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# USING SOURCE PARAMETER IMAGING (SPI) AND FORWARD AND INVERSE MODELLING METHODS FOR HYDROCARBON POTENTIALS FOR INTERPRETATION OF HIGH-RESOLUTION AEROMAGNETIC DATA OVER CHAD BASIN, NORTH EASTERN NIGERIA.

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**Abstract**

*The High resolution aeromagnetic (HRAM) data of Chibok and Damboa areas (sheets 112 and 134), north-eastern Nigeria, has been interpreted by applying source parameter imaging (SPI), and forward and inverse modelling methods. Quantitative depths estimates obtained by employing SPI have shown minimum to maximum depth to anomalous source at 72.7m to 5026.8m. Oasis montaj 6.4.2 software, Microsoft excel and potent Q 4.10.07 softwares were employed in the data analysis. The estimated depths from the forward and inverse modelling methods for profiles 1-3 are 2749, 2201, 2088 m respectively. The respective susceptibility values of 0.20407, 0.47779, 7.8043 SI, which indicate the presence of sedimentary intrusions (basalt or limestone), few metamorphic rocks (schist) and minerals (magnetite). It was concluded that this research will help to ascertain a better geophysical detail of the southern part of the Chad-Basin, and further enhanced the full coverage of the whole basin in the exploration activity.*

[redacted]

***KEYWORDS:*** *High resolution Aeromagnetic (HRAM) Data, Source Parameter Imaging (SPI), Chibok and Damboa.*



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## Introduction

The search for mineral deposits and hydrocarbon (oil and gas) has been a major business challenge in Nigeria since the pre-colonial era and the 1960s respectively. The bedrock of Nigeria's economy has been the solid mineral and currently the lucrative oil sector due to its high profitability. Over 80 percent of the country's revenue comes from export and domestic sales of the oil and gas upon which over 140 million growing population depends on. As the hydrocarbon potential of the prolific Niger delta becomes depleted or in the near future may be exhausted due to continuous exploitation, attention needs to be shifted to other sedimentary basins. The Upper Benue Trough and Borno basin in particular is one of those basins being suspected to have high hydrocarbon potential, besides economic mineral deposits concentration. Recently, the petroleum potential of the trough has been of great interest to geologists and geophysicists. The Nigerian government through the Nigerian National Petroleum Corporation (NNPC) and many oil companies had invested heavily in this part of the basin prospecting for oil which remains elusive up to today. However, efforts
are still on and more money is still being sunk into the area with the hope of finding oil in the region. Just recently, the state minister of petroleum has promised before the end of the year to give a tentative date for exploration work to begin in the Chad-Basin. Chibok and Damboa are both area that constitute part of the Basin.

The study area is in Borno State, within the Chad Basin, North-eastern Nigeria. The study area is bounded latitude 11° 13° - 12° 30ˈN and longitude 13° 00ˈ- 14°00ˈ E in the North-eastern part of Nigerian.

The Chad Basin is the largest intracratonic Basin in Africa (Mathias, 1986), covering an area of about 233,000km$^2$ ,it straddles five countries namely; Nigeria, Chad republic, Niger republic, Cameroon and Central African Republic (Obaje et al., 2004). Its western margin is marked by the water shade between the river Niger and river Chad drainage systems, and approximately one-tenth of the surface area of the Chad Basin is in the North-East Nigeria, bounded to the east by the Massif (Mandara Mountains) and in the south by the Benue Trough and Biu Plateau (Olugbemiro et al, 1997). The origin of the Chad Basin is associated with


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the separation of the African and South American continents in the early Cretaceous (Burke 1976; Fair Head and Blinks, 1991; Genik, 1993; Hartley and Allen, 1994) and from the structural styles, there is a strong indication that the evolution of the Chad Basin is related to the subsidence following intrusion of anorogenic granite in response to changing heat flow during supercontinent breakup (Klein and Hsui, 1987) or due to the subsidence caused by tectonic events at adjacent plate margins (Leighton and Kolata, 1990). The sedimentary rocks have a cumulative thickness of over 3.6 km and consists of thick Basal continental sequence and transitional Calcareous deposit. This research is aimed at using combined methods for hydrocarbon and other combine minerals in the interpretation of high-resolution aeromagnetic data over chad basin of northern Nigeria.

**Materials and Method**

Two sheets were assembled for this study (112,134) with each square block representing a map in a scale of 1:100,000. Each square block is about 55 by 55 $km^2$ covering an area of 3025 $km^2$ hence the total area studied was about 6050 $km^2$. 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, softwares and errors corrected during surveys.

**Forward and Inverse Modelling**

Forward modelling involved the comparison of the calculated field of a hypothetical source with that of the observed data; the model is adjusted in order to improve the fit for a subsequent comparison. The technique was used to estimate the geometry of the source or the distribution of magnetization within the source by trial and error approach. Inverse modelling involved direct determination (as opposed to the trial and error or indirect determination) of some parameters of the source from the measured data. In this method, it is customary to constrain some parameters of the source in some way, realizing that every anomaly has infinite number of permissible sources leading to an infinite number of solutions. The software used for the modelling and



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inversion of the anomalies is OASIS MONTAJ containing potent software. Potent is a program for modelling the magnetic and gravitational effects of sub-surface. It provides a highly interactive 3-D environment that, among other application, is well suited for detailed ore body modelling for mineral exploration. The main concept in potent include, observation, inversion, model, visualization and calculation. Interpretation of magnetic field data using potent starts with observation of the image of the observed data. The first step in interpreting the observed data was to take profiles on the filed image. In interpreting the observed data, seven profiles were taken along different parts of the field image.

**Source Parameter Imaging Method**

The source parameter imaging (SPI) is a technique that uses an extension of the complex analytical signal to estimate magnetic depths. The estimate of the depth is independent of the magnetic inclination, declination, dip, strike and remnant magnetisation. The Source Parameter Imaging (SPI) function is a quick, easy, and powerful method for calculating the depth of magnetic sources. Its accuracy has been shown to be +/- 20% in tests on real data sets with drill-hole control. This accuracy is similar to that of Euler deconvolution; however, SPI has the advantage of producing a more complete set of coherent solution points and it is easier to use. A stated goal of the SPI method (Thurston and Smith, 1997) is that the resulting images can be easily interpreted by someone who is an expert in the local geology.

The Source Parameter Imaging (SPI) technique is represented mathematically (Thurston and Smith, 1997) as:

$$Depth = \frac{1}{K_{max}\frac{1}{(\sqrt{(\partial Tilt/\partial x)^2+(\partial Tilt/\partial y)^2})_{max}}} \qquad 1$$

Where Tilt is given as:

$$Tilt = arctan(\frac{\partial T/\partial z}{\sqrt{(\partial T/\partial x)^2+(\partial T/\partial y)^2}}) = arctan(\frac{\partial T/\partial z}{HGRAD}), \qquad 2$$

Where HGRAD is horizontal gradient, T is total magnetic intensity (TMI), K is the wave number, $\partial T/\partial x$, $\partial T/\partial y$, $\partial T/\partial z$ are derivatives of T with respect to x, y and z.
Source parameter imaging (SPI) method calculated source parameters for gridded magnetic data. The method assumes either a 2D slopping contact or a 2D dipping thin-sheet model and is based on the complex analytic signal. The SPI depth of magnetic data will be determined using Oasis Montaj software and employing the first vertical derivatives and horizontal

**Results and Discussions**

Potent modelled

Interpretation of magnetic field data using potent starts with observation of the image of the observed data, this is done by taken profiles on the field image. The associated subsets are automatically created by potent and displayed in a profile window (Fig. 1-3). The model is consistent with observed physical values if its calculated field matches the observed values to some degree of precision. This is assessed by calculating the total magnetic field intensity due to the model and comparing it with the observed fields. Three profiles taken on the TMI grid of Figure 8 at **P1- P3** were modelled using potent software. Forward and inverse modelling methods conducted on those locations give results and modelled parameters.

**Profile 1 (P1)**

**P1** is a profile taken in the central part of the study area, about 5km from Shaffa to the west. During the forward and inverse modelling using an ellipsoid geometrical body (that is by adjusting the background, shape, position and other properties of the geometrical body), a good mutual or complementary relationship between the observed (blue) and calculated (red) field was achieved with the root mean square R.M.S difference of 3.00% indicating a good model. The model revealed to magnetic source at depth Z of 2749m, with susceptibility value of 0.2047SI. Telford et al. (1990) and Dobrin and Savit, (1988) suggested that the susceptibility value correspond to basalt rock material.

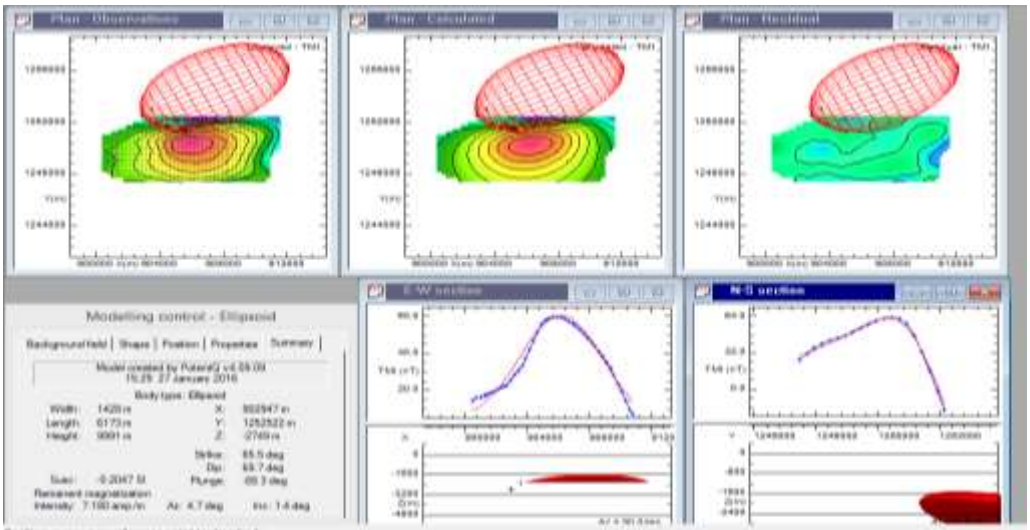

Fig. 1: Model (Ellipsoid) result of Profile 1

**Profile 2 (P2)**

Another profile was taken in the location marked **P2** on the grid, still within the central region of the study area about 10km distance from Askira to the south and about 14 - 15km to the north of Mbalala in Chibok area of Borno state. The detail of forward and inverse modelling method conducted on **P2** is given in Figure 2 and the model revealed magnetic source at depth Z of 2201m, the R.M.S difference of 2.5% was used and a susceptibility value K of 0.4779SI which correspond to limestone and sandstone was obtained. The mineral group associated with these rocks includes gypsum and calcite.

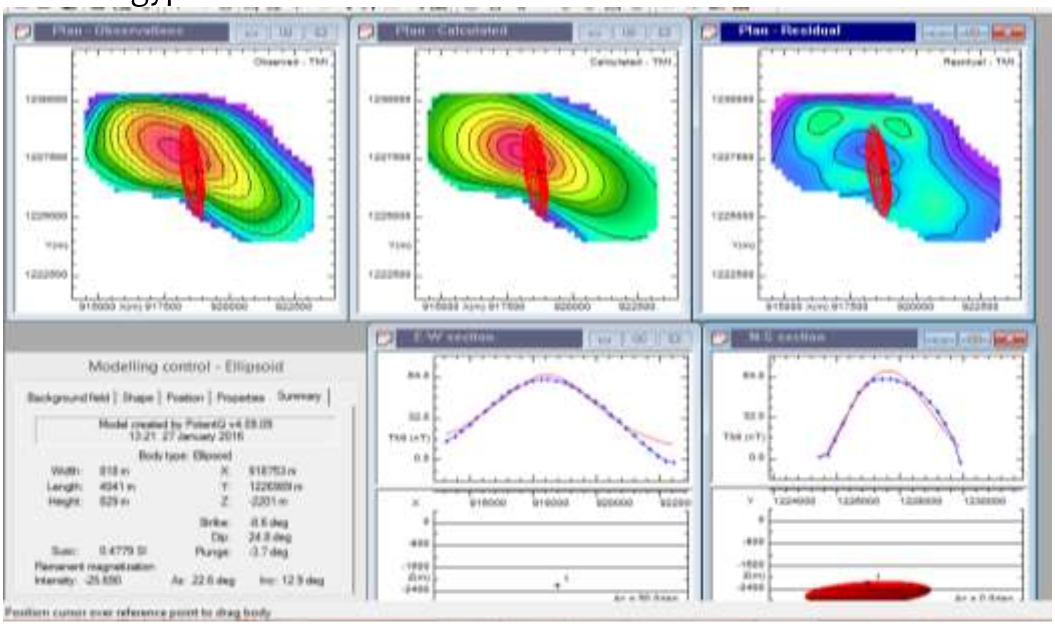

Fig. 2: Model (Ellipsoid) result of Profile

**Profile 3 (P3)**

Profile at **P3** taken from about 6 -7km to the east of Askira community in Damboa local govt. area of Borno state was also examined using an ellipsoid geometric shape for the model since it gives a better result than other geometric bodies such as sphere and rectangular prism. Figure 3 gives **P3** modelled summary results with depth to magnetic source Z of 2088 meters, R.M.S difference of 2.6% and susceptibility value of 7.8043 SI. The susceptibility value corresponds to the sedimentary rock material**,** Telford and Sheriff, (1990).

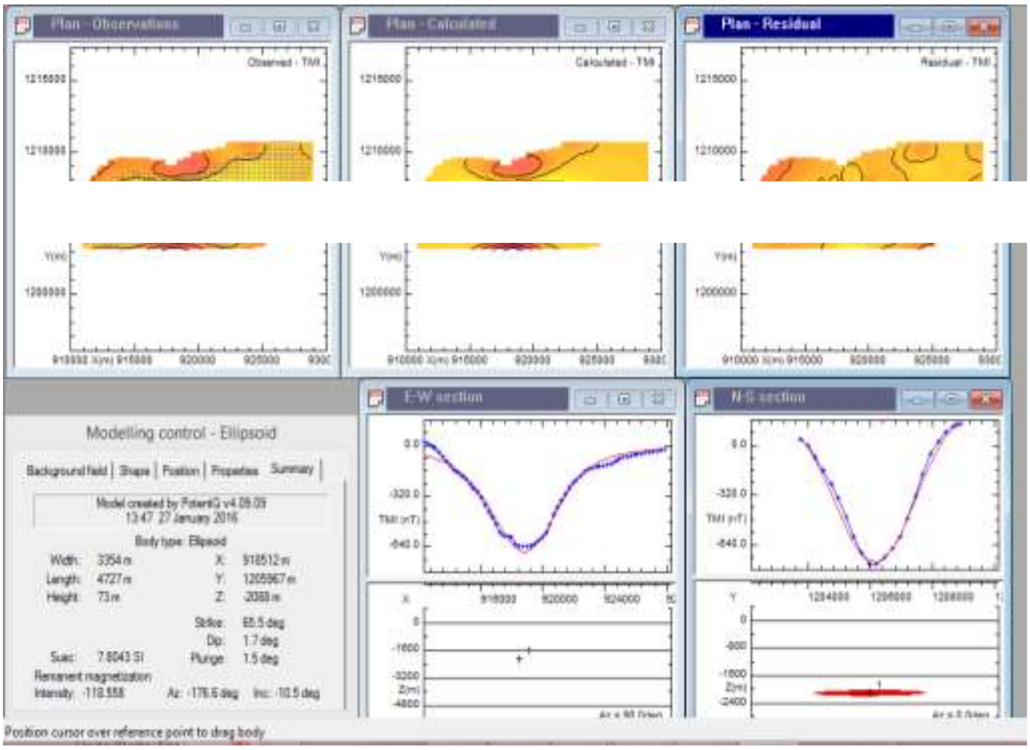


Fig. 3: Model (Ellipsoid) result of Profile 3

Table 1: Summary of the forward and inverse modelling results

| Model | Depth(M) | Dip (Deg) | Plunge (Deg) | Strike (Deg) | Body Shape | Magnetic Susceptibility Value, K (Si) | Possible Minerals | Permanent Magnetization Intensity(Amp/M) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2749 | 69.7 | -88.3 | 65.5 | ELLIPSOID | 0.2047 | BASALT | 7.18 |
| 2 | 2201 | 24.8 | -3.7 | -8.6 | ELLIPSOID | 0.47779 | SCHIST | -25.69 |
| 3 | 2088 | 1.7 | 1.5 | 65.5 | ELLIPSOID | 7.8043 | LIMESTONE | -118.558 |

**Source parameter imaging and depth estimate**

Source parameter imaging (SPI) method enhances knowledge of the thickness of the source bodies (Smith et al, 1998). Fig. 4 shows SPI grid and legend of the study area; the different colours on the grid described the depth range of the anomalies portraying undulation in the sub-surface rocks of the study area. The depth increases upward and three major depth range were observed; the shallow depth represented by A, and the middle depth represented by B and lastly the deep depths represented by C (pink and orange colours) on the upper part of the SPI legend are observed in the central, north-eastern, north-western and some southern part of the grid representing areas of deeper depths. The sedimentary cover or thickness of the study area is between 72.7m (0.0727km) and 5026.8m (5.0267km).

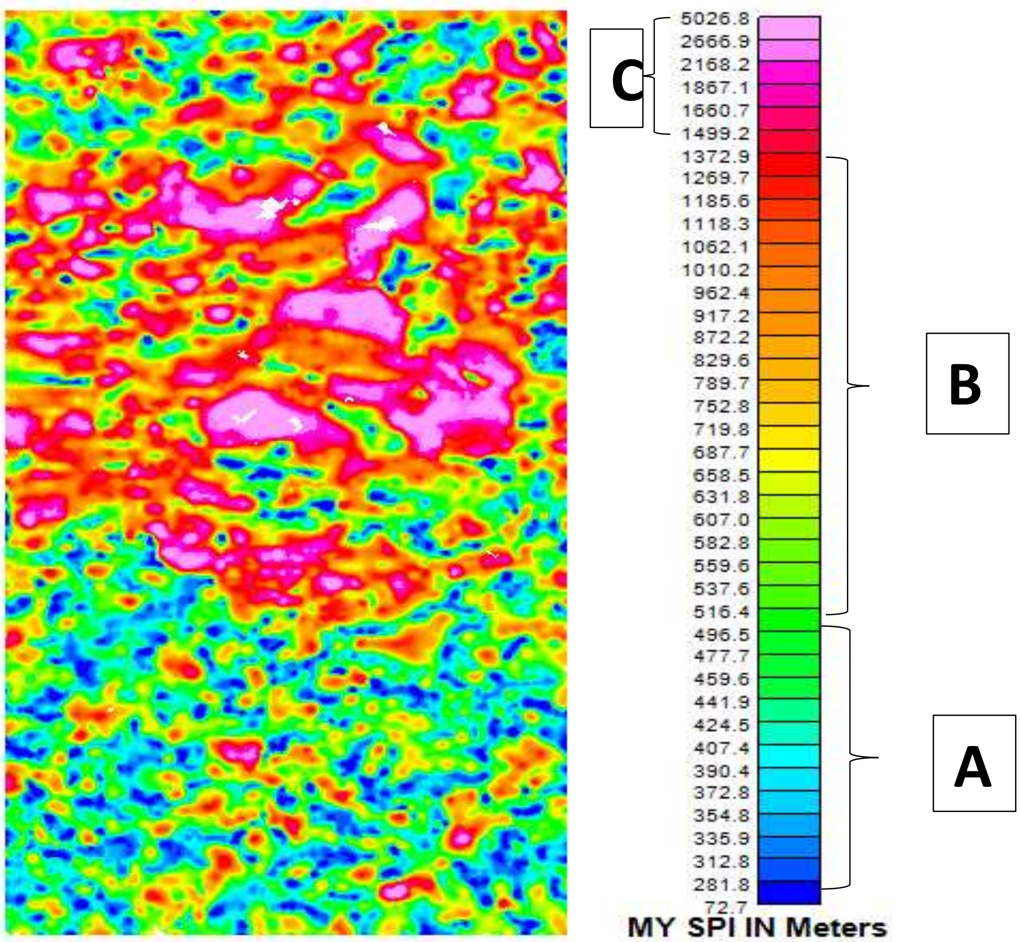


Fig. 4: Source parameter imaging and depth

Table 2: Source parameter imaging result summary

| Depth | Label | Depth range (m) | Colour range | Major towns within | Nature of rock type |
|---|---|---|---|---|---|
| **Shallow section** | **A** | 72.7-477.7 | pale blue and deep blue colours | Biu, Shaffa, Askira, Michika | Old sedimentary rock fromation |
| **Middle Section** | **B** | (i)**Intermediate** Between 496.5-1499.2 | Red, Brown, yellow | Damboa, Mbalala, Chibok | Old sedimentary rock formation |
| **Deeper section** | | (ii) **Deepest** At C between 1660.7-5026.8 | Pink and red | | Old sedimentary rock fromation |
| **Sedimentary cover (thickness)** | A,B and C | 72.7-5026.8 | | Damboa, Mbalala, Chibok, Biu, Shaffa, Askira, Michika | Basalt, Keri-keri formation, Bima sandstone, Shale, clay, Medium to coarse brain biotite granite, Migmatite, Porphyritic Granite/Coarse porphyritic biotite and biotite hornblende granite. |

In this research, two sheets of the high resolution aeromagnetic (HRAM) data covering Chibok and Damboa areas, Chad basin Nigeria was qualitatively and quantitatively interpreted, by employing the methods of source parameter imaging (SPI) and the forward and inverse modelling. Structural and stratigraphic interpretation of the study area modelled using potent software revealed that most of the structures within the area are characterized by anticline, syncline and intrusive. These depth results agree with some depth results obtained by other research works done in the Chad basin. (Kassidy and Nur 2012; Emmanuel et al., 2011; Chukwunonso et al., 2012 and Salako 2014). This represents the average thickness of the sedimentary formation that overlay the basement complex within the central portion of the study area.

The depth obtained by the source parameter imaging (SPI) method ranges from 0.072 km to 5.026 km. The maximum depth obtained from SPI is greater than the maximum depth from spectral analysis. The deep magnetic source obtained from SPI are found in the northcentral part of the study area (Fig.4). The deep values correspond to the occurrence of

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the quaternary sediments, while the relatively shallow depth values correspond to the mountainous areas.

The forward and inverse modelling method estimated depths for the profiles 1-3 are 2749m, 2201m and 2088m with respective magnetic susceptibility values of 0.20407, 0.47779, and 7.8043SI. These susceptibility value indicate the presence of minerals such as basalt, schist, limestone and pyrite (Telford et al., 1990).

The depth values obtained by the source parameter imaging (SPI) and modelling shows thick sediment that is sufficient for hydrocarbon accumulation. This agrees with the work of Wright et al., (1985) that the minimum thickness of the sediment required for the commencement of oil formation from marine organic remains would be 2.3 km. The temperatures at deep depth also indicates a favourable condition for hydrocarbon accumulation.

**Conclusions**

Sedimentary basins are very important and should not be neglected for all-natural resource exploration purposes. Hydrocarbon accumulation and its potentials is enhanced by the thickness of the sediments of the Basin, and also by the kind of geological structures existing within the basement that form traps for oil and gas. Maximum depth/thickness obtained from modelling results (2268 m), spectral analysis (4093.1 m), SPI (5026.6 m) and Euler deconvolution (2106.6 to 4808.6 m) show thick sediment that is fairly sufficient for hydrocarbon accumulation which agrees with the work of Wright *et al.* (1985) that the minimum thickness of the sediment required for the commencement of oil formation from marine organic remains would be 2300 m (2.3 km).

The results obtained from the use of the new high resolution data have shown some similarities with results obtained by some previous researchers who used old aeromagnetic data. However, results from the new data shows a better striking feature owing to the high-resolution nature of the 2009 data more than the 1970s data in terms of terrain clearance, line spacing and improvement of technology. The depth values estimated from the spectral analysis and the values of magnetic susceptibilities are indication that mineral prospecting should be intensified. This work will help to ascertain a better geophysical detail of



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the southern part of the Chad-Basin, and further enhanced the full coverage of the whole basin in the exploration activity.

**Recommendation**

Full scale seismic reflection and well logging work in the study area are recommended to fully ascertain the presence of hydrocarbon accumulation. Gravity and land magnetic survey should also be carried out in the study area to confirm the results obtained in this work, most especially in terms of the minerals present.

**REFERENCES**

Burke, K.C., (1976): Development of graben associated with the initial rupture of the Atlantic Ocean I.: Sedimentary basins of continental margins and cratons, Tectonophysics, (36) 93-112.

Chukwunonso, O.C., Onwuemesi, A.G., Emmanuel. A.K., Chinwuko, A.I., Ikumbur, B.E. and Usman, A.O., (2012): Aeromagnetic Interpretation over Maiduguri and Environs of Southern Chad Basin, Nigeria. *Journal of Earth Sciences and Geotechnical Engineering*, 2(3):77-93.

Chukwunonso, O.C. (2013): Spectral analysis of aeromagnetic data over part of the southern Bida basin, west-central Nigeria. *International Journal of Physical Sciences* 3(2):27-31.

Dobrin, M.B. and Savit, C.H. (1988): Introduction to geophysical prospecting

Emmanuel, K.A., Ajana, G.O., Augustine, I.C. and Leonard, N.O. (2011): The interpretation of the aeromagnetic anomalies over Maiduguri-Dikwa depression, Chad Basin Nigeria. *Archives of Applied Science Research*, 3(4):499-508.

Fairhead, J.D., and Blinks, R., (1991): Differential opening of the central and south Atlantic Oceans and the opening of the West African rift-system. Tectonophysics, (1987):191-203.

Genik, G.J. (1993): Petroleum Geology of Cretaceous-Tertiary rift Basin in Niger, Chad and Central African Republic. American Association of petroleum geologist, Bull. 77(8):1405-1434.


**EDITOR-IN-CHIEF**
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Hahn, A., Kind, E., Mishra, D.C. (1976). Depth estimate of magnetic sources by means of Fourier amplitude spectra. Geophysical Prospecting, (24):287-308.

Hartley, R.W., and Allen, P.A., (1994): Interior cratonic Basins of Africa: Relation to continental break-up and role of mantle convection. Basin research (6):95-113.

Ikumbur, E.B., Onwuemesi, A.G., Anakwuba, E.k., Chinwoko, A.I., Usman, A.O. and Okonkwo, C.C. (2013): Spectral analysis of aeromagnetic data over part of the southern Bida basin, West-central Nigeria. *International Journal of Fundamental Physical Sciences,* 3(2):27-31.

Kassidy, S. and Nur, A. (2012): Analysis of Aeromagnetic data over Mutum-Biyu and its environs, Northeastern, Nigeria. *Research Journal in Engineering and Applied Sciences* 1(2):142-148.

Klein, G.D., and Hsui, A.T., (1987): Origin of intrcratonic Basin. Geology (15):1094-1098.

Leighton. M.W., and Kolata, D.R., (1990): Selected interior cratonic Bsins and their place in the scheme of a global tectonics. *American Association of petroleum Geologist memoir*. (51):729-797.

Matheis, G. (1986): Short review of the geology of the Chad Basin in Nigeria, in C. A. Kogbe (ed). Geology of Nigeria: Elizabeth publishing, surulere Nigeria. 289-294.

Obaje, N.G.J., Wehner, H., Hamza, H.and Scheeder, G. (2004): New Geochemical data from the Nigerian sector of the Chad basin: Implication on hydrocarbon propectively. *Journal of African Earth Sciences*, 38(5):477-487.

Olugbemiro, R.O., Ligouis, B., and Abaa, S.I., (1997): The Cretaceous Series in the Chad Basin, NE, Nigeria: Source rock potential and thermal maturity. Journal of Mining and geology, 20(1), 51-68.

Salako, K.A. (2014): Depth to basement determination using Source Parameter Imaging (SPI) of aeromagnetic data: An application to upper Benue Trough and Borno Basin, Northeastern, Nigeria. *Academic Research International*, 5(3): 54-57.

Smithson, S.B. and Decker E.R. (1974). "A Continental Crustal Model and its Geothermal Implications". *Earth Planet ScienceLetter*,(22):215-225.



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Smithson, S.B. and Brown, S.K. (1977). A Model for the Lower Continental Crust. *Earth Planet Science Letter,*(35):134-144.

Telford, W.M., Geldart, L.P. and Sheriff, R.E. (1990): Applied geophysics (2nd edition), Cambridge University Press, Cambridge.

Thurston, J.B. and Smith, R.S. (1997): Automatic conversion of magnetic data to depth, dip, and susceptibility contrast using the SPITM method. *Geophysics*, 62(3):807-813

Wright, J.B., Hastings, D., Jones, W.B., Williams, H.R. (1985): Geology and mineral resources of West Africa. George Allen and Urwin, London.


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