Spectral Re-Evaluation Of The Magnetic Basement Depth Over Parts Of Middle Benue Trough Nigeria Using HRAM

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Abstract: The new high resolution aeromagnetic data have been used to re-evaluate parts of the Middle Benue Trough Nigeria using spectral analysis technique in order to appraise the hydrocarbon accumulation potential of the area. The regional field was separated with a first order polynomial using polifit program. The residual data was subdivided into 16 spectral blocks allowing spectral probe of 12.5km by 12.5km area for 15minute by 15minute windowing using OASIS MONTAJ software program. Two prominent magnetic depth source layers were identified. The deeper source depth values obtained ranges from 2.33km to less than 5.66km with an average depth of 3.65km as the magnetic basement depth while for the shallower sources, the depth values ranges from 0.07km to less than 0.42km with an average depth of 0.21km. The shallow depth source is attributed to the volcanic rocks that intruded the sedimentary formation and this could possibly be responsible for the mineralization found in parts of the study area. The significance of the magnetic depth value indicate that the sedimentary layer of the Albian Age, Coniacian – Turonian Age, and Turonian – Senonian Age is thick enough to generate hydrocarbon if other conditions are met.

Keywords: Spectral analysis, Middle Benue Trough, Magnetic anomaly, HRAM (high resolution aeromagnetic data), OASIS, MONTAJ, Magnetic basement depth, shallow depth source.

1.0 Introduction:

Aeromagnetic surveys flown in Nigeria in the 1970s with a flight line spacing of 2km, average terrain clearance of 150m, and a nominal tie line spacing of 20km have played a key role in understanding the country's regional geology, but due to their low resolution have become of limited use. The new high-resolution airborne survey carried out for the Nigerian Geological Survey Agency by Fugro airborne services in 2009 surveys flown at 500m line spacing and 80m terrain clearance is of higher resolution and in digital form (HRAM). This data was used to re-evaluate the basement depth of some parts the middle Benue trough using the spectral analysis technique. Among the major previous studies using old aeromagnetic data in Nigeria include Ofoegbu, (1984, 1985, 1986); Ahmed, (1991); Ofoegbu and Onuoha (1991); Onwuemesi, (1996), and so on. Nwachukwu, (1985) using geochemical technique considered the Middle Benue Trough to have high prospects for hydrocarbon within the trough. Mapping of magnetic basement depth beneath sedimentary cover is one of the key functions of aeromagnetic survey and its interpretations. This study therefore aims to appraise the hydrocarbon potential of the study area by accomplishing the following objectives: determination of sedimentary thickness within the study area, and magnetic basement topography through surface plots.

2.0 The Location and Geology of the Study area.

The study area is located in the Middle Benue Trough Nigeria and it lies within Latitude $7^0$00'N to $8^0$00'N and Longitude $8^0$50'E to $9^0$50'E, it's shown in Fig. 1. The tectonic evolution of the Benue trough originated from the separation of the African Continent from the South American continent in the Aptian (Grant, 1971). This separation led to the development of the Triple junction (RRF) characterized by South Atlantic Margin, the Gulf of Guinea and the Benue Trough. The Benue trough failed to develop into rift thereby creating an aulacogen (Olade, 1975). The Benue trough is part of the long stretch arm of the Central African rift system originating from the early Cretaceous rifting of the central West African basement uplift (Samuel et.al, 2011). The trough has been categorized into three different zones and they are: the Lower Benue Trough at the southern part, the Middle Benue Trough at the center while the Upper Benue Trough at the Northern part. The geology of the Middle Benue Trough is characterized by the presence of thick sedimentary cover of varied composition whose age ranges from Albian to Maastrichtian (Obaje, 2004). The Asu-River Group of marine origin is the oldest deposited sediment in this area followed by Ezeaku Formation, keana/Awe Formation, Awgu Formation and Lafia Sandstone which is the youngest sediment (Obaje, 2004). More on this geology could be found in the work of Cratchley and Jones, (1965), Burke *et al* (1970); Offodile, (1976); Osazuwa *et al* (1981) and Offoegbu (1985).

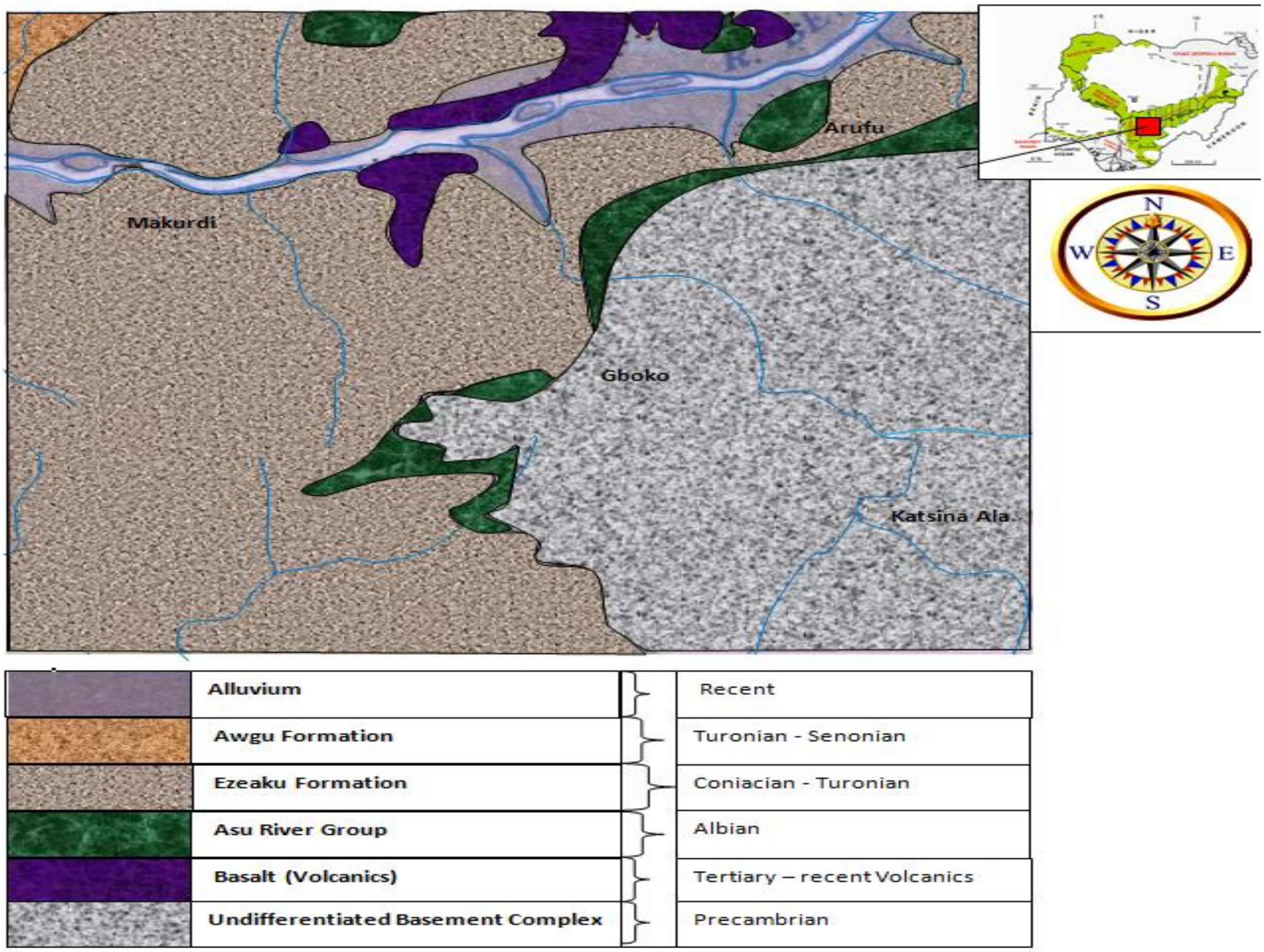


Fig.1Geological map of part of the Middle Benue Trough (Modified from NGSA, 2003)

3.0 Materials and Methods

Four sheets were assembled for this study (251,252,271 and 272) with each square block representing a map in the scale of 1:100,000. Each square block is about 55 x 55 km^2 covering an area of 3,025km^2 hence the total area studied was about 12,100km^2. The new high-resolution airborne survey carried out for the Nigerian Geological Survey Agency by Fugro airborne services in 2009 used for this study was flown at 500m line spacing and 80m terrain clearance using various survey parameters, software, and errors were corrected during surveys. This created a higher resolution data and in digital form too Fig2. This eliminated many errors usually associated with the old map.

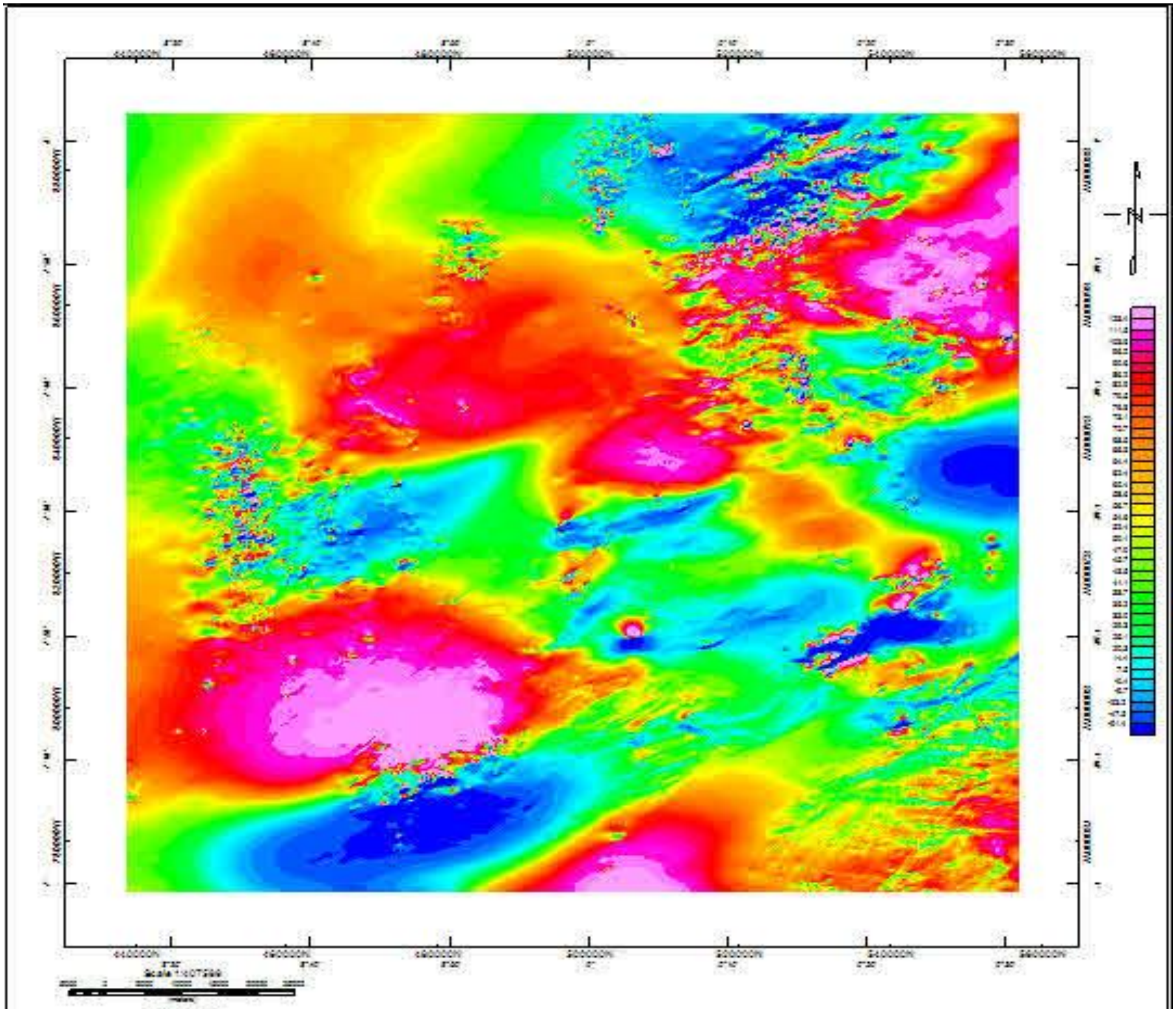


Fig. 2: Magnetic anommaly map of Makurdi-Gboko Axis of the Middle Benue Trough Nigeria

4.0 The theoretical background of Spectral Analysis

It has become a familiar concept to interpret aeromagnetic data with one or two dimensional spectral analysis consisting of various frequencies which characterize the anomalies. The application of the power spectrum method to potential field data was proposed by Bhattacharyya, (1966); and the determination of the anomalous body depth was given by Spector and Grant, (1970). This method has been used extensively by many researchers like Mishra and Naidu (1974); Ofoegbu and Onuoha, (1991). It is based on the principle that a magnetic field measured at the surface can be considered the integrals of magnetic signatures from all depths. The power spectrum (obtained through Fourier transform) of the surface field can be used to identify average depths of source ensembles. In its complex form, the two dimensional Fourier transform pair may be written as in eqn 1.1 and 1.2 (Bhattachrayya, 1966; Bath, 1974):

$$G(u,v) = \int\int_{-\infty}^{\infty} g(x,y)\, e^{i(Ux-Vy)} dxdy.$$

…………………………………1.1and

$$G(x,y) = \frac{1}{4\pi^2}\int\int_{-\infty}^{\infty} g(u,v)\quad e^{i(Ux-Vy)} dudv.$$

………………………………….. 1.2

Where u and v are the angular frequencies in x and y directions respectively.G(u,v) when broken up into its real and imaginary parts is given as in eqn. 1.3

G(u,v) = P(u,v) + iQ(u,v) …….……………..…………1.3

The energy spectrum is given by eqn 1.4

$E(u,v) = [G(u,v)]^2 = (P^2 + Q^2)$ ………..……...1.4

Relating the energy spectrum with the depth of the magnetic source:

Expression for the energy spectrum in polar form (Spector and Grant, 1970): follows that

If $r = (u^2 + V^2)$ and

$\theta = \arc\tan(u/v)$,

The energy spectrum $E(r, \theta)$ could be given by

$E(r, \theta) = 4^2 K^2 e^{-2hr} (1-e-tr) S^2 (r, \theta)$

$R^2 T(\theta) R^2 k(\theta)$.

Where; $S(r,\theta) = \frac{sin(arCos(\theta))}{arCos(\theta)} = \frac{sin(brCos(\theta))}{brCos(\theta)}$

$$R_T^2(\theta) = [n^2 + (1\,cos(\theta) + Msin(\theta))^2]$$

$$R_k^2(\theta) = [N^2 + (L\,cos(\theta) + Msin(\theta))^2]$$

$$<ECr> = 4\pi^2 K^2 <1^{-2tr}><(1-1-tr)^2><S^2(r)>$$

$$<S^2(r)> = \frac{1}{\pi}\int_1^{\pi} < S(r,\theta) > d\theta.$$

The ensemble average depth h enters only into the factor from the energy spectrum as shown by eqn 1.5

$<I-2hr> = \frac{1^{-2hrs} \sin h(2r\Delta h)}{4r\Delta t}$ …………………….……….........1.5

For depth estimations for magnetic field data this was approximated to eqn 1.6

$E(u,v) = \exp(-2hr)$ (Spector and Grant,1970) ………..…….1.6

The exp (-2hr) term is the dominant factor in the power spectrum. The average spectrum of the partial waves falling within this frequency range is calculated and the resulting values together constitute the redial spectrum of the anomalous field. If we replace h with Z and r with f; then

$\text{Log } E = -2Zf$ ……………………………………………..…1.7

Where Z is the required anomalous depth; and f frequency. Therefore the linear graph of logE against f leaves slope (m) =-2Z. The mean depth (Z) of the magnetic source is thus given by eqn 1.8

$Z=m/2$. ………………………………………………..……1.8

5.0 The Analysis (Quantitative interpretation)

The following operations were performed on the acquired digitized aeromagnetic data leading to the quantitative determination of depth to magnetic sources.

5.1 Regional-Residual separation: The regional field was removed from the total magnetic intensity data (observed data) to obtain the residual data with a first order polynomial using polifit program. The residual data was subdivided into 16 spectral blocks allowing spectral probe of 12.5km by 12.5km area for 15minute by 15minute windowing.

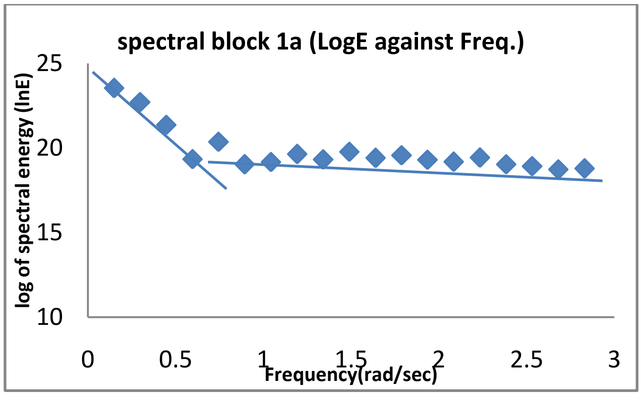
5.2 Divisions into Spectral cells and Windowing: For the purpose of easier handling of the large data involved, the four residual blocks of the study area was subdivided into 16 spectral cells (labelled 1a- 4d in table 1) of 12.5km by 12.5km in order to accommodate longer wavelength so that depth up to about 12km could be investigated. Each signal was then widowed 15 minutes by 15 minutes.

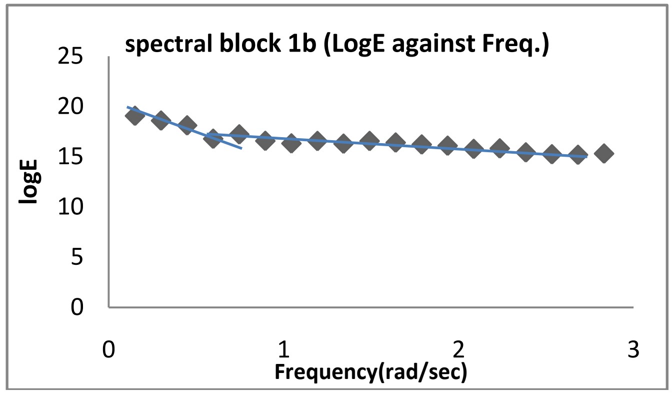
Table 1: 16 spectral cell blocks for spectral analysis

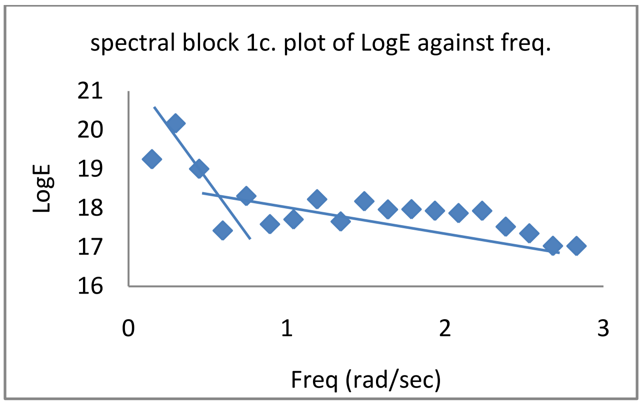
1a	1b	1c	1d
2a	2b	2c	2d
3a	3b	3c	3d
4a	4b	4c	4d

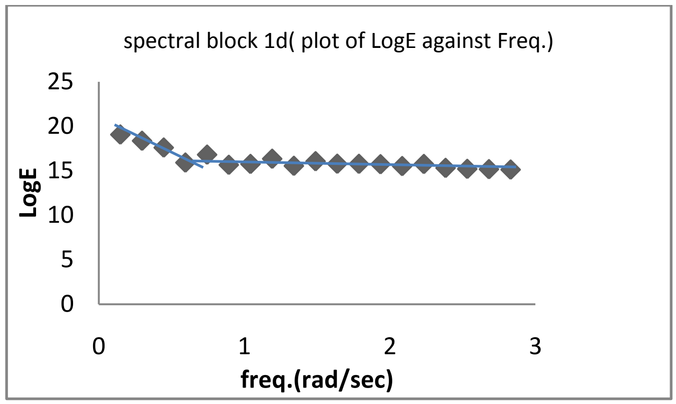
***5.3Generation of radial energy spectrum*:** Digital signal processing software (OASIS MONTAJ) program employing the fast Fourier transform technique was used to transform the residual magnetic data into the radial energy spectrum for each block. The average radial power spectrum was calculated and displayed in a semi-log figure of amplitude versus frequency.

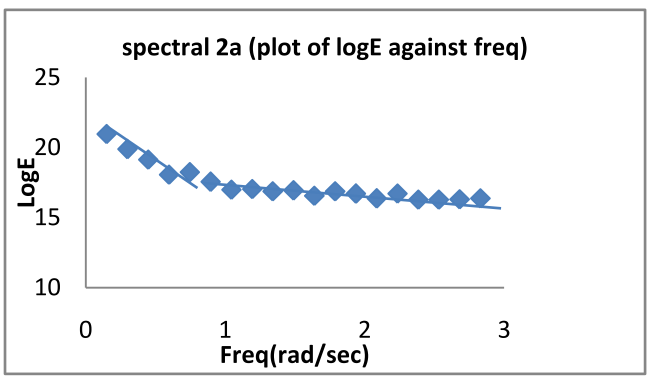
***5.4 Plots of Log of Energy and the frequency*:** Spector and Grant, (1970) have shown that the Log-power spectrum of the source have a linear gradient whose magnitude is dependent upon the depth of the source. Graphs of logarithm of the spectral energyagainst frequencies for the 16 spectral cells was plotted and shown on fig 3.

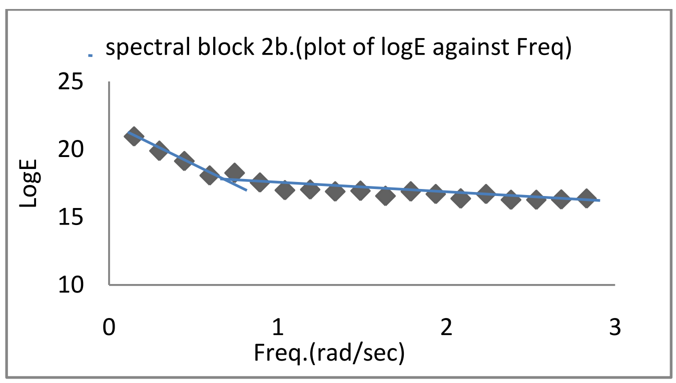

spectral block 1a (LogE against Freq.)
log of spectral energy (lnE)
25
20
15
10
0
0.5
1
1.5
2
2.5
3
Frequency(rad/sec)

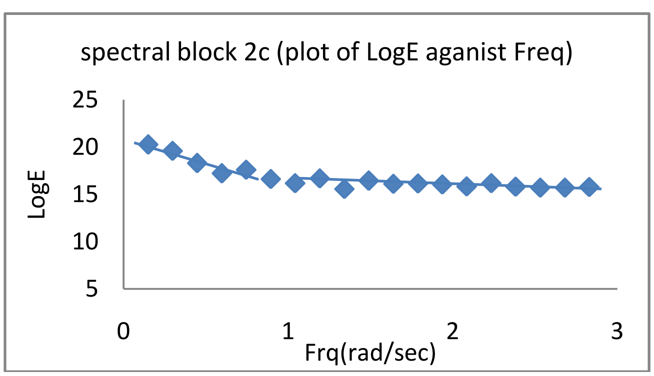

spectral block 1b (LogE against Freq.)
logE
25
20
15
10
5
0
0
1
2
3
Frequency(rad/sec)

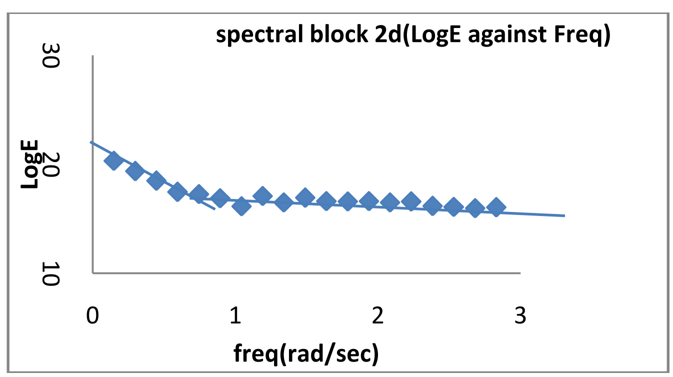

spectral block 1c. plot of LogE against freq.
LogE
21
20
19
18
17
16
0
1
2
3
Freq (rad/sec)


spectral block 1d(plot of LogE against Freq.)
LogE
25
20
15
10
5
0
0
1
2
3
freq.(rad/sec)


spectral 2a (plot of logE against freq)
LogE
25
20
15
10
0
1
2
3
Freq(rad/sec)


spectral block 2b.(plot of logE against Freq)
LogE
25
20
15
10
0
1
2
3
Freq.(rad/sec)


spectral block 2c (plot of LogE aganist Freq)
LogE
25
20
15
10
5
0
1
2
3
Frq(rad/sec)


spectral block 2d(LogE against Freq)
LogE
30
20
10
0
1
2
3
freq(rad/sec)

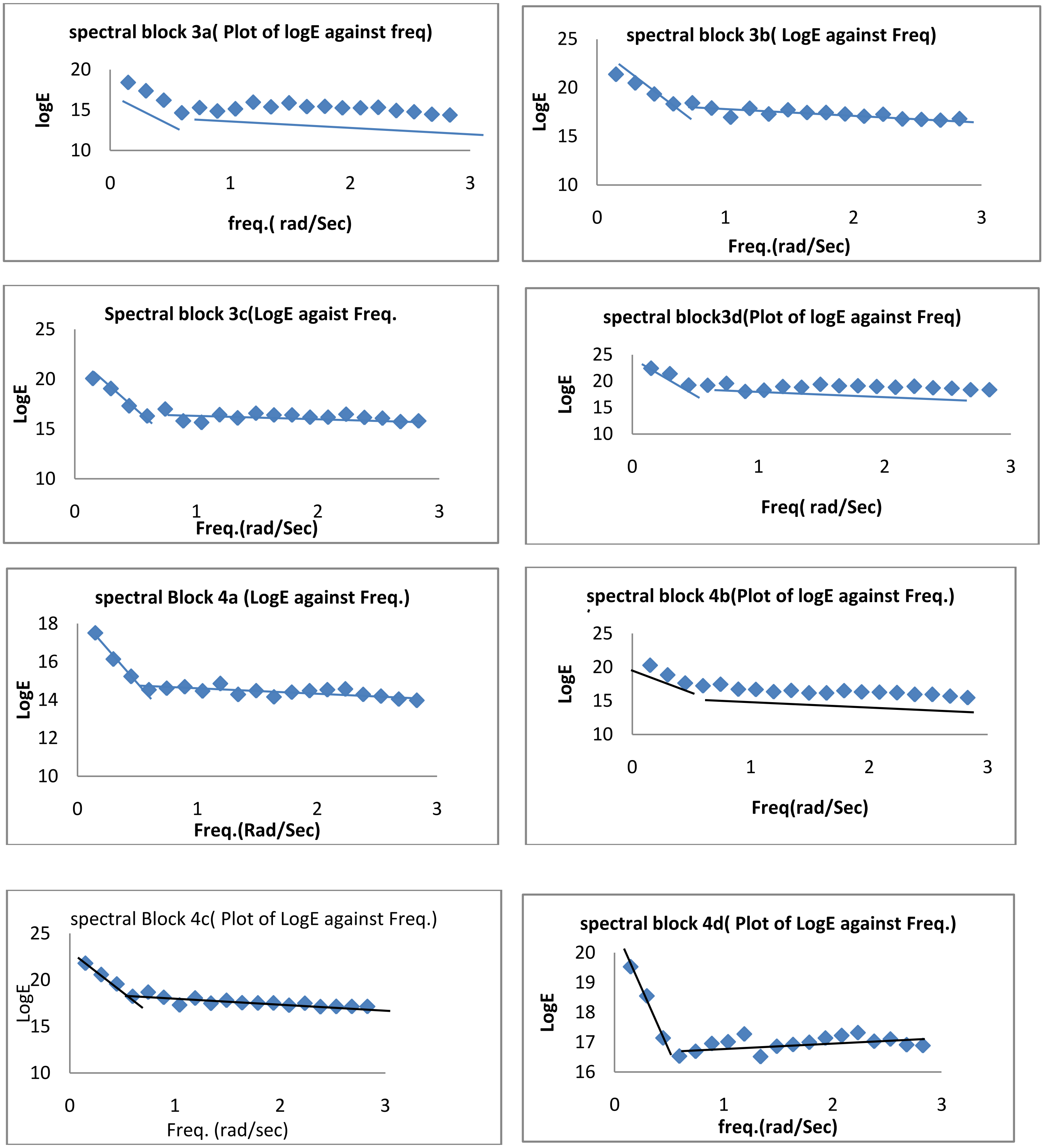


Fig. 3: Spectral plots of log (E) against Frequency (rad/sec)

For each cells two linear segments could be identified which implies that there are two magnetic source layers in the study area. Each linear segment group points are due to anomalies caused by bodies occurring within a particular depth range. The line segment in the higher frequency range is from the shallow sources and the lower harmonics are indicative of sources from deep - seated bodies.

5.5 Estimation of the depth to magnetic sources: The gradients $m = \frac{\Delta LogE}{\Delta freq}$ of each of the line segments in fig6 were first evaluated. The mean depth (*z*) of burial of the ensemble was as given in eqn1.8 ie $Z = -\frac{m}{2}$. The coordinates and the two depth estimates (z_1 and z_2) for each of the sixteen spectral blocks are given on table 2.

Table 2: DEPTH ESTIMATES OF THE FIRST AND SECOND MAGNETIC LAYERS FOR THE I6 SPECTRAL BLOCKS AND THEIR COORDINATES.

S/NO	SPECTRAL BLOCKS	CO-ORDINATES		DEPTH SOURCE VALUES	
	SECTIONS	X(Longitude)	Y(Latitude)	DEEP (Z_1)Km	SHALLOW(Z_2)Km
1	1A	8.63	7.12	5.65	0.21
2	1B	8.63	7.37	3.04	0.42
3	1C	8.63	7.62	2.23	0.20
4	1D	8.63	7.88	3.43	0.27
5	2A	8.88	7.13	3.16	0.22
6	2B	8.88	7.38	3.16	0.22
7	2C	8.88	7.63	3.98	0.28
8	2D	8.88	7.88	3.17	0.22
9	3A	9.13	7.13	3.71	0.12
10	3B	9.13	7.38	3.43	0.31
11	3C	9.13	7.63	4.37	0.09
12	3D	9.13	7.90	3.94	0.07
13	4A	9.38	7.13	3.30	0.13
14	4B	9.38	7.38	4.44	0.33
15	4C	9.38	7.63	3.91	0.27
16	4D	9.38	7.88	3.50	0.05
AVERAGE DEPTH				**3.65km**	**0.21km**

The deep anomaly source depth averaging 3.65km deep could possibly represent the magnetic basement surface of the study area while the other depth averaging 0.21km could possibly represent the shallow source.

6.0 Magnetic basement surface plot:

Making use of Z_1 data of table1 above, the surface plot of the magnetic basement depth depicting its undulating nature was plotted with Surfer32 software and shown on fig 4 a-c

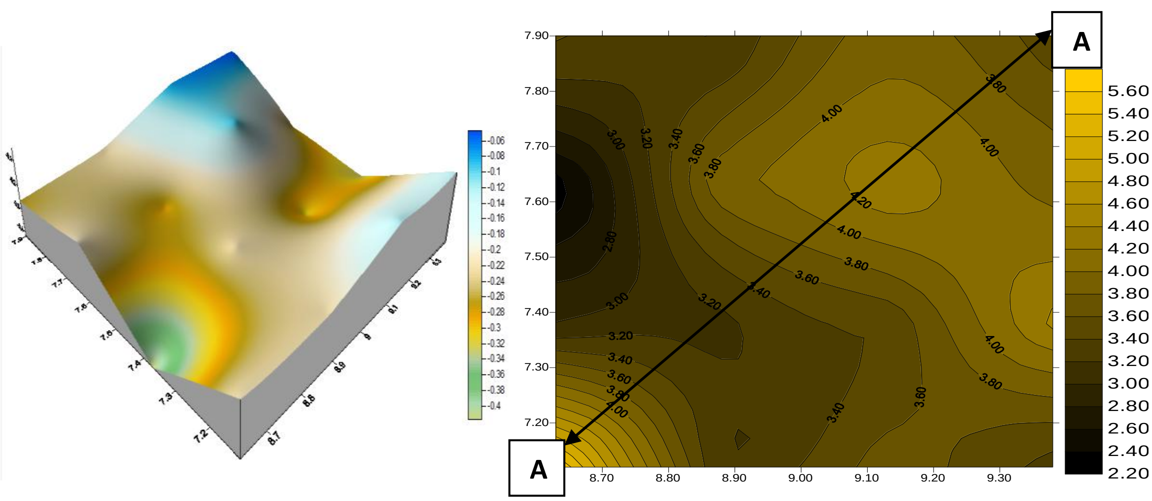
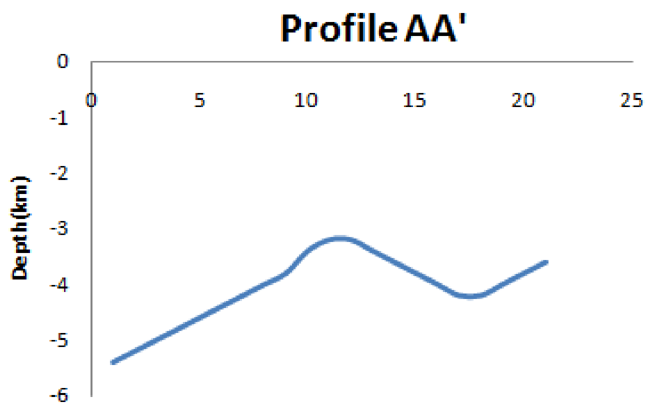


Fig.4 (a): 3-D model of the magnetic basement surface of the study area (b): 2-D contour plot of the magnetic basement surface, Contour interval 0.2km



4.c Profile AA'

7.0 Discussions:

Spectral analysis of the aeromagnetic data of the study area in the middle Benue trough has revealed two main magnetic anomaly sources depth as shown on table 2. These are the deep magnetic anomaly sources and the shallow magnetic anomaly sources. The deep source anomalies vary between 2.23km and 5.66km with an average depth of 3.65km and this represents the magnetic basement depth. The shallow anomaly sources varies from 0.07km to 0.42km with an average of 0.21km and this may be regarded as the magnetic intrusions into the sediment, probably through the magmatic activities and could be responsible for the lead-Zinc mineralization found in the area. Active magmatisms have been reported in the Benue Trough with Ofoegbu and Odigi, (1989) confirming the close associations between magmatisms, mineralizations and fractures in the area. The revelation from this study of 3.65km magnetic basement depth is synonymous to depth of over-burden sediment which has a very important significance as regards to the hydrocarbon generation potential of the area. Previous study showed the geology of the area to be associated with the marine Albian Asu River Group which commenced sedimentation in the middle Benue Trough. Wright et al, (1985) reported that when all other conditions for hydrocarbon accumulation are favourable, and the average temperature gradient of 1^{o}C for 30m obtainable in oil rich Niger Delta is applicable, then the minimum thickness of the sediment required to achieve the threshold temperature of 115^{o}C for the commencement of oil formation from marine organic remains would be 2.3km deep. Therefore, the calculated maximum depth of 3.65km from the study area is sufficient for oil to generate if other conditions are met. Profile AA has equally shown the undulating nature of the study area which may act as traps for hydrocarbons accumulation. More attention should be paid to the Markurdi and Araufu area because it has more favourable geologic features/sediments. Previous studies have confirmed that the geology of the Benue Trough offers promises to prospective investors and researchers in general. This middle Benue trough was considered to be the most prospective area for hydrocarbon within the trough by Nwachukwu,(1985) with estimated depths to the mature zones of (2-4) km. Geological and geophysical studies carried out by Ofoegbu,(1984,1985,1986) in the Benue trough have shown that the area possessed qualities like thick sedimentary sequence, marine source bed, block faulting and suitable traps notable with oil producing regions of the country. One dimensional Spectral calculation done in the area by Ahmed, (1991) using the 1970s data showed the magnetic basement depth to vary from 1.513km and 4.936km. Osazuwa *et al*, (1981) estimated the thickness of sediments in the upper Benue Trough to vary between 0.9km and 4.6km. Results of the 2-D spectral analysis and Landsat Imagery study of the adjacent lower Benue trough was Onyewuchi, et.al, (2012) equally revealed a two layer depth model and predominant NE-SW lineament trend, his shallower magnetic source (d1) has an average depth of 1.041km while the deeper magnetic source bodies (d2) have an average depth of 3.574km.

8.0 Conclusions

These results obtained from the use of the new high resolution data have shown some similarities with those from the previous old data. However, they could be more dependable and exacts owing to the high resolution nature of the 2009 data more than the 1970s data in terms of terrain clearance, line spacing and improvement in technology since then. Also the stressful work of digitizing a map and the likely error that could be introduced during the process have all been eliminated because the 2009 data is in a digitized format. The depth values estimated from spectral analysis over part of the Middle Benue is an indication that hydrocarbon prospecting should be intensified over Asu-River Group of Albian age, Ezeaku Coniacian – Turonian age, and Awgu Turonian – Senonian age since the sediment over the area are sufficient to generate hydrocarbon and therefore may likely be a good source rocks.

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