Zimbabwe Journal of Science & Technology pp 97 – 109 Vol.13 [2018]
e-ISSN 2409-0360
Zimbabwej.sci.technol

Determination of sedimentation thickness within the Eastern part of Benue Trough, Nigeria from high resolution aeromagnetic data

Adetona. A, A.

Federal University of Technology Minna, Niger state, Nigeria

E-mail: tonabass@gmail

ABSTRACT

The estimation of basement depth within the eastern part of Lower Benue Basin was based on both Source Parameter Imaging and Spectral method of analysis of the high resolution Aeromagnetic data covering the study area. The total area covered is 18,150 km^2 which include Markudi, Gboko, Otukpo Agena, Akwana, and Katsina-Ala, all in Benue state of Nigeria. The areais bounded by latitude 7^0.00' and 8^0.00' and longitude 8^0.00'and 90.50'. The aeromagnetic data was subjected to Vertical derivative, Analytical signal, Source parameter imaging SPI) and spectral depth analysis. These derivatives help demarcate regions of relatively thick sedimentation and regions of basement rock outcrop and intrusions into sedimentary formations at shallow depth. Maximum depth of sedimentation from SPI method is 4.146 Km which is located at the Eastern edge below Akwana, depth in the range of 3 Km were also obtain at the Western edge below Gboko, Makurdi and around Agena. Shallow sedimentations were observed at the South Eastern and North Eastern corner of the study area. Result from the spectral depth analysis give depth values that varies from 2.36 Km to 5.42 Km. Results from these two methods correlate in location and value. Regions with depth estimate above 4 Km could be explored for hydrocarbon and gas exploration. The South-Eastern corner and the North-Eastern corner of the study area which depict consolidated lithology at relatively shallow depths can serve as locations for water reservoirs at the height of rainy seasons to avoid flooding.

Key words: *Sedimentation thickness, Lithology, Vertical Derivative, Aeromagnetic:-*

Received: 05.09.18 **Accepted:** 09.12.18

1. Introduction

The maturation of hydrocarbon source rocks depends on a range of factors, including the primary rock type and its original content of organic matter (kerogens); the history of sedimentation and burial (depth); the local geothermal gradient (temperature); and duration of sedimentation (time). Filipo and Giammaria (1999).

In oil exploration, the main use of magnetic method is on the estimation of the sedimentary thickness from the depth to magnetic sources. It is sometimes used to map topographic features on the basement surface that might influence the structures of the overlying sediments.The study area which is part of the Benue Basin is the largest inland basin in the country covering a total area of about 1000 Km^2. Ojoh, K.A., (1992) Some analysis that has been carried out in other parts of the basin Adetona and Abu (2013) has giving a depth estimate of about eight kilometres, that motivates further research in line of hydrocarbon and gas exploration.

The second factor worthy of note is that the Eastern portion of the Benue trough, where the study is carried out share similar lithology such as Mamu, Nkporo and Imo shale, with the Anambra basin where hydrocarbon deposits has been discovered. This depth factor will be explored in this research to establish the viability of the study area for hydrocarbon exploration.

2. Location of the study area

The study area covers the eastern part of lower Benue trough it is bounded by latitude 7^0.00' and 8^0.00' and longitude 8^0.00' and 90 as marked out in figure , the six aeromagnetic sheets covering the study area are Agane (250), Markudi (251), Akwana (252), Oturkpo (270), Gboko(271) and Katsina-Ala(272), with a total area of 18,150 km^2. The major physiological features recognized in the area is the River Benue running over the upper part of the study area.

2.1 Geology of the study area

The Geology map in figure 2 shows that the western part of the study area consisting of Asu formation in the lower Benue trough (sandstone, gravel, clay and limestone) and the eastern part host the undifferentiated old biotite granites.

Benue trough is known to be major structural feature in the Eastern part of Nigeria. It bears an important element in the tectonic framework of Africa. The entire Benue Trough is believed to have evolved as a result of the continental separation of Africa and South America (King, 1950) and is variously described as a rift system (Crachley and Jones,1965), and an extensional graben system (Stoneley,1966 and Wright, 1968). The failed arm of a three-armed rift system is related to the development of domes associated with hotspots (Burke and Dewey, 1974; Olade, 1978).

Sedimentation in the Lower Benue Trough commenced with the marine Albian Asu River Group, although some pyroclastics of Aptian – Early Albian ages have been sparingly reported (Ojoh, 1992). The marine Cenomanian – Turonian Nkalagu Formation (black shales, limestones and siltsones)and the Inter-fingering regressive sandstones of the Agala and Agbani Formations,rest on the Asu River Group. Mid-Santonian deformation in the Benue Trough displaced the major depositional axis westward (sandstone, gravel, clay and limestone) which led to the formation of the Anambra Basin. Post-deformational sedimentation inthe Lower Benue Trough, therefore, constitutes the Anambra Basin.
The Eastern portion rock type of the study area is identified from the geology map Figure 2 as Undifferentiated older granite, mainly biolite granite rock type at the western portion isidentified as Emu formation (sandstone, clay, gravel and limestone) that forms the lithologic units at the surface within these sedimentary basin. River Alluvium deposition identified along the river channel.

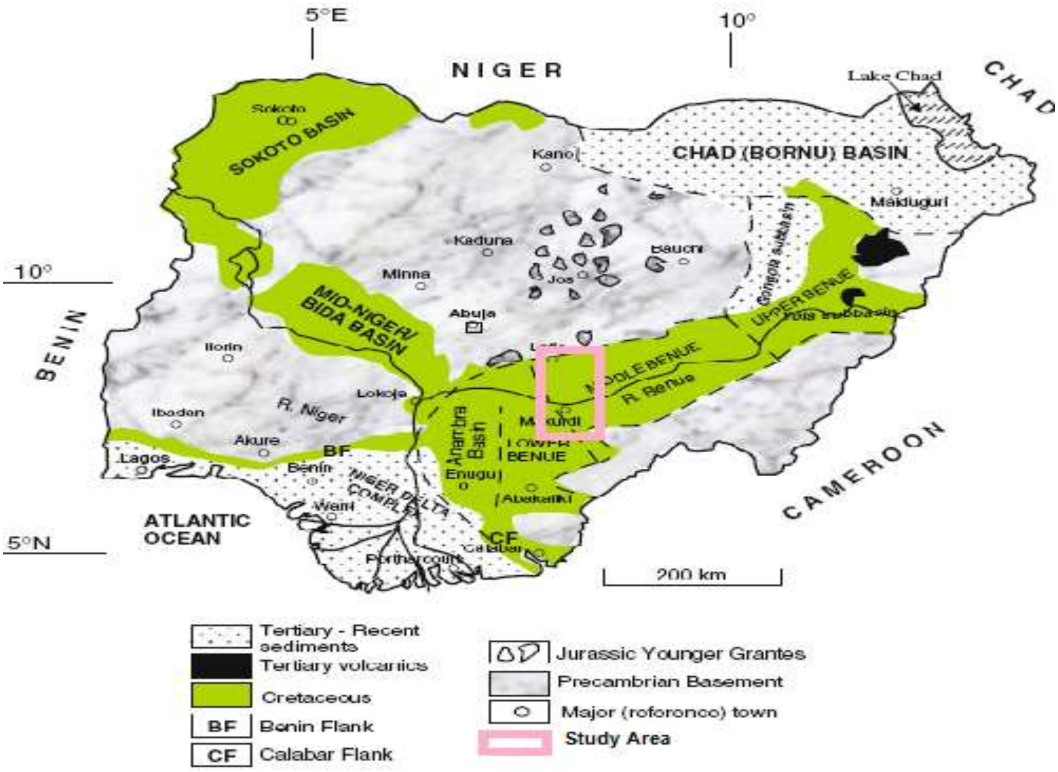
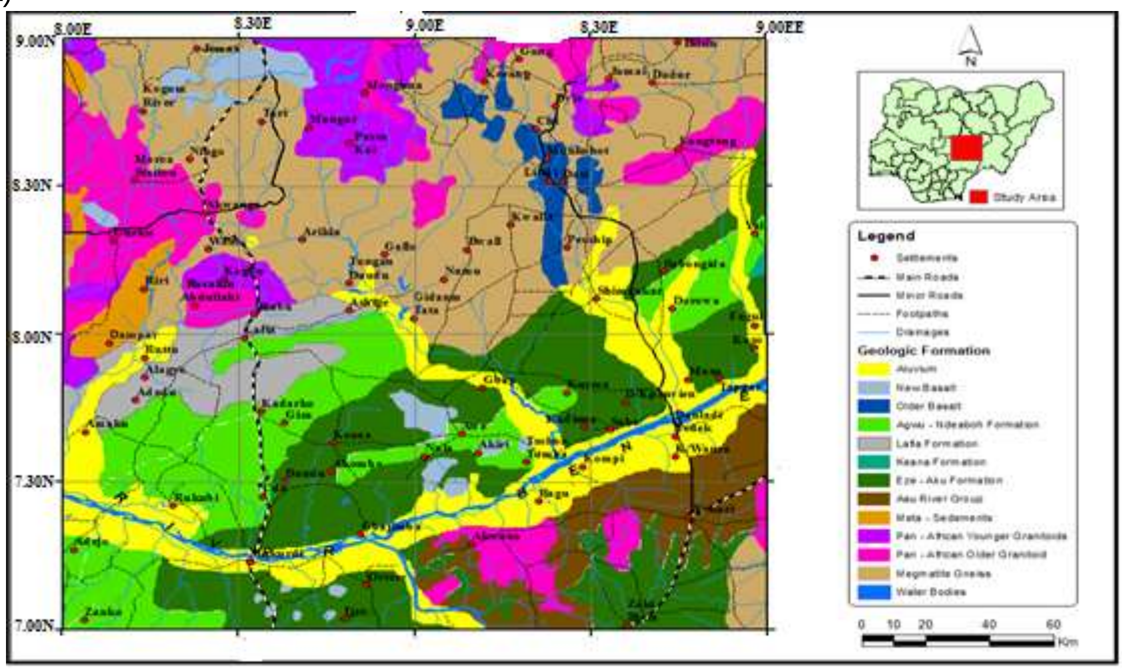


Figure 1: geological map of Nigeria showing the basement complex and the sedimentary terrain. (Obaje, 2009)

Figure 2; Geology map showing the major mineralogy of the study area (adopted from NGSA)

3.0 .
. .
3.
3.



3.MATERIAL AND METHOD

3.1. Source of data

The data for the analysis were obtained from the Nigerian Geological Survey Agency (NGSA) in digital/grid format. A high resolution Airborne Geophysical Surveys involving magnetic, radiometric and limited electromagnetic surveys aimed at assisting and promoting mineral exploration were carried out in Nigeria between 2003 and 2009. The surveys for these two phases were carried out from 2004 to 2009. Fugro Airborne Survey Limited, Johannesburg carried out the flying for data collection in all projects as well as for the interpretation of Ogun state and Phase I programmes. The interpretation of Phase II was carried out by Patterson Grant and West (PGW) consultants of Canada.

Technical details of the survey: Flight Parameters;

Total line kilometres: 36,500 km (Ogun state), 1,930,174 km (Phases I & II)

Flight line spacing: 500 metres

Terrain clearance: 100 m (Ogun state), 80 m (Phases I & II)

Flight direction: NW – SE

Tie lines spacing: 2 km

Tie lines direction: NE – SW

Measured Parameters:
Magnetic gradient and Multi-channel radiometric

3.2. Methodology

The data collected at the Nigerian Geological survey Agency (NGSA), will be subjected to the following corrections:

- Magnetic Compensation
- Noise Removal
- Diurnal Removal
- Micro levelling
- IGRF removal of 33,000nT.

Thus the data for this interpretation which range in values from -691.5 nT to 614.6 nT are mostly of residual origin; and will be subjected to:

- Regional residual separation using polynomial fitting method to establish the regional trend within the field
- Reduction to the equator to observe if there is any shift in anomaly position as a result of removal of data dependence on the angle of inclination.
- Horizontal derivatives $\Delta x,\ \Delta y, \Delta z$ to observe anomalies of shallow origin and as an input value for other analysis.
- First Vertical Derivatives to delineate the major structures and lineament in the study area
- Analytical Signal will help in delineating the area into regions of bedrock outcropping, intermediate structures and basement under the influence of thick sedimentation.
- Spectral Depth Determination to estimate the depth to basement rocks.
- Source Parameter Imaging to also establish the depth of sedimentary rocks within the study area.

These analytical analysis ware achieved using Oasis montaj version 9.0, Surfer 10.0, Matlab and Microsoft Excel worksheet

4. Theory of method

Vertical derivatives (VD), also known as vertical gradients majorly helps enhancing short-wavelength (high wave-number) anomalies and suppress long-wavelength (low wave- number) anomalies in magnetic data (Dobrin and Savit, 1988; Telford *et al*., 1998). Short-wavelength anomalies are caused by surface and near-surface/shallow causative geological bodies, whereas long-wavelength anomalies are mainly due to deeper geological source bodies. Generally, it accentuates the edges of anomalies and the physical expression of shallow causative geological bodies. The zero contour values on VD maps occur directly over edges of magnetic source bodies is (Reynolds, 2011). Mathematically described as followed:

$$\text{FVD} = \frac{dT}{dz} \quad (1)$$

$$\text{SVD} = \frac{d^2T}{dz^2} \quad (2)$$

THD= $\sqrt{(\frac{dT}{dx})^2 + (\frac{dT}{dy})^2}$ (3)

Where FVD and SVD are the first and second vertical derivative respectively and THD is the total Horizontal derivative.

One main advantage of the THD is being less sensitive to short-wavelength noise in the data since only the two first-order horizontal derivatives are utilised during its computation (Phillips, 1998). Generally, the THD is very effective in accentuating the source body edges of both shallow and deep geological bodies and thus useful in mapping linear geological features such as faults, contacts, and dykes, on a RTE-TMI anomaly maps.

The Analytical signal can be applied either in space or frequency domain, generating a maximum directly over discrete bodies as well as their edges source. Its amplitude is independent on the magnetisation direction.

This property is mostly used for edge detection and depth estimation of magnetic bodies by several authors: Roest *et al*.,(1992) as well as detecting causative body location. Hsu *et al*,.(1996) also used it for geologic boundary edge detection.

Nabigian (1972, 1984), was the first to relate the energy of magnetic anomalies to analytical signal. He developed the notion of 2-D analytical signal or energy envelope of magnetic anomalies. An analytical signal is nothing but a complex number of the type:

$$Z(x, y) = x + iy \quad (4)$$

with a real and imaginary parts. Roest *et al*,. (1992), showed that the amplitude (absolute value) of the 3-D analytic signal at location (x, y) can be easily derived from the three orthogonal gradients of the total magnetic field using the expression

$$|A(x, y)| = \sqrt{\left(\frac{dT}{dx}\right)^2 + \left(\frac{dT}{dy}\right)^2 + \left(\frac{dT}{dz}\right)^2}$$

(5)

where *A(x, y)* is the amplitude of the analytic signal at (x, y), and *T* is the observed magnetic field at (x, y)

Computing the amplitude of the analytic signal then requires calculating the X and Y derivatives of the vertical integral and the use of the original total field (IGRF removed) in equation 5

The burial depth extent, dipping angle of the source body, body's magnetisation direction and earth's field direction also constitute to Analytical signal amplitude (Li, 2006).

Spectral Depth-Determination Methods

The Fourier transform of the potential filed due to a prismatic body has a broad spectrum whose peak location is a function of the depth to the top and bottom surfaces and whose amplitude is determined by its density or magnetization. The peak wavenumber (ω') can be related to the geometry of the body according to the following expression.

$$\omega' = \frac{lin\left(h_b / h_t\right)}{h_b - h_t}$$

(6)

Where,

ω' is the peak wavenumber in radian /ground – unit

h_t is the depth to the top

h_b is the depth to the bottom.

for a bottomless prism, the spectrum peak at the zero wavenumber according to the expression:

$$f(\omega) = e^{-h\omega}$$

(7)

Where ω is the angular wavenumber in radians/ground – unit and h is the depth to the top of the prism. (Bhattacharyya, B.K., 1996)

When considering a line that is long enough to include many sources, you can use the log spectrum of this data to determine the depth to the top of a statistical ensemble of sources using the relationship (Spector and Grant 1970).

$$\text{Log } E(k) = 4\pi hk \quad (8)$$

Where h is the depth in ground – units and k is the wavenumber in cycles / ground – unit.

The depth of an 'ensemble' of source can be determine by measuring the slope of the energy (power) spectrum and dividing by 4π. A typical energy spectrum for magnetic data may exhibit three parts – a deep source component, a shallow source component and a noise component.

Figure:9, illustrates the interpretation of an energy spectrum into these three components:

Spector (1968).

Source Parameter Imaging (SPI)

This is based on Thurston & Smith (1997). The basics are that for vertical contacts, the peaks of the local wave number define the inverse of depth. In other words

$$Depth = \frac{1}{K_{\max}} = \frac{1}{\left(\sqrt{\left(\frac{\partial Tilt}{\partial x}\right)^2 + \left(\frac{\partial Tilt}{\partial y}\right)^2}\right)_{\max}} \quad (9)$$

where $K_{\max}$ =wavenumber, $\partial Tilt$ = tilt derivative, ∂x ∂y horizontal derivative in x and y direction respectively ∂T = derivative of the magnetic field the Tilt is given as

$$Tilt = \arctan\left(\frac{\frac{\partial T}{\partial z}}{\left(\sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2}\right)}\right) = \arctan\left(\frac{\partial T / \partial z}{HGRAD}\right) \quad (10)$$

The Source Parameter Imaging (SPI) method calculates source parameters from gridded magnetic data. The method assumes either a 2-D sloping contact or a 2-D dipping thin-sheet model and is based on the complex analytic signal. Solution grids show the edge locations, depths, dips, and susceptibility contrasts. The estimate of the depth is independent of the magnetic inclination, declination, dip, strike and any remanent magnetization. Image processing of the source-parameter grids enhances detail and provides maps that facilitate interpretation by non-specialists Naudy (1970).

Estimation of source parameters can be performed on gridded magnetic data. This has two advantages. First, this eliminates errors caused by survey lines that are not oriented perpendicular to strike. Second, there is no dependence on a user-selected window or operator size, which other techniques like the Naudy H (1970) and Euler methods require. In addition, grids of the output quantities can be generated, and subsequently image processed to enhance detail and provide structural information that otherwise may not be evident.

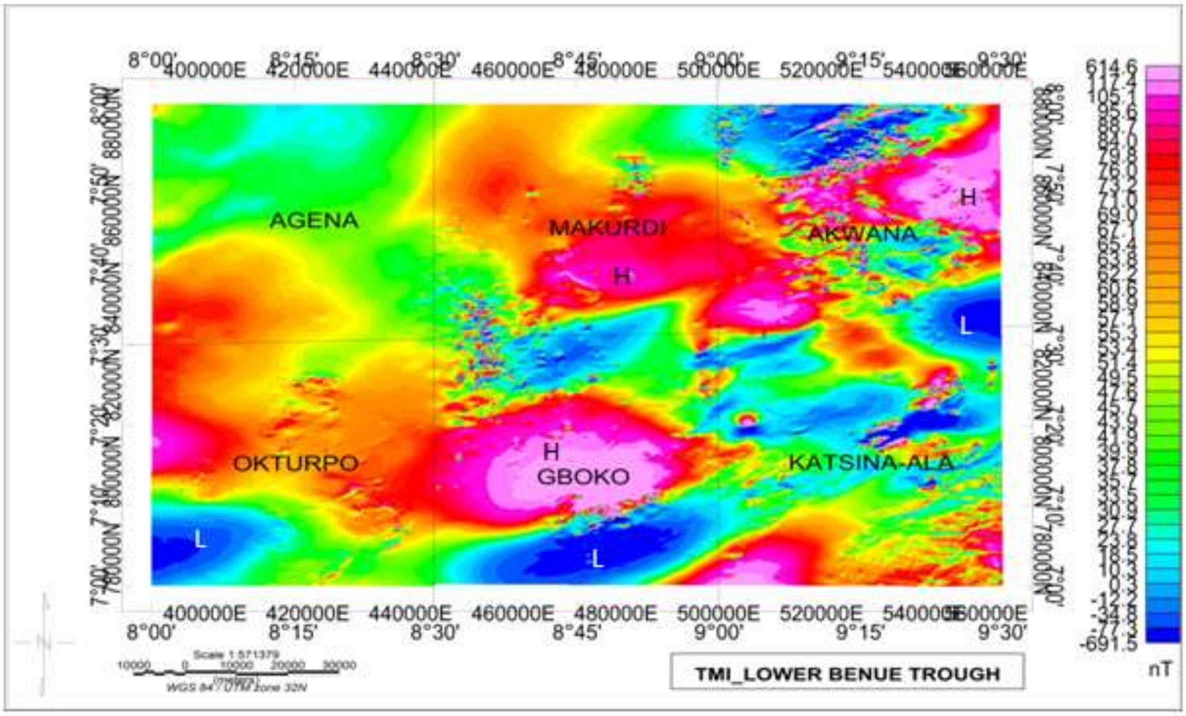
5. RESULTS AND INTERPRETATION

The Total Magnetic Intensity TMI map of the study area as shown in figure 3 indicate regions of High and Low magnetic signatures which signify the variation of susceptibility of the lithology. Susceptibility values ranges from -691.5 nT to 614.6 nT. Major structures within the study area trends NE-SW and N-W.

The high magnetic anomalies might be as a result of basement intrusion into the sedimentary while low magnetic anomalies are associated with the thick sedimentation and majorly magnetic susceptibility of the lithology.

The First Vertical Derivative (Figure 4) where the High Frequency (short wavelength) signatures observed dominantly at the NW portion (Agene) of the study area. Long wavelength signatures observed at the major part of the study area trending from the SW to Eastern part which is as a result of deep magnetic source typical of Sedimentary basin which are dominantly found at Akwana, Gboko, Katsina-Ala and Oturkpo of the study area

The Analytical signal area (Figure 5) whose amplitude ranges 0.00 to 4.591M/nT helps in delineating the area into region of



outcrop, intermediate intrusive structure and basement under thick sedimentation.

Figure 4: The First Vertical Derivative of the study area

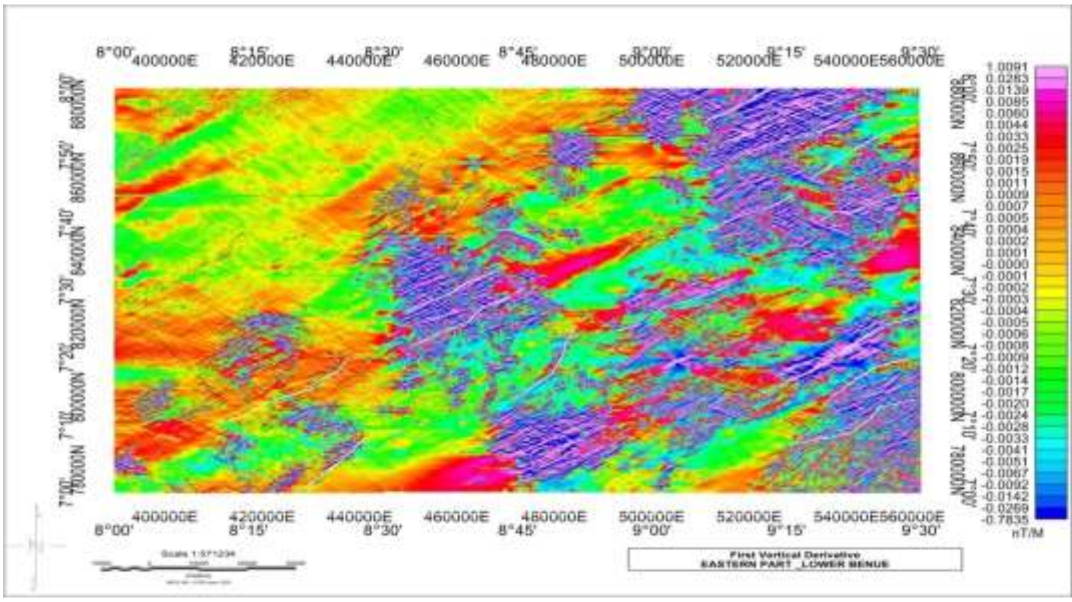
Two region predominantly basement outcrop with a varying degree of deformation are around Gboko, Akwana and Katsina-Ala of the study area.Amplitude range of 0.034 to0.001 depicts region with relatively good sedimentation.

Source Parameter Imaging SPI Figure 6 was used for depth to basement rocks analysis. The SPI shows a maximum depth of 4146.2m. Though some depth values exceed the estimated value of about 4.2 Km (Figure 7) this could be depth evaluations that falls directly on fault lines. The result shows that deepest part of the study area are at the Eastern edge below Akwana between latitude 7.30^{0}N to 7.45^{0}N, also deep is around Gboko at the Western edge,

Figure 3: Total Magnetic Intensity Map 33000 nT has been removed from the field data as IGRF equally deep is around Makurdi at the centre part and finally at the North-eastern part of the area.

The High resolution aeromagnetic (HRAM) data was windowed into twelve (15) overlapping windows or sub-sheets (Figure 8). Upon each of the windows Fast Fourier Transform (FFT) and subsequently spectral depth analysis was undertaken this art decomposed the anomalies into its energy and wave number components. Thereafter a plot involving Energy versus wave number in cycle/km was made. A straight line is then manually fit to the energy spectrum both in the higher and lower portion (figure 9).

Two depth source models; H_1 and H_2 were revealed. The depth to the deeper magnetic bodies (H_1) Table 1, varies between 2.07 km and 5.42 km but with an average value of about 3.55 km while the depth due to the shallow causative magnetic sources (H_2) lies between 0.24 km and 1.08 km, with an average depth value of 0.49 km. Regions with high sedimentation include the Eastern end of the study area, the lower southern end and the North-western corner, which coincide with the results from the SPI analysis. Also, one of the shallowest depths is found around Makurdi.



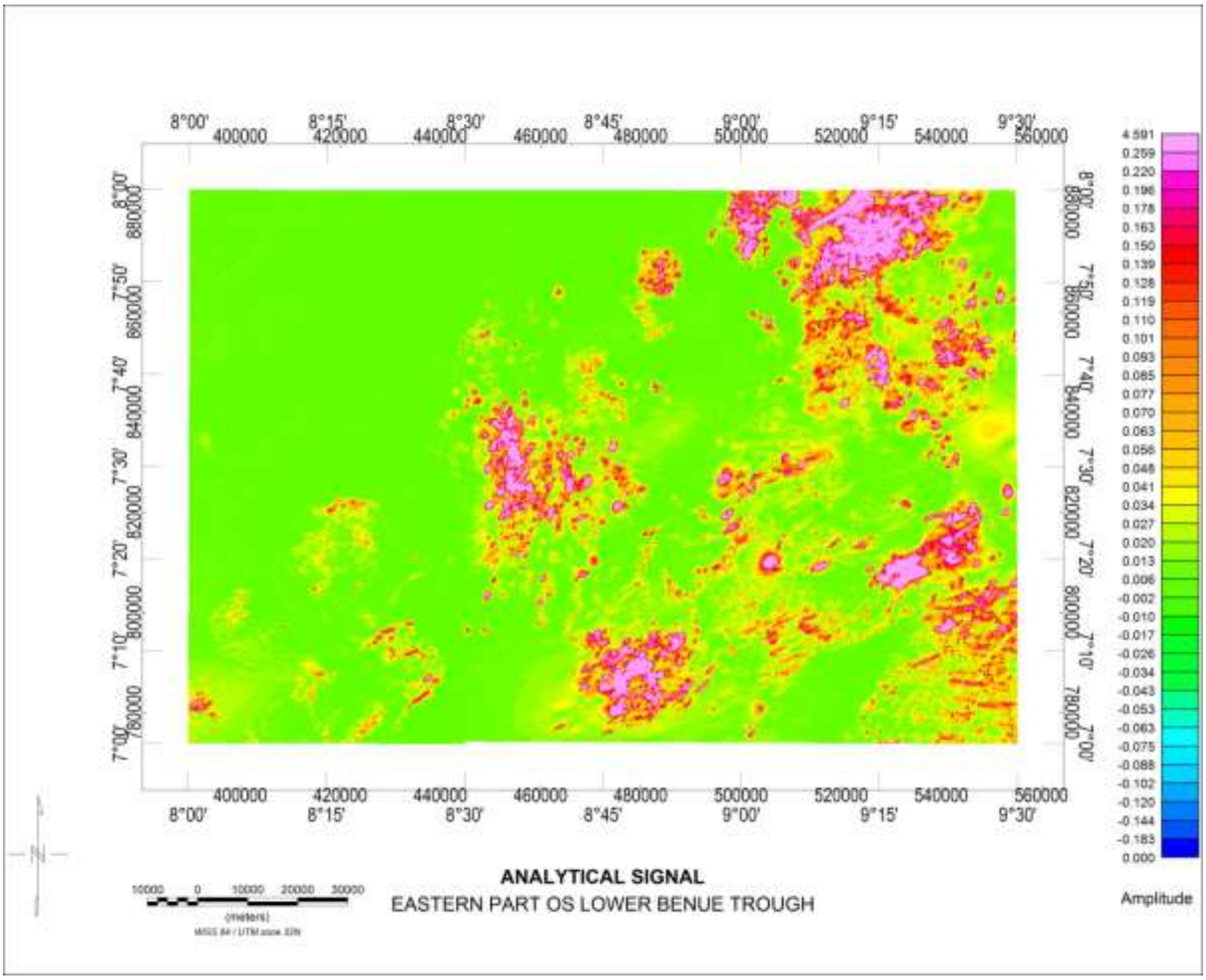


Figure 5: The Analytical signal of the study area

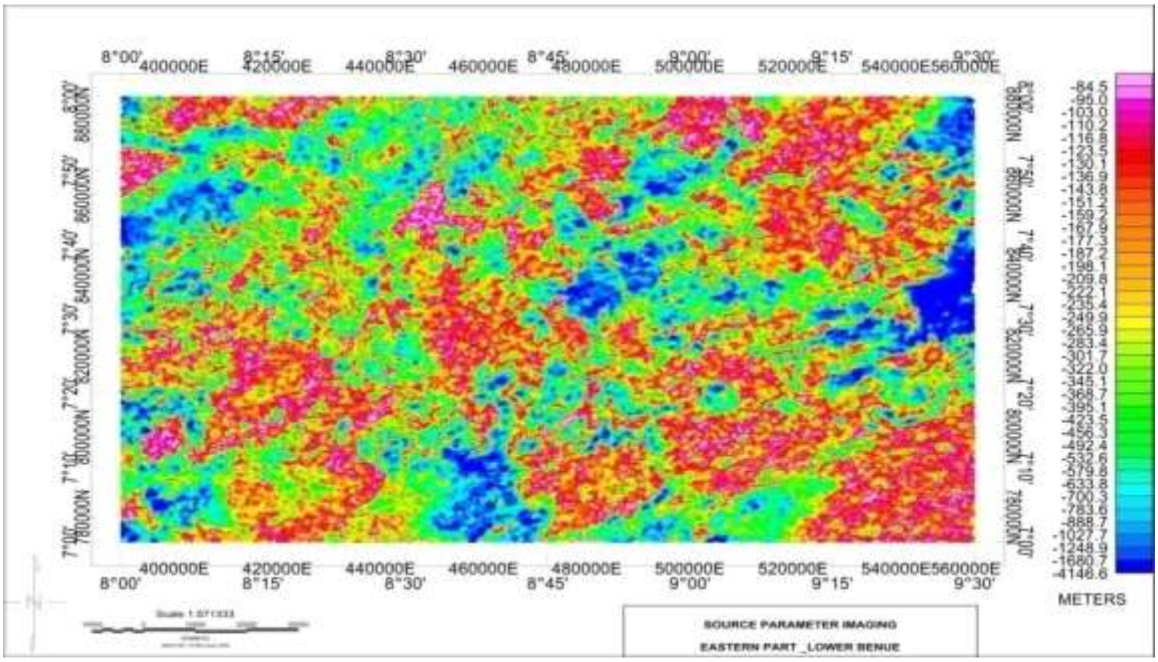


Figure 6: The Source Parameter Imaging of the study area

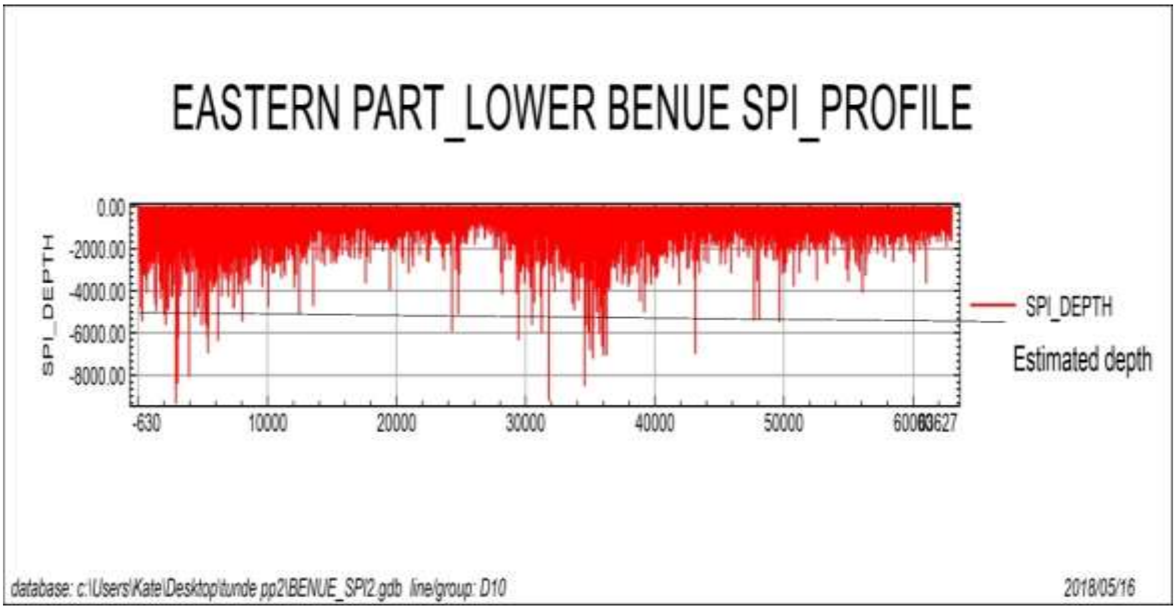


Figure 7: Source Parameter Imaging Depth Profile Map of the study area

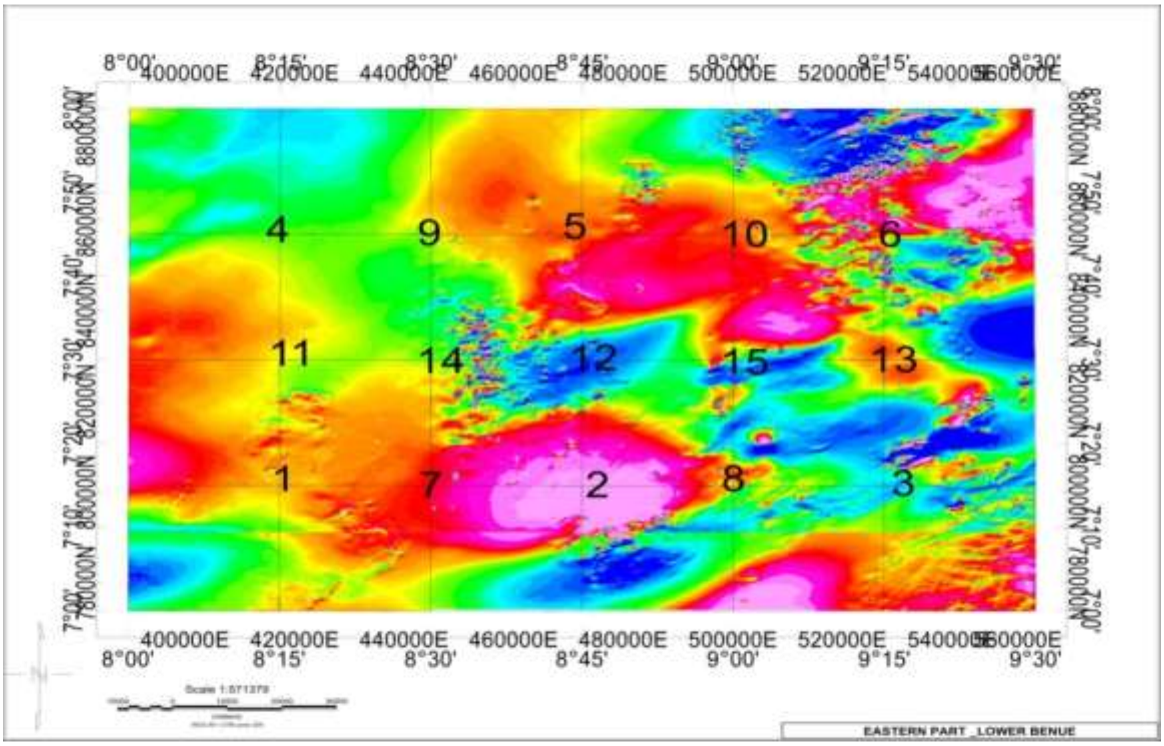


Figure 8: Total Magnetic Intensity Map showing the spectral sections

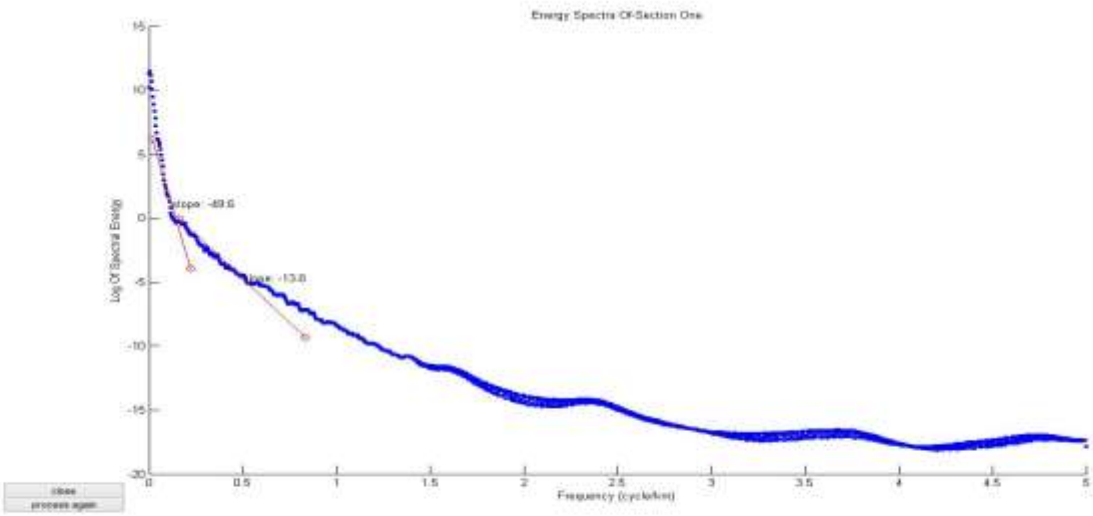


Figure 9: The matlab plot of the log of spectral energy against frequency

Table 1: The estimated values of the depth to basement and curie-point depth within the study

SECTIONS	LONG(°E)	LAT (°N)	GRADIENT(D1)	DEPTH H1	GRADIENT (D2)	DEPTH H2
1	8.15	7.15	49.6	-3.947	-1.082113304	1.08
2	8.45	7.15	65.4	-5.204	-0.501273074	0.50
3	9.15	7.15	34.1	-2.713	-0.324633991	0.32
4	8.15	7.45	65.7	-5.228	-0.541056652	0.54
5	8.45	7.45	26	-2.069	-0.428071292	0.43
6	9.15	7.45	34.3	-2.729	-0.272119669	0.27
7	8.3	7.15	32.3	-2.570	-0.4781986	0.48
8	9	7.15	38.5	-3.063	-0.322246976	0.32
9	8.3	7.45	29.6	-2.355	-0.243475493	0.24
10	9	7.45	38.9	-3.095	-0.471833227	0.47
11	8.15	7.3	33.9	-2.697	-0.318268619	0.32
12	8.45	7.3	58.4	-4.647	-0.711330363	0.71
13	9.15	7.3	68.1	-5.419	-0.335773393	0.34
14	8.3	7.3	39.3	-3.127	-0.625397836	0.63
15	9	7.3	55.1	-4.384	-0.714513049	0.71

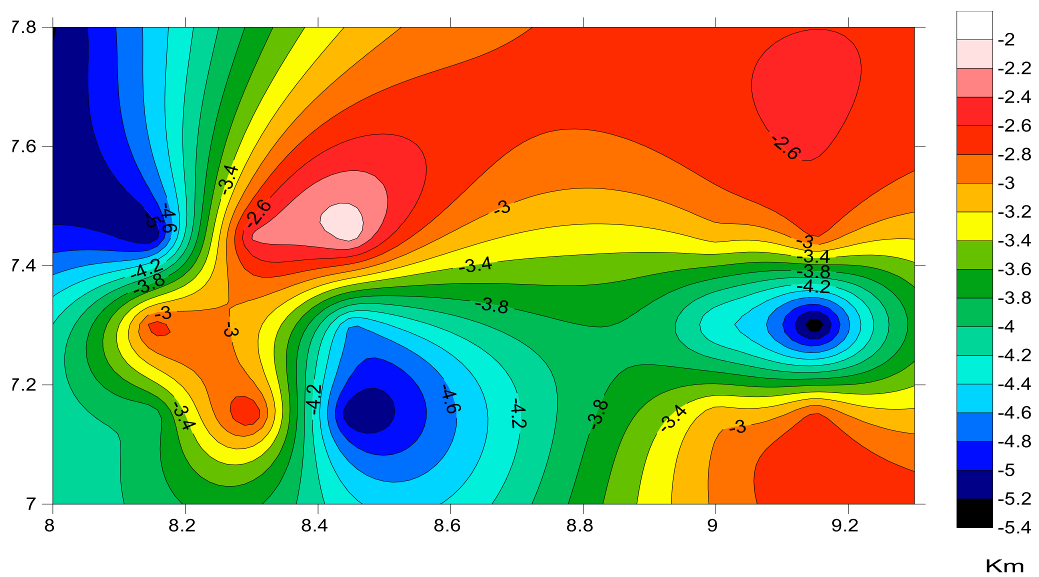


Figure 10: Contour map of the depth to basement of the study area

6. DISCUSSIONS.

Previous geophysical works carried out in the area suggested the existed of near surface intrusions volcanic plunge and basement features that deeply rooted, (Ofoegbu 1984; Ajakaiye *et al* 1986), this is confirmed by the result obtained in the present work as evident in the First Vertical Derivative and the Analytical signal such can be seen around Gboko, Makurdi, Katsina-Ala and upper part of Akwana. Worthy of note is that the effect of these intrusions into the basement and consequently the sedimentary formations has resulted into lineated structural features that are host to solid minerals, these lineaments are mapped on the FVD and the horizontal derivative employed in computing the Source Parameter imaging, this will be a target for further research.

The lower Benue Trough is a linear intracatonic garben basin trending NE-SW whose origin is associated with the separation of the African and South American continents in the early cretaceous, Fatoye and Gedeon (2013) this fact is confirm by the direction of the lineaments obtained on the FVD map on (Figure 4) trending NE-SW indicating they are created by the shear stress generated during the separation.
A depth estimate of 4.03 Km for second layer and 5.39 Km was obtained by Abubakar *et al* (2010) within this area, while a depth estimate of 6 Km was obtained by Fatoye *et al* (2013) just below the study area, and Adetona and Abu Mallam obtained a depth estimate of 7 Km at the contact between the Benue Trough and Anambra Basin. These results correlating them with the result of the present study (5.3 Km) shows that the thickness of sedimentation increases as one move from the Anambra end into the Lower Benue trough up into the Middle Benue Basin. A depth of 5 Km is convincing enough for further research for hydrocarbon exploration but in addition it is observed that smilar lithology such Agwu and Eze-aku formations that exist within the Anambra end where hydrocarbon accumulation has been discover exist within this area. In the absence of crude oil gas and coal can not be completely rule out.

7. Conclusion

The First Vertical Derivative FVD of the study area shows region of high distortion to the magnetic signature where the high and low magnetic anomalies are mixed mostly at South-Western to the Eastern part (Akwana, Gboko, Katsina-Ala and Oturkpo). Region of little or no distortion of magnetic signatures are around Agene at the North-eastern corner indicating arelatively settle basement. The major magnetic anomalies trend in the North-East South-West direction. On Analytical signal map, two regions can be observed from the amplitude ranging from 0.042 to 4.591, these are basement outcrop or intrusive rocks at shallow depth and regions of relatively good sedimentation.
The Source Parameter Imaging SPI map of the study area gave an approximate depth is 4 km which is a relatively adequate depth to attract further research in view of hydrocarbon and gas exploration. Spectral depth analysis help to determine the depth to magnetic source bodies, which shows a shallow basement depth of 0.2 Km to 1.08 km at the NW (Makurdi) and NE (AKwana) part of the study area, the deepest at 5.2 km at the western edge (Agene), south (Gboko) and eastern (Katsina-Ala) part of the study area . Regions with depth estimate above 4 Km could be explored for hydrocarbon and gas exploration. The South-Eastern corner and the North-Eastern corner of the study area which depict consolidated lithology at relatively shallow depths can serve as locations for water reservoirs at the height of rainy seasons to avoid flooding.

References

Adetona A. Abbass and Abu Mallam, (2013) Estimating the Thickness of Sedimentation within Lower Benue Basin and Upper Anambra Basin, Nigeria, Using Both Spectral Depth Determination and Source Parameter Imaging,*" ISRN Geophysics, vol. 2013, Article ID 124706, 10 pages, doi:10.1155/2013/124706.* Available at http://www.hindawi.com

Abubakar Y.I, Umego M.N and S.B. Ojo, 2010. Evolution of Gongola Basin Upper Benue Trough Northeastern Nigeria. *Asian Journal of Earth Sciences, 3: 62-72.*

Ajakaiye, D. E, Hall, D. H., Millar, T. W. (1986). Aeromagnetic anomalies and tectonic trends around the Benue trough Nigeria Nature. *Physical Science,* 319,582,584

Bhattacharryya, B.K.and L.K. Leu.,(1976). Spectral analysis of gravity and Magnetic anomalies due two dimensional structures, *Geophysics*, Vol. 40, pp. 993-1031

Blakely, R.J (1995) Potential theory in gravity and magnetic applications. Cambridge University Press, Cambridge

Burke, K. C., Dessauvagie, T. F. J. and Whiteman, A. J. (1974). Geological history of the Benue Valley and adjacent areas, in T. F. J. Dessauvagie and A. J. Whiteman eds. African Geology; Ibadan, Ibadan University Press, p. 187 - 205

Cratchley C. R and Jones, G. P. (1965). An interpretation of the Geology and Gravityn Anomalies of the Benue Valley Nigeria British Oversea Geol, Survey *Geophysics* Paper no1:126

Dobrin, M.B and Savit, C.H., (1988). Introduction to Geophysical Prospecting,fourth edition.McGraw-Hill, New York, Pp867

Fatoye F. B. and Gideon Y. B. Adv. Appl. Sci. Res., 2013, 4(6):21-28 Available online at www.pelagiaresearchlibrary.com

Filipo and Giammaria (1999) *Geophysical Journal International*, Volume 139, Issue 1, 1 October 1999, Pages 248–260, https://doi.org/10.1046/j.1365-246X.1999.00877.x

Hsu, S. K., Sibuet, J. C., &Shyu, C. T. (1996). High-resolution detection of geologic boundaries from potential-field anomalies; an enhanced analytic signal technique**.** *Geophysics, 61*, 373-386.

King, L. C. 1950: Outline and Description of Gondwanaland-Geological Magazine. Vol. 87 p. 353-359.

Naudy, H. (1970). Unemethoded'analyse sur profiles aeromagnetiques. *Geophysical Prospecting*, 18, 56-63.

Obaje N . G (2009) Geology and Mineral Resources of Nigeria Lecture Notes in Earth Sciences, Springer pp 287.312

Ofoegbu, C. O. (1984). A model for the tectonic evolution of the Benue Trough of Nigeria: *GeologischeRundschau*, v. 73, p.1009-1020.

Telford, W.M., Geldart, L.P., Sheriff, R.E., 1998. *Applied Geophysics,* second ed. Springer, Berlin, 770p

Telford, W. M., Geldart, L. P., Sherif, R. E. and Keys, D. A. (1990). Applied Geophysics.Cambridge: Cambridge University Press.

Thurston, J. B. and Smith, R. S. (1997).Automatic conversion of magnetic data to depth dip, and susceptibility contrast using the SPI^{TM} method.*Geophysics*, 62, 807-813

Wright J.B (1976) Fracture system in Nigeria and initiation of fracture zones in the south Atlantic, *Tectonophysics* pp34, 43-47

Ojoh, K.A., (1992) The Southern part of the Benue Trough (Nigeria) Cretaceous stratigraphy, basin analysis, paleo-oceanographyand geodynamic evolution in the equatorial domain of the South Atlantic. 7: pp131–152

Olade, M. A. (1978). Early cretaceous basaltic volcanism and initial continental rifting in benue trough. *Journal of mining geology* 16, 17-25

Philip, K., Michael, B., Ian, H. (2002). *An Introduction to Geophysical Exploration*. London: Blackwell Science Ltd.

Stoneley, R, (1966). The Niger Delta region in the light of the theory of continental drift *Geology Magnetic* 103, pp 385-397

Spector, A. and Grant, F.S., (1970). Statistical models for interpreting Aeromagnetic data,*Geophysics*. Vol.35, pp. 293- 302.

Reynolds, J.M., 2011. An Introduction to Applied and Environmental Geophysics.second ed., Wiley-Blackwell, West Sussex. 696p

Roest, W. R., Verhoef, J., & Pilkington, M. (1992). Magnetic interpretation using the 3- D analytic Signal.*Geophysics, 57*(6),Pp116-125. http://dx.doi.org/10.1190/1.1443174