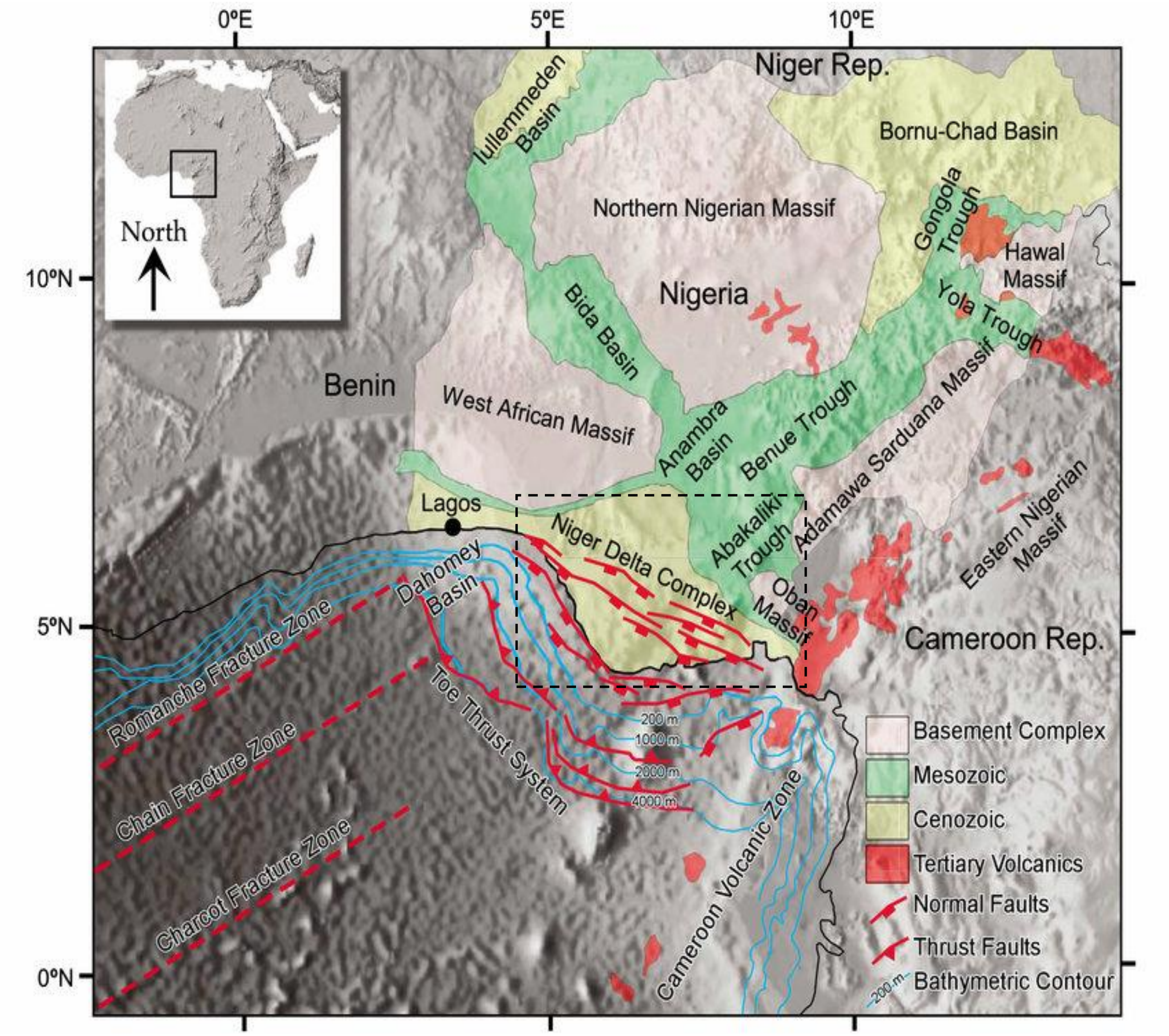


Figure 1: Map of the Niger Delta showing province outline ([8]).

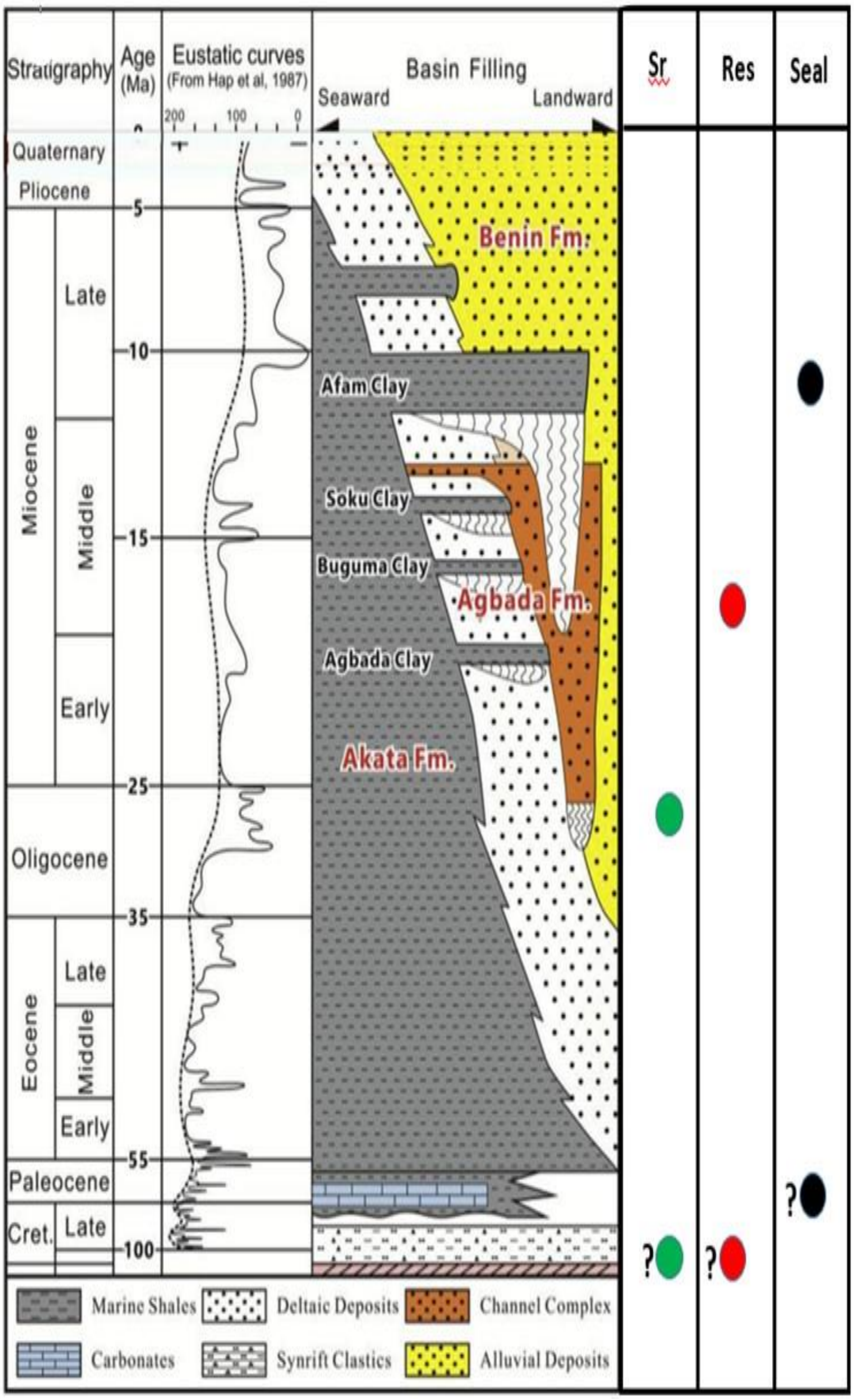


Figure 2: The Stratigraphic Column of the Niger Delta with source (Sr), Reservoir (Res), and Seal displayed (Modified after [30]).

3.1 MATERIALS AND METHODS

High resolution airborne gravity data for this work were obtained from the Nigerian Geological Survey Agency ([20]). The sensor height for the acquisition of the data was at 570 m above sea level with a flight line spacing of 4 km, flown at a flight line direction betwee n 0^{o} and 180^{o}. Projection method used in processing the data was the Universal Transverse Mercator (UTM) and the WGS 84 as Datum. The Spheroid model used was the Clarke 1880 (modified), 33ºE Central Meridian, a scaling factor of 0.9996, a 500,000m X Bias, a 0m Y Bias and 50m grid mesh size were the plotting specification. The data were collected in the year 2010 by Fugro Airborne Surveys.

The Bouguer Anomaly (BGA) obtained in grid format were then subjected to the Spectral Depth Analysis and 3D Euler Deconvolution procedures using Oasis Montaj Version 8.4 software.

3.2 SPECTRAL ANALYSIS

The rapid decay of potential anomalies with distance from source allows for basement depth estimation by computing their power spectra in a technique known as the Spectral Analysis. Spectral analysis of potential field data has been used extensively over the years to derive depth to certain geological features ([19], [27], [15], [7], and [17]). The spectral depth analysis was performed grid – wisely in blocks (Fig. 4) following the steps in Fig. 5 below.

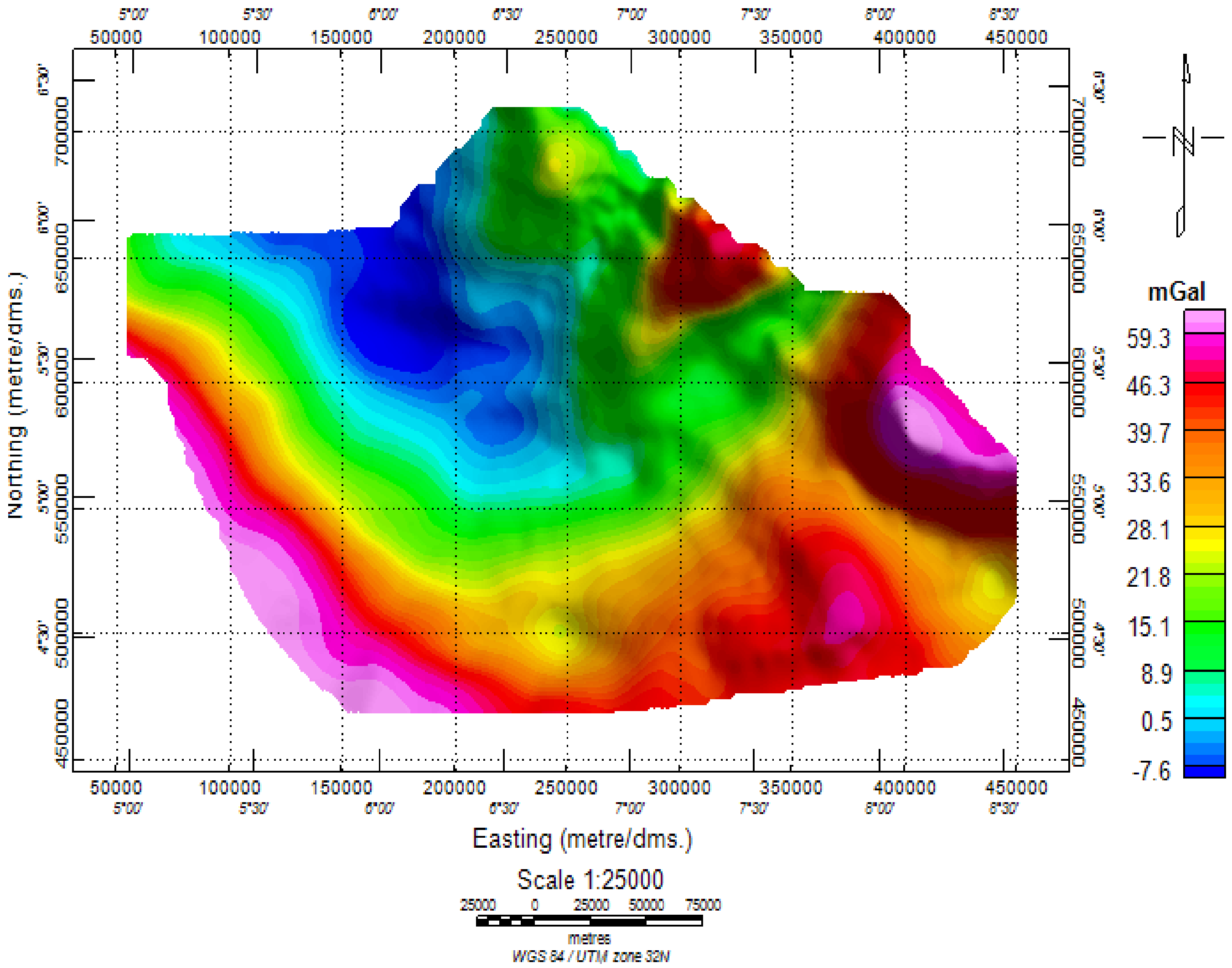


Figure 3: Bouguer Anomaly of the Niger Delta.

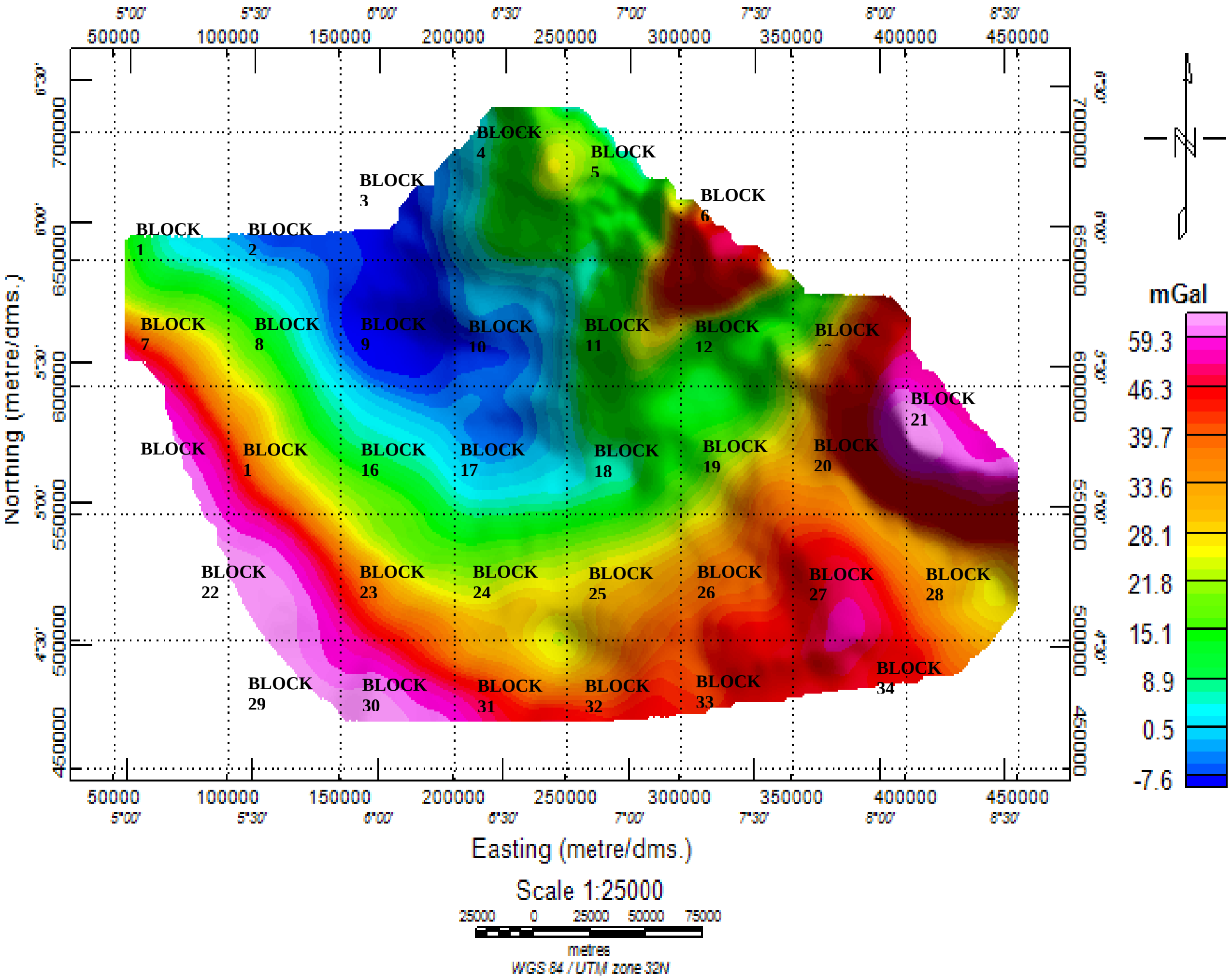


Figure 4: Selected Blocks for Spectral Analysis.

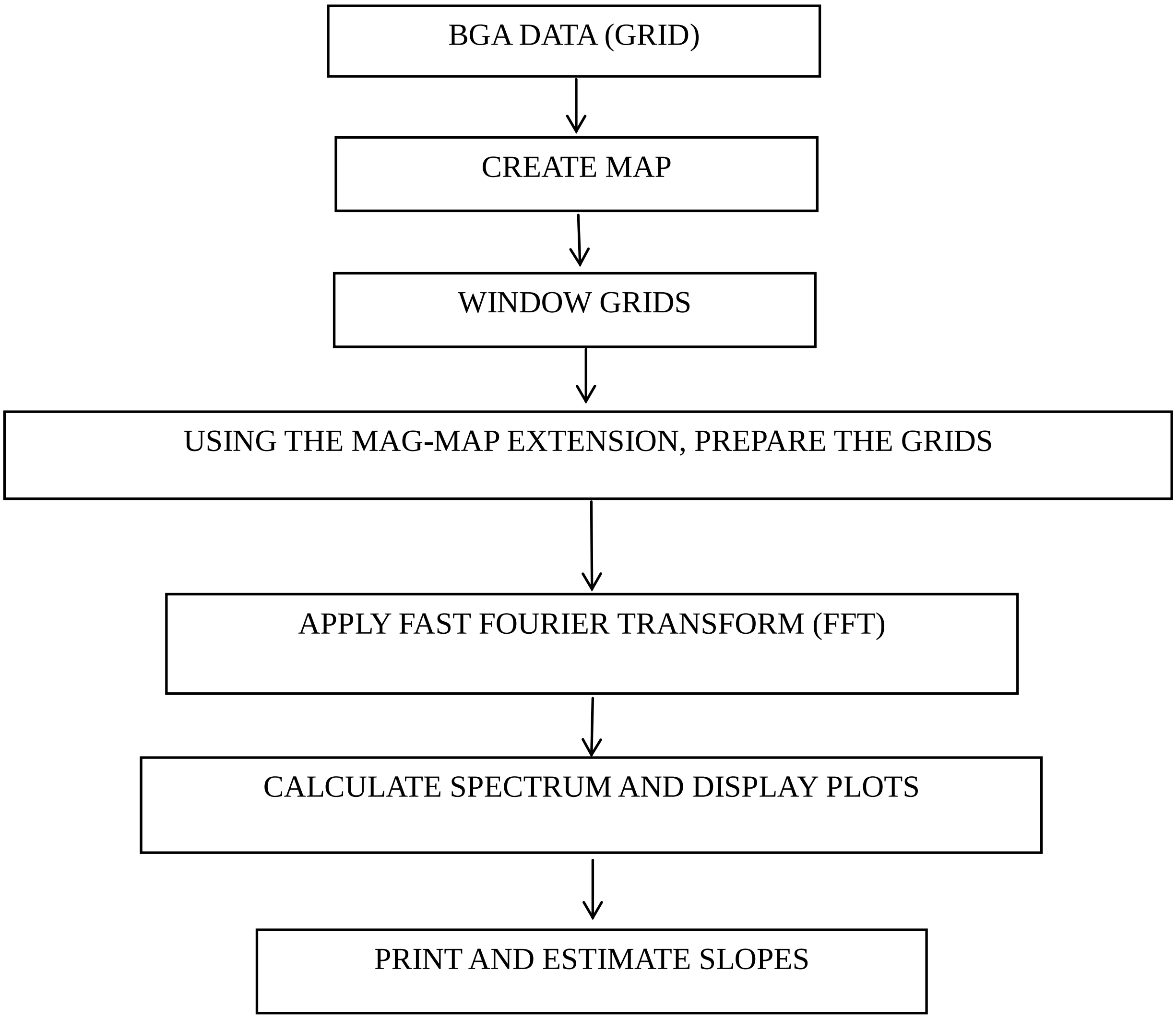


Fig. 5: Spectral Analysis Procedure (Using Oasis Montaj™)

It is essential to express the power spectrum of a gravity anomaly in relation to the average depth of the disturbing interface. It is also pertinent to note 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’s equation in 2D is,

$$F_g\left(x_j, z\right) = \sum_{j=0}^{n-1} A_k e^{i2\pi k x_j e^{\pm 2\pi k z}} \qquad 1.0$$

where wavenumber, k, is defined as $k = {}^{1}/_{\lambda}$ and A_k is therefore the amplitude coefficients of the spectrum.

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

Therefore, for $z = 0$, the equation can be written as,

$$A_k = (A_k)_0 e^{\pm 2\pi kz} \qquad 2.0$$

Then, the power spectrum is defined as,

$$P_k = (A_k)^2 = (P_k)_0 e^{\pm 4\pi kz} \qquad 3.0$$

Taking the logarithm of both sides,

$$\log_e P_k = \log_e (P_k)_0 \pm 4\pi kz \qquad 4.0$$

The plots obtained some of which are displayed in Figures 6, 7 & 8 are those of $\log_e P_k$ against wave-number k in order to obtain average depth to the disturbing interface. Computing the slopes of the deep and shallow segments, the depths of anomalous sources can be determined using the equation 5.0 below:

$$h = \frac{\Delta P}{4\pi\Delta k} = \frac{m}{4\pi} \qquad 5.0 \qquad ([3])$$

where h is the average depth and m is the slope.

The longitude and latitude of individual grids along with their estimated depths for both shallow and deep sources are presented in Table 1.0. Using these parameters, depth maps (Figs. 9 & 10) were then generated.

To get a sense of the topography across the basement, 'deep' depth values were plotted across blocks (Fig. 11).

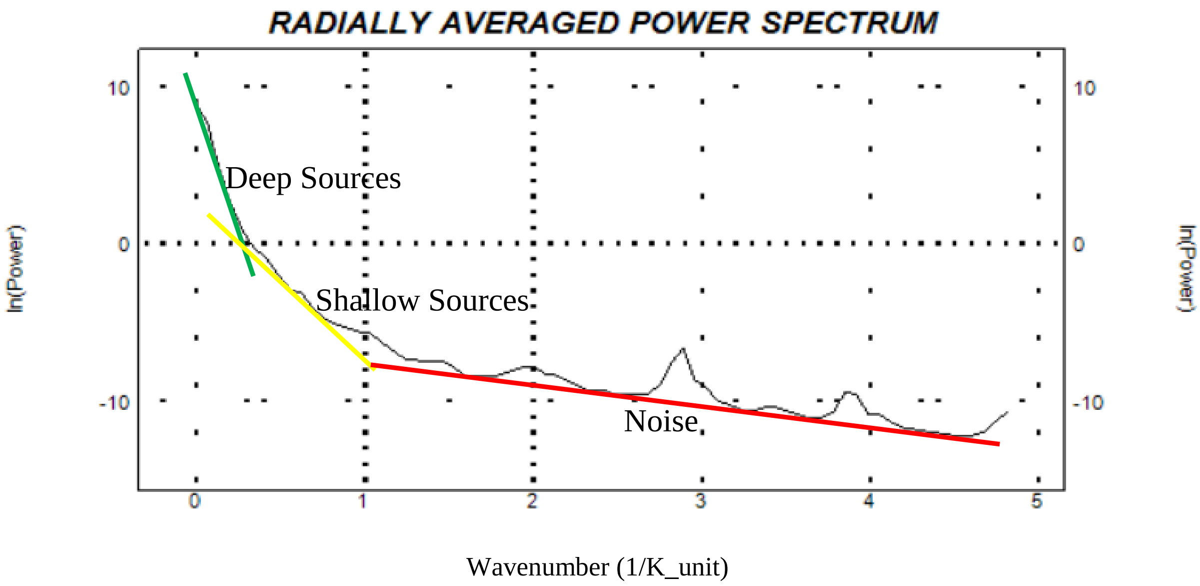
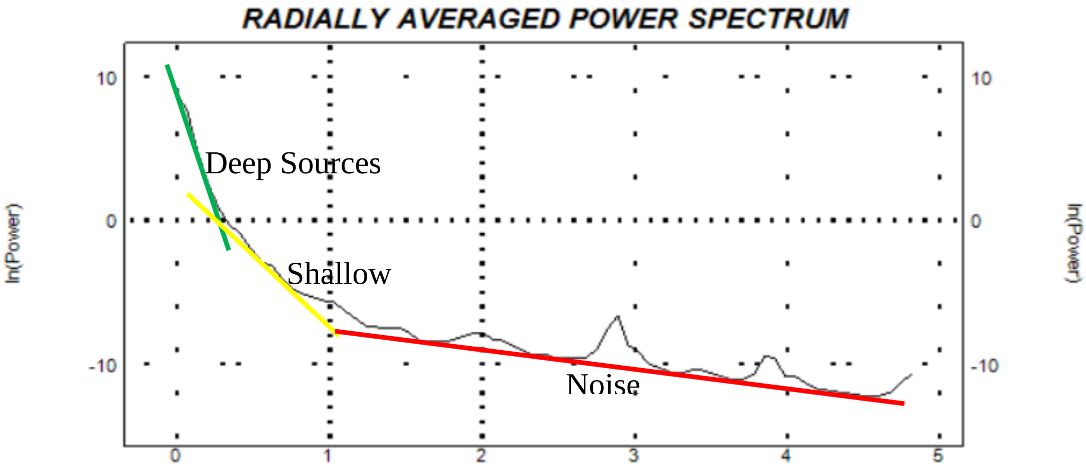
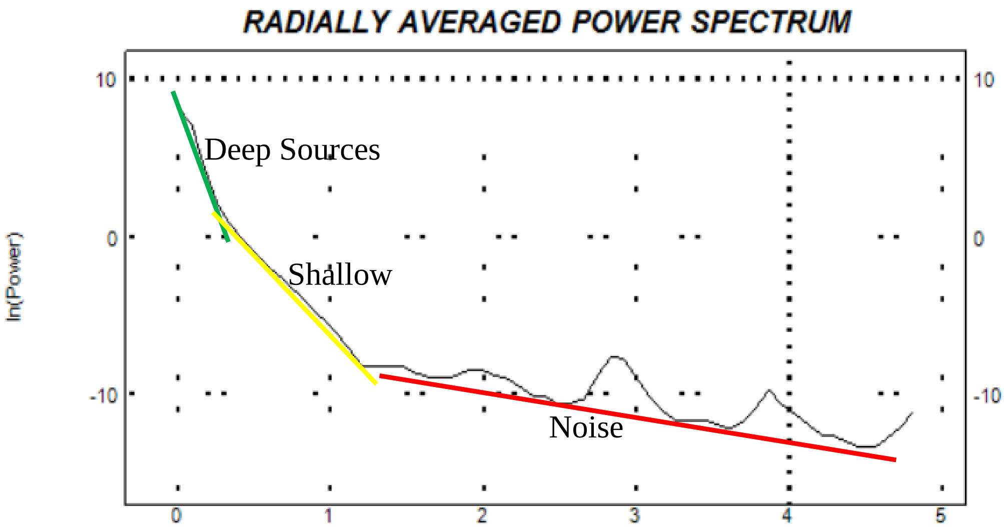


Figure 6 : Spectrum plot of Block 1



Wavenumber (1/K_unit)

Figure 7 : Spectrum plot of Block 2



Wavenumber (1/K_unit)

Figure 8 : Spectrum plot of Block 3

TABLE 1: Shallow and Deep Depths Estimated From Each Block

X (m)	Y (m)	Block	DEEP DEPTHS	SHALLOW DEPTHS
75750.75	655972.6	1	2.4	0.7
125372.5	655972.6	2	1.6	0.9
176569.5	658335.5	3	1.8	1
225403.6	672513.2	4	1.3	0.5
235643	707957.2	5	2.1	1
271087.1	670937.9	6	2.7	0.7
311257.1	660698.5	7	2.7	0.7
75750.75	629192.6	8	3.6	0.6
123797.2	625254.4	9	2.6	0.4
174994.2	626042	10	2.6	0.5
223828.3	623679.1	11	4.8	0.8
274237.7	624466.7	12	4	1
324647	623679.1	13	3.6	0.3
375056.4	618165.5	14	0.8	0.4
88353.1	581933.8	15	3.1	0.6
123797.2	577207.9	16	2	0.5
172631.3	574845	17	2.6	0.5
223828.3	576420.3	18	3.4	0.5
273450	575632.6	19	3	0.4
325434.7	578783.2	20	4	0.5
375056.4	576420.3	21	5	0.6
423102.9	574057.3	22	4.8	0.4
127735.4	526798.5	23	4	0.6
174994.2	522860.3	24	3.2	0.8
223040.6	524435.6	25	2.9	0.4
275813	526798.5	26	2.6	0.6
324647	526010.9	27	2.6	0.5
374268.8	522860.3	28	4	0.6
423102.9	524435.6	29	2.9	0.4
168693	486628.6	30	3.8	0.6
225403.6	485840.9	31	2.4	0.53
274237.7	485053.3	32	3.6	0.8
324647	488991.5	33	2.7	0.4
384508.2	494505	34	3	0.9

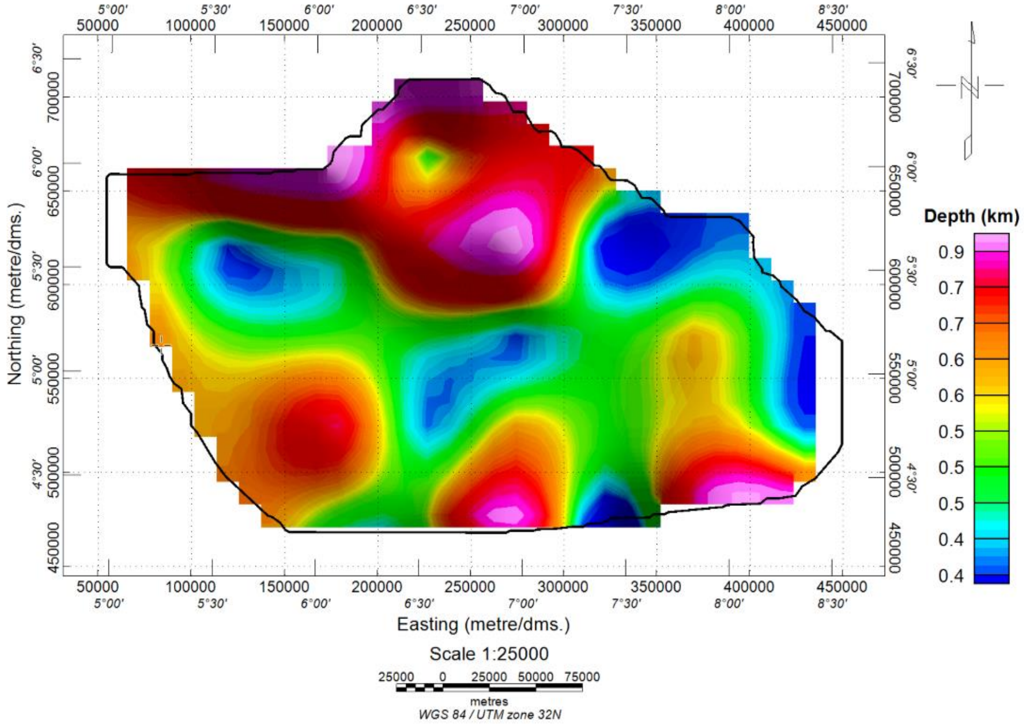
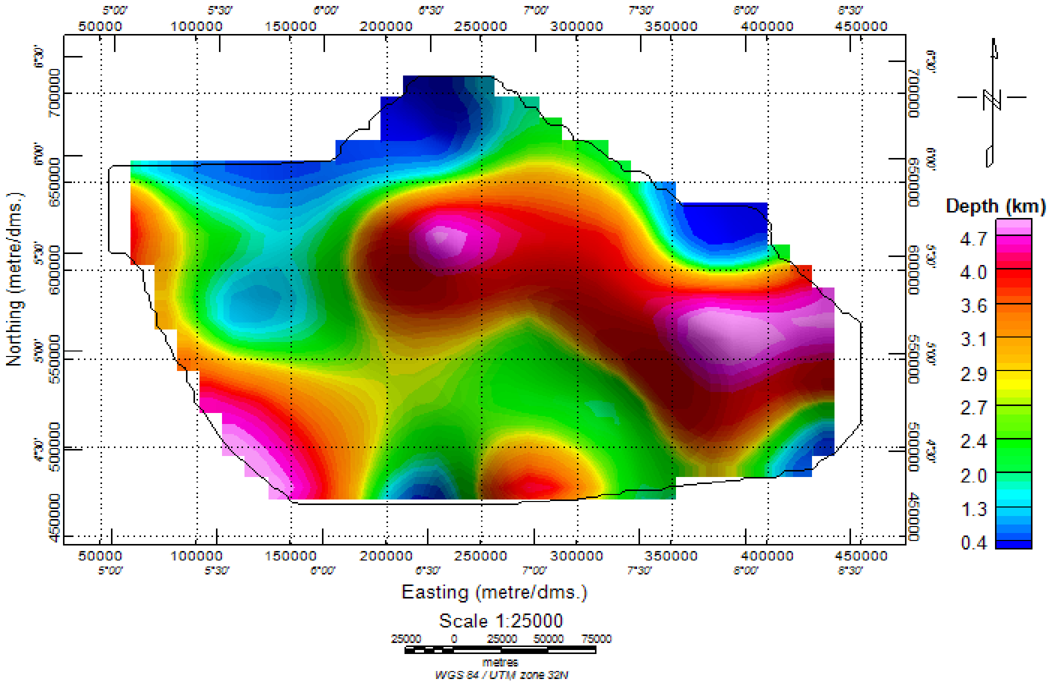


Figure 9: Spectral depth (Shallow).



Figue 10: Spectral depth (Deep).

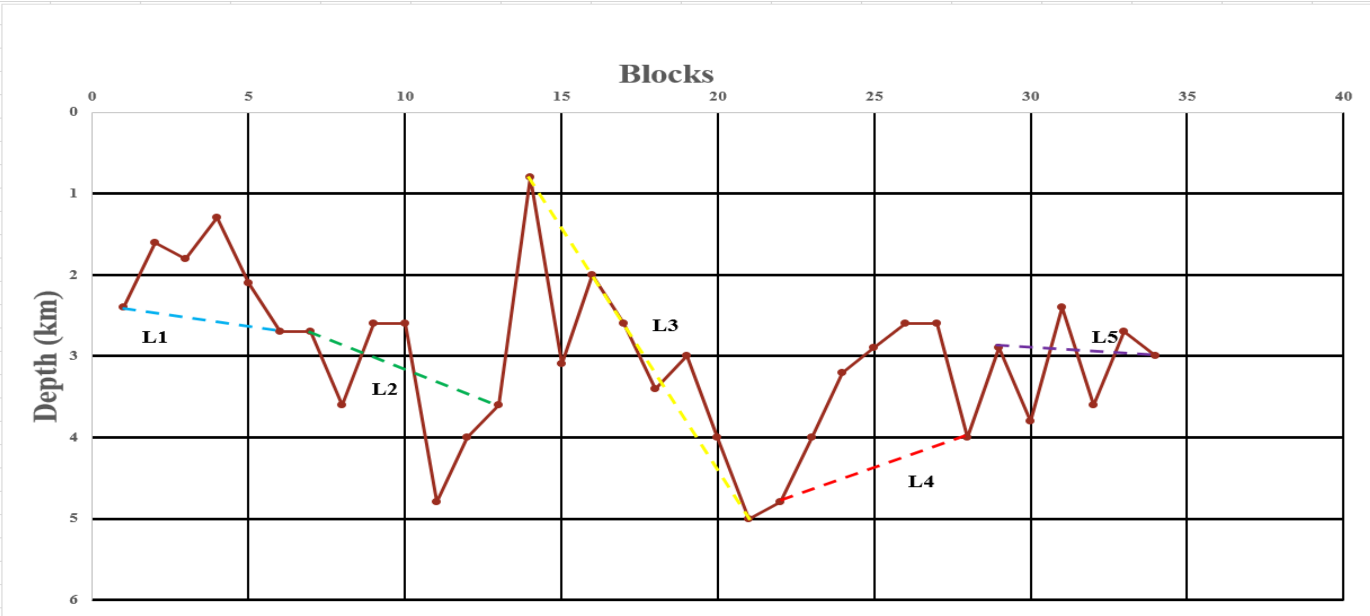


Figure 11: Basement topography plot from 'deep' depth values. L1 to L5 represents transects across blocks.

3.3 EULER DECONVOLUTION

This method is a depth weighing technique which relates potential field and their gradient components to the location of the source of an anomaly, with the degree of homogeneity expressed as Structural Index. The Euler deconvolution as described by [24] and [29] obtains its solutions by inverting Euler's homogeneity equation (Equation 6.0) over a window of data at every grid point.

$$(x - x_o)\frac{dT}{dx} + (y - y_o)\frac{dT}{dy} + (z - z_0)\frac{dT}{dz} = N(B - T) \qquad 6.0$$

where $(x_{o,} y_o, z_0)$ is the location of a gravity field source, whose Bouguer 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. Equation (6.0) was solved by calculating the anomaly gradients for various areas of the anomaly and selecting a value of N = 0.0. This was done on the Oasis montaj 8.4 version software as shown in Fig. 12. Gridding interval of half of the line spacing was used in order to improve recognition of basement anomalie

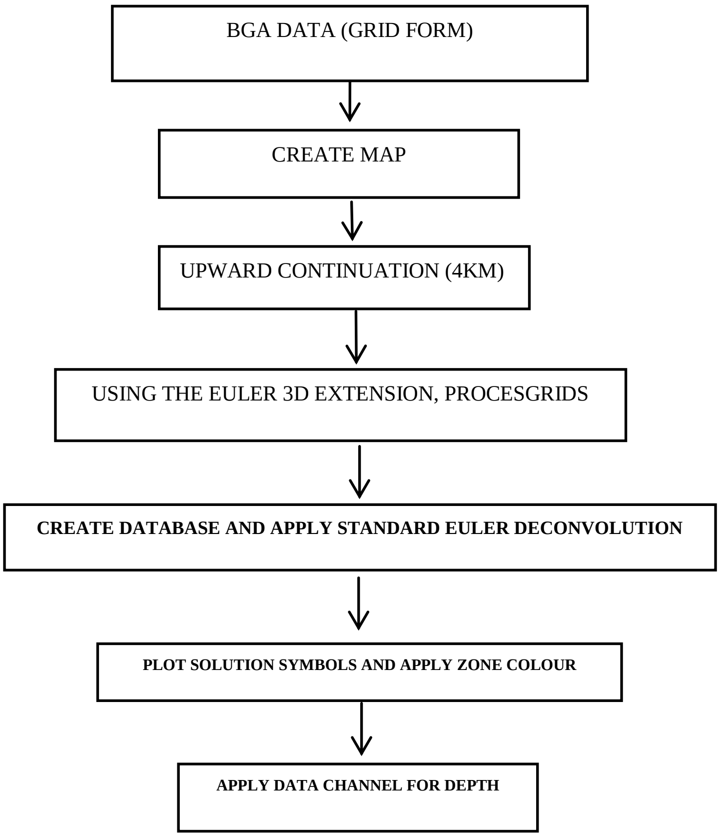


Figure 12: 3D Euler Deconvolution Procedure on Oasis Montaj^{TM}.

A total of approximately 11,781 points were obtained. Results with tightest cluster around apparent sources always indicate the best solutions and were therefore accepted. These were then windowed to select the most accurate results. This was done by adjusting the acceptance limits of solution depths appropriately- The vertical uncertainty, horizontal uncertainty, and the offsets along X and Y.

4.1 RESULTS AND DISCUSSIONS

4.1.1 SPECTRAL DEPTH ANALYSIS

The spectrum plots some of which are presented in Figures 6, 7 and, 8 and slope for different portions of the curve are estimated. Table 1 shows 'shallow' and 'deep' depths as estimated and correlated to the longitude and latitude for 34 blocks and these data were subsequently used to generate depth maps (Figs. 9 and 10). Generally, the depths range from 0.4 to 4. 7 Km. The North – western region of the study area of the spectral depth map for 'deep' sources (Fig.10) is characterized by shallow depths. This coincides with the region described by [10] as the Onitsha high which report thin sedimentary layer covers the region (< 1.1 km to 2.7 km). The central to the South – Eastern portions however are characterized by deeper sources. The Akata formation have been reported to be deepest in these portions of the Delta. The southern part having significant depth to basement rocks have been reported to have sedimantary thickness in excess of 3 km earlier determined by the analysis of through well log analysis. The Euler map (Fig. 13) shows a good clustering over the edges of potential field sources, and depth trends largely agree with the Spectral analysis.

4.1.2 BASEMENT TOPOGRAPHY

An attempt is made at estimating the basement topography by plotting 'deep depth' values with respect to blocks (Fig. 11). The various transects that resulted in this profile are labelled L1 to L5. L1 is the transect across block 1 to block 6 (Fig. 4), L2 cuts across block 7 to block 13 (Fig. 4), L3 is for block 14 to block 21 (Fig. 4), L4 for block 22 to block 28 (Fig. 4) and L5 for block 29 to block 34 (Fig. 4). The topographical plot of the basement (Fig. 11) show pronounced undulations perhaps occasioned by faulting systems.

4.2 EULER 3D SOLUTION

The Euler solution map is presented in fig. 13. The depths obtained from the Euler Analysis suggests that a good portion of the delta are characterized by depths ranging from 10 – 15 Km. The depth variation across depobelts described by [28] which prograde southwesterly are easily recognizable on both the 'deep' spectral depth and Euler maps (Figs. 10 & 13). A thickening of sediments towards the shore is observed.

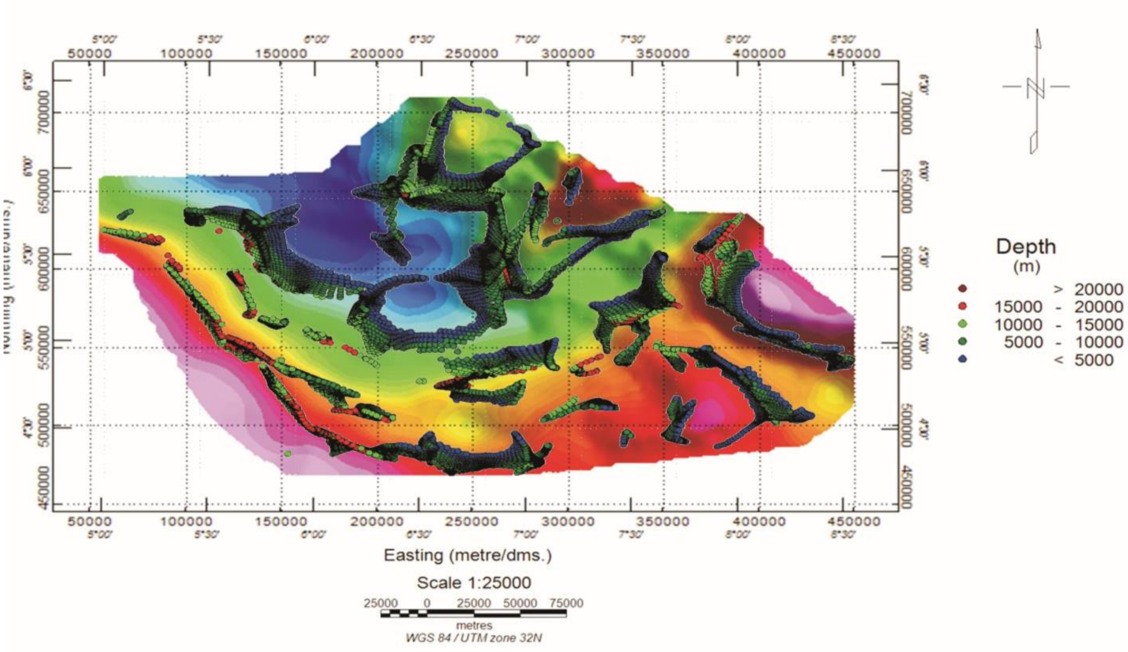


Figure 13: Euler solution map for BGA, structural index, N = 0.0

5.0 CONCLUSIONS

Spectral analysis and 3D Euler Deconvolution of gravity data of the entire Niger Delta has been carried out with the aim of determining depth/thickness of the sedimentary Basin, delineate boundaries and calculate source depths using the Oasis Montaj software.

The results from the spectral analysis technique of the study have shown that the area is characterized with an average sedimentary thickness of 2.8088 km for the deep sources and 0.607km for the shallow source models.

While the results from the Euler Deconvolution reveal that the depth to basement in the study area ranged from slightly less than 5 km to a little more than 15 km.

The huge discrepancy between the Euler solution and Spectral analysis could be due to the fact that the latter technique is better suited to solving near-surface problems.

However, the range of variations from both techniques are reflective of deep undulations across the basement surface. This suggests that the petroleum system plays may vary very much across the delta. The idea that Late cretaceous clastics within the delta host hydrocarbon deposits is therefore very probable.

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