OPEN ACCESS

Journal of
Geology and Mining Research

August 2018
ISSN 2006-9766
DOI: 10.5897/JGMR
www.academicjournals.org

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The Journal of Geology and Mining Research (ISSN: 2006-9766) is published twice a month (one volume per year) by Academic Journals.

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Journal of Geology and Mining Research

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Vol. 10(6), pp. 57-71, August 2018
DOI: 10.5897/JGMR2018.0292
Article Number: 2271C8D57898
ISSN: 2006-9766

http://www.academicjournals.org/JGMR

Journal of Geology and Mining Research

Full Length Research Paper

Investigation of magnetic anomalies of Abakaliki area, Southeastern Nigeria, using high resolution aeromagnetic data

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Received 26 February, 2018; Accepted 26 March, 2018

Aeromagnetic data over Abakaliki area of lower Benue trough, Nigeria was interpreted qualitatively and quantitatively using Oasis montaj software. The qualitative interpretation unveiled basic intrusive bodies like dykes, laccolites and batholitic bodies in the area. It also revealed fault zone which trends southeastern part of the study area. Quantitative interpretation was carried out by forward and inverse modeling, source parameter imaging and Euler deconvolution methods. Depth obtained by source parameter imaging (SPI) ranged from 99.50 to 5930.78 m. Results from this study indicate that deep seated bodies are predominant in the southwestern part of the area, while shallow bodies are predominant in the southeastern part of the area. The anomalies over the area were modeled by bodies in the form of sphere and ellipsoid by varying the total magnetic intensity parameters. Depth obtained by model A is 546 m with susceptibility value of 0.0180 signifying limestone. The height of Model B is 50 m signifying outcrop, likely to be the outcrop near college of Agricultural Sciences of Ebonyi State University, Abakaliki, with susceptibility value of -0.0017 signifying calcite. Depth obtained for models C, D and E are 956, 6366 and 477 m respectively, with respective susceptibility values of -0.0134, -0.009 and -0.006 signifying rock salt, quartz and Calcite. Maximum depth obtained by forward and inverse modeling is 6366m while that obtained by source parameter imaging is 5930.78 m.

Key words: Abakaliki area, aeromagnetic anomalies, qualitative and quantitative interpretation, intrusive bodies, hydrocarbon accumulation.

INTRODUCTION

The study of geophysics has helped man to locate buried materials usually of geophysical interest in the earth's sub-surface. These materials usually manifest as anomalies which could be sensed by different geophysical

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survey methods. The subsurface which is based on the variation of the magnetic field of the earth that results from the magnetic properties of the underlying rocks is studied using magnetic survey. Magnetic survey may be carried out in air (aeromagnetic), land and sea. The magnetic field of the earth acts on the magnetic minerals in the crust, inducing a secondary field which reflects the distribution of the minerals. The main magnetic field induces a field which varies slowly from one place to another while the crustal field which is the portion of the magnetic field associated with the magnetism induced by the earth's main magnetic field varies more rapidly (Reford, 1962).

The major role of aeromagnetic investigations over continental zones is to establish geologic and tectonic frame works and to explore for minerals. The magnetic technique is a relatively cheap method of learning about geologic threats such as seismically dynamic faults, trivial magma cavities and volcanic cores. Petroleum industry has mapped structures and enhanced depth to magnetic basement using aeromagnetic data (Steenland, 1965).

Aeromagnetic survey is the exploration method of the intensity of the magnetic field of the earth with magnetometers installed in airplanes or helicopters. The process is to operate the magnetometer continuously along equally spaced parallel flight lines covering the survey area. The principle of the aeromagnetic survey is related to a magnetic technique performed with a magnetometer held with hand but it permits more surface areas of the earth to be covered more quickly. The aircraft flies in a grid-like pattern with height and line spacing determining the resolution of the data. The magnetometer registers minute differences in the intensity of the ambient magnetic field due to the temporal effects of the frequently fluctuating solar wind and spatial differences in the magnetic field of the earth, as the aircraft flies. The spatial variation of the earth's field is due to the regional magnetic field and the local effect of magnetic minerals in the earth crust. Subtraction of the solar and regional effects reveals the spatial distribution and relative abundance of magnetic minerals.

Magnetic method is used in many areas such as locating intra-sedimentary faults, defining subtle lithological contacts, mapping salt domes in weakly magnetic sediments. The major aim of aeromagnetic geophysical technique is to spot rocks and minerals with uncommon magnetic properties that disclose themselves by producing anomalies in the intensity of the magnetic field of the earth (USGS, 1997). The anomalies may be due to subsurface structures that have bearing on the site of oil deposits (Lowrie, 2004). Residual magnetic anomaly charts are valuable for hydrocarbon investigation, since they detect the presence of intrusive, lava flows or igneous plugs which are parts that need to be evaded in hydrocarbon exploration (Selley, 1998). Ground and aeromagnetic data are employed to study the existence of a mineral deposit in conjunction with gravity survey for the exploration purposes. Both magnetic and gravity techniques are broadly employed in mining industry as investigation tools to map subsurface geology and evaluate ore reserves for some enormous ore bodies (Biswas and Sharma, 2016; Mandal et al., 2015; Biswas et al., 2014a, b).

The region of mineralization emanating from the tectonic events in the Benue Valley seems to run in the narrow tract spreading from the southeast in the Abakaliki Trough axis to the northeast. The Benue Trough is mostly recognized to have many mafic and felsic intrusives, sub-basinal structures combined with a positive prospect for hydrocarbon accumulation (Ugbor and Okeke, 2010). Abakaliki area is considered to have a quantity of economic mineral deposits which have created a lot of attention on the commercial significance of this mineral region. The area has a lot of possibilities for hydrocarbon and minerals like lead, zinc, silver, salt, limestone and dolerite which form quarry that provide commercial influence to the people of Abakaliki (Ezema et al., 2014). The major component units of the Lower Benue Trough are the Abakaliki anticlinorium, Afikpo syncline and Anambra basin (Obaje, 2009). By way of increasing the nationwide exploration and production base and thus enhance the proven reserves strength, several investigation operations have been embarked on, in the inland basins of Nigeria. The Bida basin, southeastern sector of Bornu basin (Chad basin), Benue Trough, Sokoto basin and Anambra basin encompass the inland basins of Nigeria. The inadequate information on the geology of these inland basins and the distant from existing structure (finding should be sufficiently great to permit production investments) have frustrated the efforts of many explorers. These made many international companies to turn their attention from frontier onshore to frontier deep-water and ultra-deep water offshore of the Niger Delta zone. The inland basins of Nigeria institute a set of sequences of Cretaceous and later rift basins in Central and West Africa whose source is linked to the opening of the South Atlantic (Obaje, 2009).

The purpose of this study is to interpret magnetic anomalies of Abakaliki area with the intention of providing information on: (i) nature of intrusive in the area and mineral deposits associated with it, (ii) hydrocarbon potentials of the area and (iii) depths to the magnetic anomalous bodies. The results from this study will be compared with results from land gravity survey and results from previous studies in the area and within Lower Benue Trough generally.

Geology of the study area

Abakaliki area falls within the lower Benue Trough and it is located between latitude 6° 35' N and 6° 45' N and Longitude 8° 42'E and 8° 47'E, with average elevation of 117 m. Separation of South American plate from the

African plate is assumed to form the Benue Trough (Petters, 1978). The separation of the continents led to an aborted rift (Aulacogen) which was later filled with transgressive and regressive sedimentary deposits. Aside Abakaliki anticlinorium towards the Anambra basin, the Afikpo cyncline is also part of the Lower Benue Trough. The order of actions that led to the development of the Benue Trough and its constituent components are fairly written (Burke et al., 1971; Nwachukwu, 1972; Olade, 1975; Benkhelil, 1982; Ofoegbu, 1985a). Sedimentation in the Lower Benue Trough began with the marine Albian Asu River Group, though certain pyroclastics of Aptian-Early Albian ages were sparingly stated (Ojoh, 1992). Shales, limestones and sandstone lenses of the Abakaliki Formation in the Abakaliki area constitute the Asu River Group in the Lower Benue Trough and the Mfamosing Limestone in the Calabar Flank (Petters, 1982). A series of tectonic activities characterize the formation of block faulting.

The Lower Benue Trough underlain by thick sedimentary sequences deposited in the cretaceous and the Precambrian basement complex is essentially made up of granitic and magnetic rocks which are predominant in the eastern part of the study area (Ofoegbu and Onuoha, 1990). The development of Abakaliki anticlinorium was adversely affected by the folding episode which occurred during the Santonian; hence, the main compressional nature of the fold that took place over the time was exposed by their asymmetry and reversed faults. Asu-River Group (Albian), Awgu shale (caniacian), Nkporo shale, and Ezeaku shale (Turonian) are four geologic formations in which the sediments that arise in the Abakaliki anticlinorium belonged.

The Albian Asu-River Group contains of bluish black shales with slight sandstone components. The shales are fissile, fractured and are related with Pyroclastic rocks. Calcareous sand stones of caniacian age, limestone and marine fossiliferous grey bluish shales make-up the Awgu shales, which are overlay by Nkporo shales that are mostly marine in character. The Eze-Aku Formation consists of black shale and siltstones which sits unconformably at the Precambrian gneiss to the north of Ugep (Ukaegbu and Akpabio, 2009). Reporting on the geology of Abakaliki, Benkhelil (1988) accredited its geological development to what happens in a comprehensive Orogenic cycle which involves sedimentation, magmatism, compressive tectonics and metamorphism. Injection of numerous intrusive bodies into the shales of Eze-Aku and Asu-River groups resulted from magmatism. Intrusive occurs mainly in sills in the study area. The sills could be lacolith, batholiths or dyke (Ofoegbu, 1985b; Mamah et al., 2000). The Eze-Aku Formation at the Afikpo basin forms the Amasiri sandstones. This unit is conformably overlain by the Senonian Sandstones and Upper-coal beds along Afikpo, Udi and Ugep. The coal seams are the Mamu Formations which are Maastritchtian. Figure 1 shows the geologic map of Abakaliki.

METHODOLOGY

Source of data

The digitized aeromagnetic data used in this study were gotten from the Nigerian Geological Survey Agency (NGSA). The aeromagnetic data were acquired in 2008 through the airborne geomagnetic survey conducted by Fugro Surveys Limited for the NGSA, as part of the nationwide aeromagnetic survey in 2008. The data were digitized along flight lines and plotted with a contour interval of 2.5 nT with an average flight height of about 80 m and across tie of 2 km which assisted in smoothing the data. The nominal flight line spacing was 500 m. -13.9 and -6.6° were, respectively the average magnetic inclination and declination across the survey area. The digital form of the data (sheet 303) was made available on a scale of 1:50,000.

Method of data analysis

The data passed through different processing stages (removal of geomagnetic gradient, filtering and depth estimation) to get it ready for interpretation. Two methods of interpretation were employed in this study: qualitative and quantitative. Qualitative interpretation involves the extraction of geologic information from maps and grids. This information is geared towards mapping surface and subsurface structures such as intrusive. The first step in qualitative interpretation was the preparation of magnetic maps or grids on which the intensity values at different stations were plotted and on which contours were drawn at suitable intervals. The contouring was done using Oasis Montaj software by interpolation. The contour was observed in this work in the form of coloured maps and grids, where the colour gradations represent areas enclosed between successive contours.

Quantitative interpretation was carried out by employing forward and inverse modeling, source parameter imaging (SPI) and Euler-3D methods. Quantitative interpretation includes making numerical approximations of the depth and dimensions of the causes of anomalies and this frequently takes the method of modeling of sources which could, in theory, reproduce the anomalies noted in the survey (Reeves, 2005; Biswas et al., 2017; Biswas, 2016). The first stage of quantitative aeromagnetic data interpretation involved the application of mathematical filters. Filtering encompasses the use of low pass or high pass in the removal of either high frequency or low frequency from the data. But in this work, low pass was used to filter off high frequency signal from the data. The different filtering methods employed include: first vertical derivative (FVD), second vertical derivative (SVD), horizontal derivative (HD), reduction to pole (RTP) and upward continuation (UP).

The form of a magnetic anomaly relies on the nature of the causative body, inclination and declination of the magnetization of the body, inclination and declination of the local magnetic field of the earth and the orientation of the body with regards to magnetic north. The observed magnetic anomaly is transformed into the anomaly that would be measured if the magnetization and ambient field were both vertical by reduction to pole. Reduction to pole removed the effect of the earth’s magnetic field by way of a gross shift of the observed magnetic readings. The procedure was nothing more than a correction factor applied across the study area to remove the non-vertical magnetic component, leaving only the causative body in its correct spatial position. This process helped to define the boundaries between different basement lithology with different magnetic susceptibilities. Interpretation of magnetic survey is best done on the pole. The vertical alignment enhanced

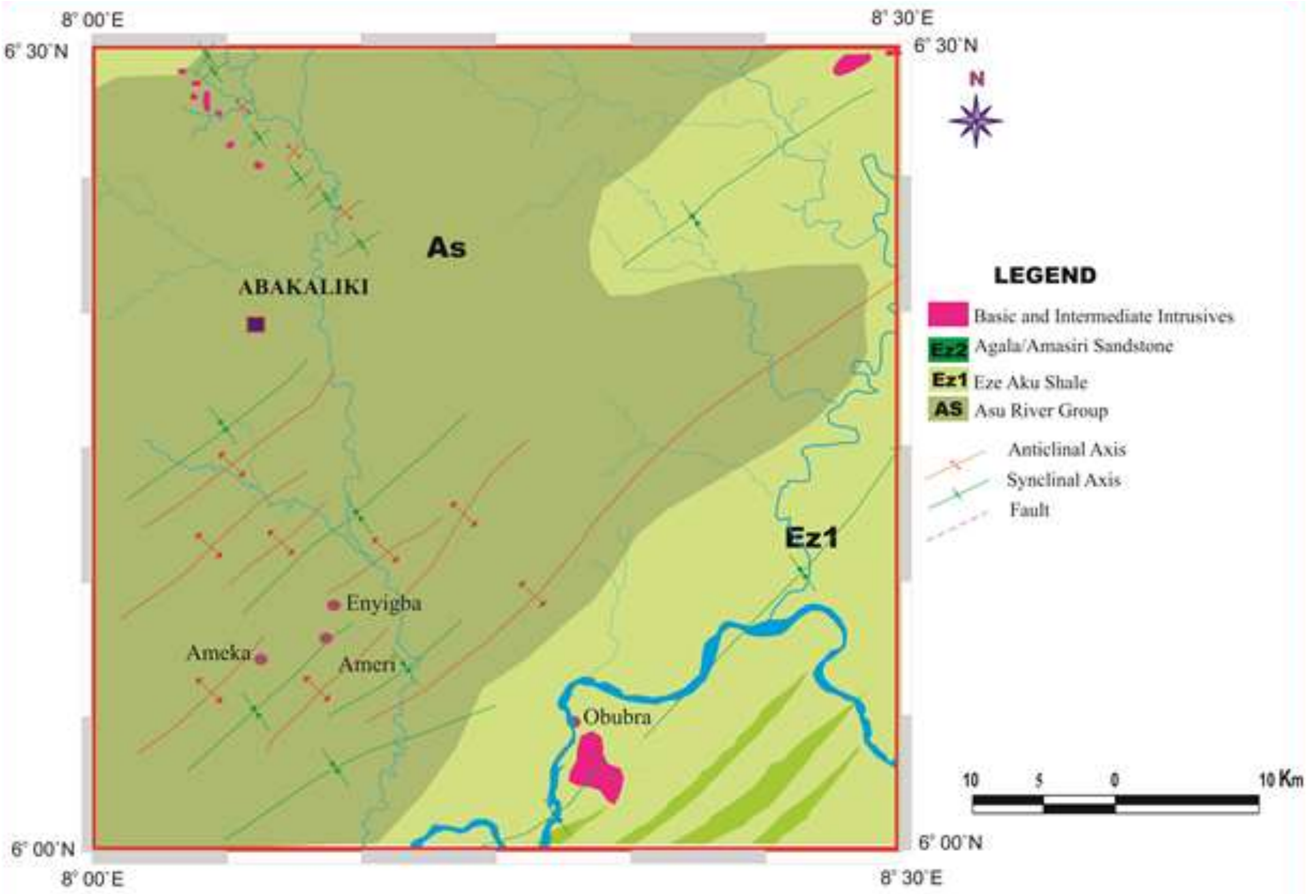


Figure 1. Geologic map of Abakaliki.

overview and interpretation of the anomalous magnetic anomalies.

First and second vertical derivatives emphasized shallower anomalies and can be calculated either in the space or frequency domains. These derivatives were employed to sharpen the edges of the anomalous bodies. The effect of these derivatives was to suppress regional anomalies and enhance local anomalies. The FVD portrays the rate of change of the anomaly with elevation or the variation of the anomaly with height. This enhanced knowledge of the shallow depth of the magnetic anomalies. SVD explains the rate of change of gradient with depth. It sharpened the edges of the anomalous bodies or the boundary between the anomalies. Many modern methods for edge detection and depth to source estimation rely on horizontal and vertical derivatives. In this work, the horizontal gradient was filtered in the x and y directions. Upward continuation is the process of transforming measured data on a given plane to data measured at a higher elevation, hence, smoothening the anomalies and projecting the surfaces upward above the original datum. The upward continuation enhanced knowledge of deeper depth of the anomalous bodies.

Depths estimation to anomalous bodies was carried out using three different methods: forward and inverse modeling, SPI and Euler deconvolution. Modeling is a method used to determine depth to the buried magnetic anomalies, susceptibilities of rocks in the modeled area, angle of dip of anomalous body, plunge and strike angles of the bodies, length, width and height of the bodies (shape).

Forward modeling is a process of creating a shape that could be attributed to the shape of the causative magnetic anomaly buried below the surface by the software. This involves generating a field which could be compared with the observed field displayed. The process of comparing the field is achieved by inputting the following total magnetic field intensity parameters: susceptibility, inclination, declination and profile azimuth. These parameters were changed until the calculated curve best-fits the observed curve. The depth and dimensional parameters of the body is adjusted by trial and error until a satisfactory agreement is achieved between the calculated and observed values (Parasnis, 1986). Inverse modeling is the reverse procedure of the forward modeling and involves determining the geometry and the physical properties of the source from measurement of the anomalies. Modeling was done using Potent Q software (an extension of Oasis Montaj software). SPI method calculated source parameters (edge locations, depths, dips and susceptibility contrasts) for gridded magnetic data. SPI depth of magnetic data was determined using Oasis Montaj software and employed the first and second vertical derivatives to locate depth to the center of the anomalous bodies. It also enhanced knowledge of the thickness of the source bodies (Smith et al., 1998). Euler 3D deconvolution was used to estimate depth to shallow magnetic bodies. This technique uses first order, x, y and z derivatives to determine location and depths to anomalous targets like sphere, cylinder, thin dyke, etc. Each of the shapes is characterized by specific structural index. Euler deconvolution is not limited to bodies that have known structural indices as Reid et al. (1990) extended the technique to 3D data by applying the Euler operator to windows of gridded data sets. For the purpose of this work, the mathematical calculation and gridding of Euler 3D was performed using Oasis Montaj, wherein images were produced and depth to the suspected

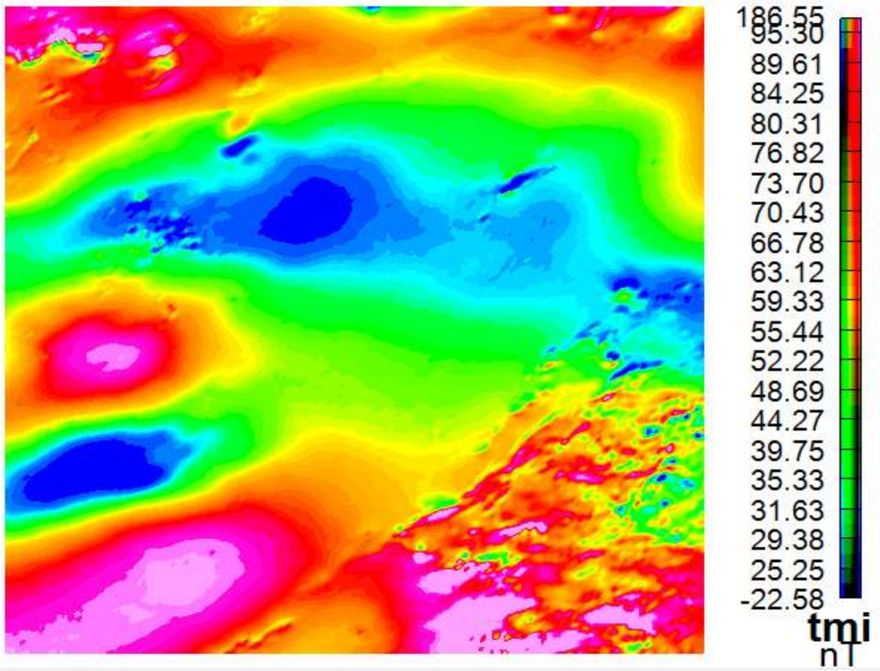


Figure 2. Grid map of the total magnetic intensity of the study area (TMI).

magnetic bodies was estimated. Using three structural indices (SI = 1, 2, 3), three Euler 3D grids were generated.

RESULTS AND DISCUSSION

Figure 2 shows grid map of the total magnetic intensity (TMI) of the study area resulting from qualitative interpretation. The pink colour areas are high intensity areas which have the tendency of producing large gabbro formation with long ore bodies. The circular contours are areas of basic intrusives with ore bodies. The basic intrusives could be lacolyte, batholyte or dyke. The TMI grid also shows fault zone or dislocation zone which is the area where one magnetic anomaly is displaced with respect to another. The fault zone trends northeast to southwestern (NE-SW) part of the area. The green colour areas in the grid are areas with no distinctive contour pattern. These areas are termed quiet areas and have the tendency of limestone, quartzitic rocks and monzonite formation (Parasnis, 1986). The grid shows prominent area of mineralization in the southeastern part of the study area.

When the data used in this work were reduced to pole, the deep seated magnetic bodies represented by the blue colour aligned vertical while the shallow magnetic bodies represented by red, pink and light pink colours tend to align vertical (Figure 3). The vertical alignment enhanced overview and interpretation of the anomalous magnetic anomalies.

The first vertical derivative (FVD) (Figure 4) enhanced knowledge of the shallow depth of the magnetic anomalies, while the second vertical derivative sharpened the edges of the anomalous bodies or the boundary between the anomalies. The second vertical derivative was associated with noise as a result of the presence of both short wavelength and long wavelength anomalies in the sedimentary area. This effect is noticed in the blurred image of the grid (Figure 5). Figure 6 shows the grid of the horizontal derivative (HD). The upward continuation enhanced knowledge of deeper depth of the anomalous bodies (Figure 7).

Modeling was done using Potent Q software. Figure 8 shows the models used in the interpretation, while the subsets of the modeled portions (A, B, C, D, E) are as shown in Figure 9. From the longitude and latitude of the modeled areas, the modeled areas were delineated as: Obubara, Abakaliki, Enyigba, Ameka and Ameri, respectively. In the model, parameters like position and susceptibility were varied until the calculated curve best fits the observed curve. The observed curve is the blue curve while the calculated is the red curve.

The summary of the modeling results is shown in Table 1. The susceptibility (k) values obtained from profiles A, B, C, D and E are 0.0180, -0.0017, -0.0134, -0.009 and -0.006, respectively which signifies limestone, calcite, rock salt, quartz and calcite (Telford et al., 1990). The height of model B is 50 m which signifies outcrop, likely to be the outcrop near College of Agricultural Sciences of Ebonyi State University, Abakaliki. Depth for model A (Obubara) is 546 m, depth for model C (Enyigba) is 956 m, depth for model D (Ameka) is 6366 m and depth for

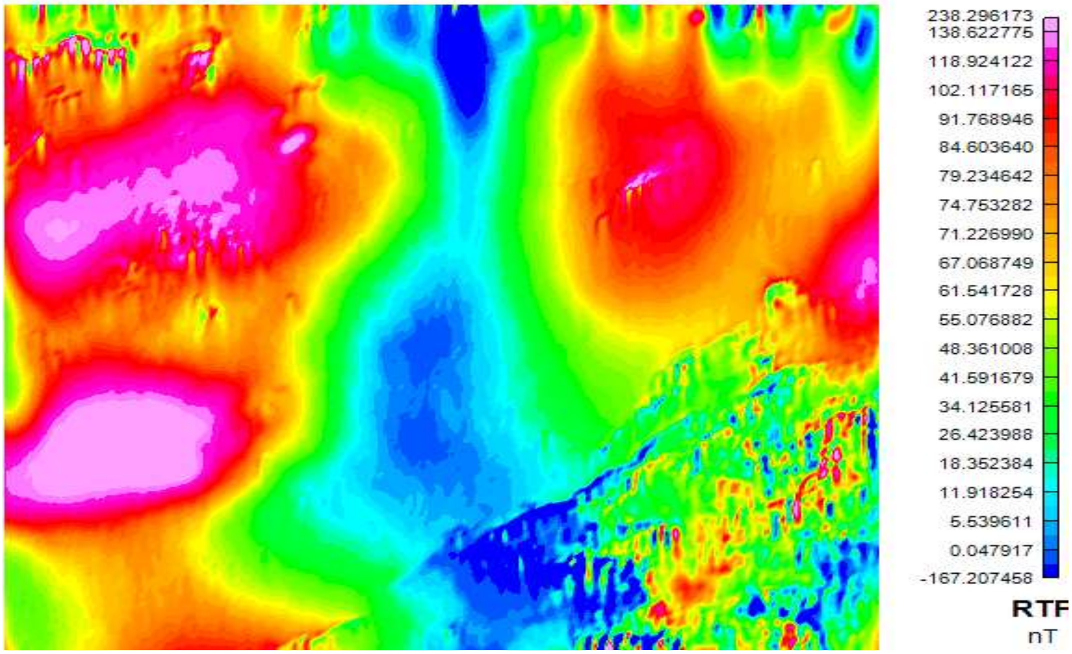


Figure 3. Grid map of reduction to pole.

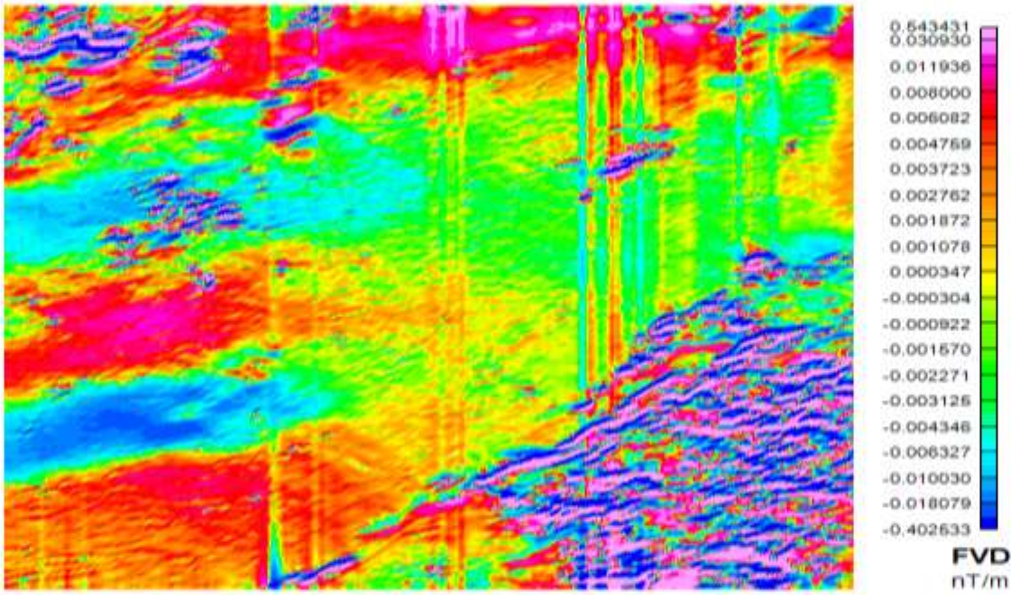


Figure 4. Grid map showing FVD.

model E (Ameri) is 477 m.

Depth to the magnetic anomalous bodies computed by employing SPI (Figure 10) ranged from 99.50 to 5930.78 m. The colour variations indicate different magnetic depths and susceptibility contrasts in the study area. The deep blue to light blue colour which ranged from 99.59 to 143.44 m show depth to shallow magnetic bodies while the pink to light pink colour ranging from 1070.71 to 5930.78 m signify deep seated bodies. The deep seated bodies are predominant in the southwestern part of the study area.

The mathematical calculation and gridding of Euler 3D was performed using Oasis montaj where images were produced and depth to the suspected magnetic bodies

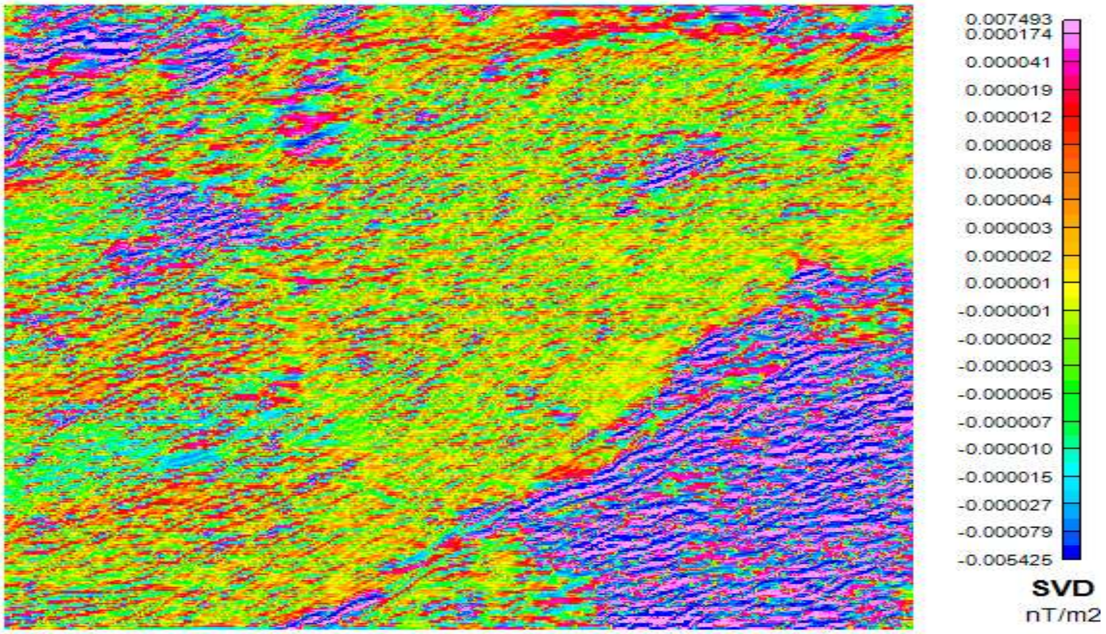


Figure 5. Grid map of SVD.

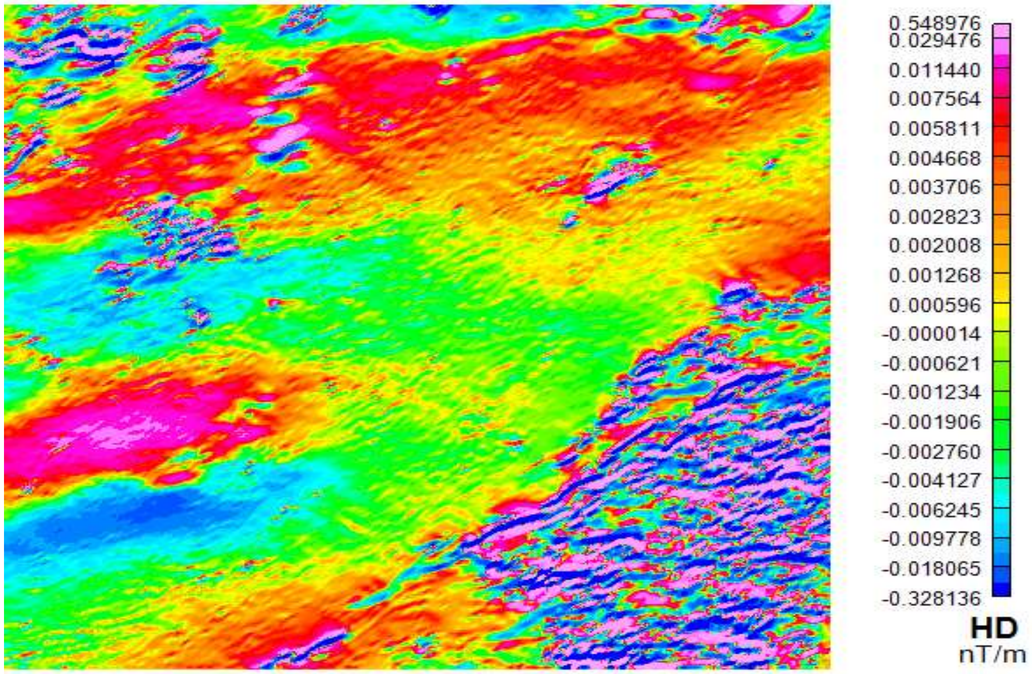


Figure 6. Grid map of HD.

estimated. Using three structural indices, three Euler 3D grids were generated. The legends by the grids showed both positive values and negative values. The positive values signify outcrops in the study area while the negative values signify depth below the surface. However, there are scattered values or colours in the grid. The light blue to deep blue colour on the grid shows depth below the surface, while the pink colour shows outcrop. The portions in the grids without magnetic signature signify no Euler solutions to the structural index

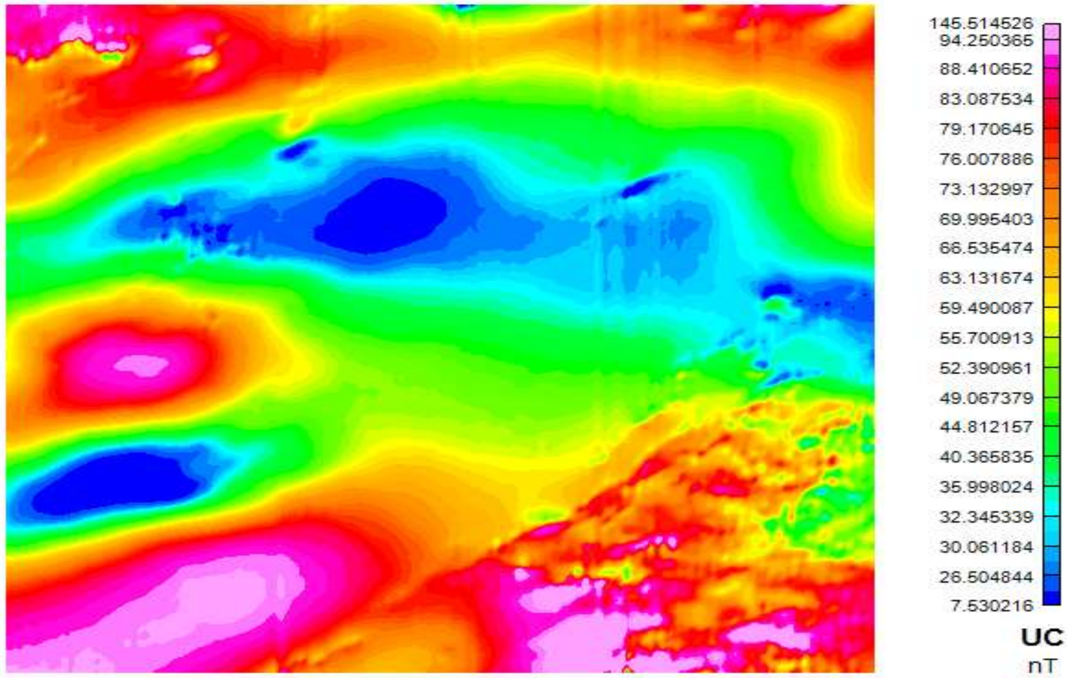


Figure 7. Grid map of upward continuation.

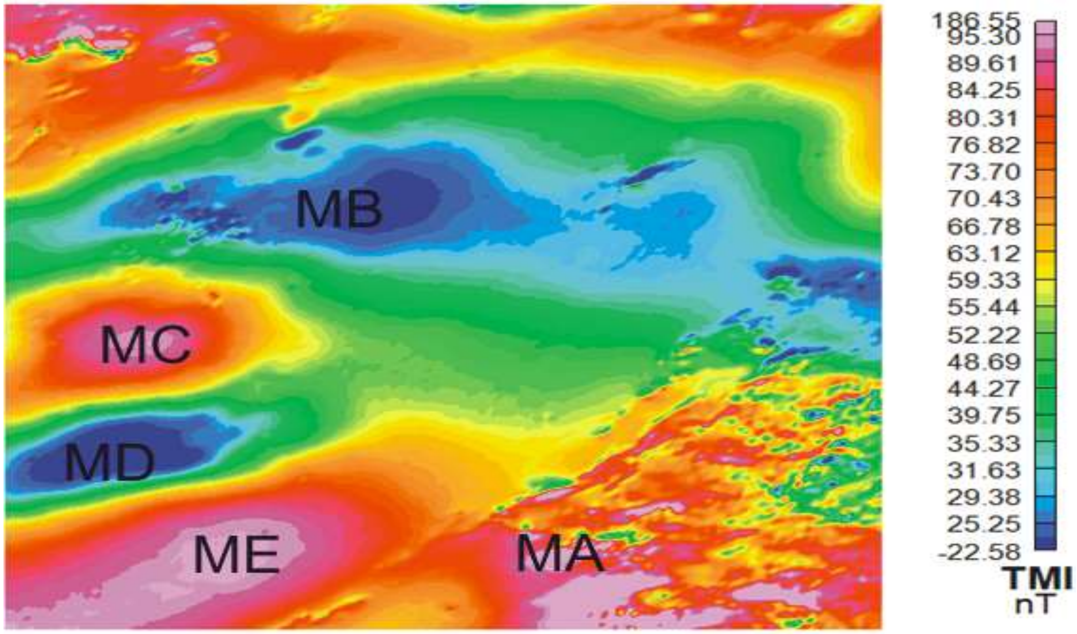
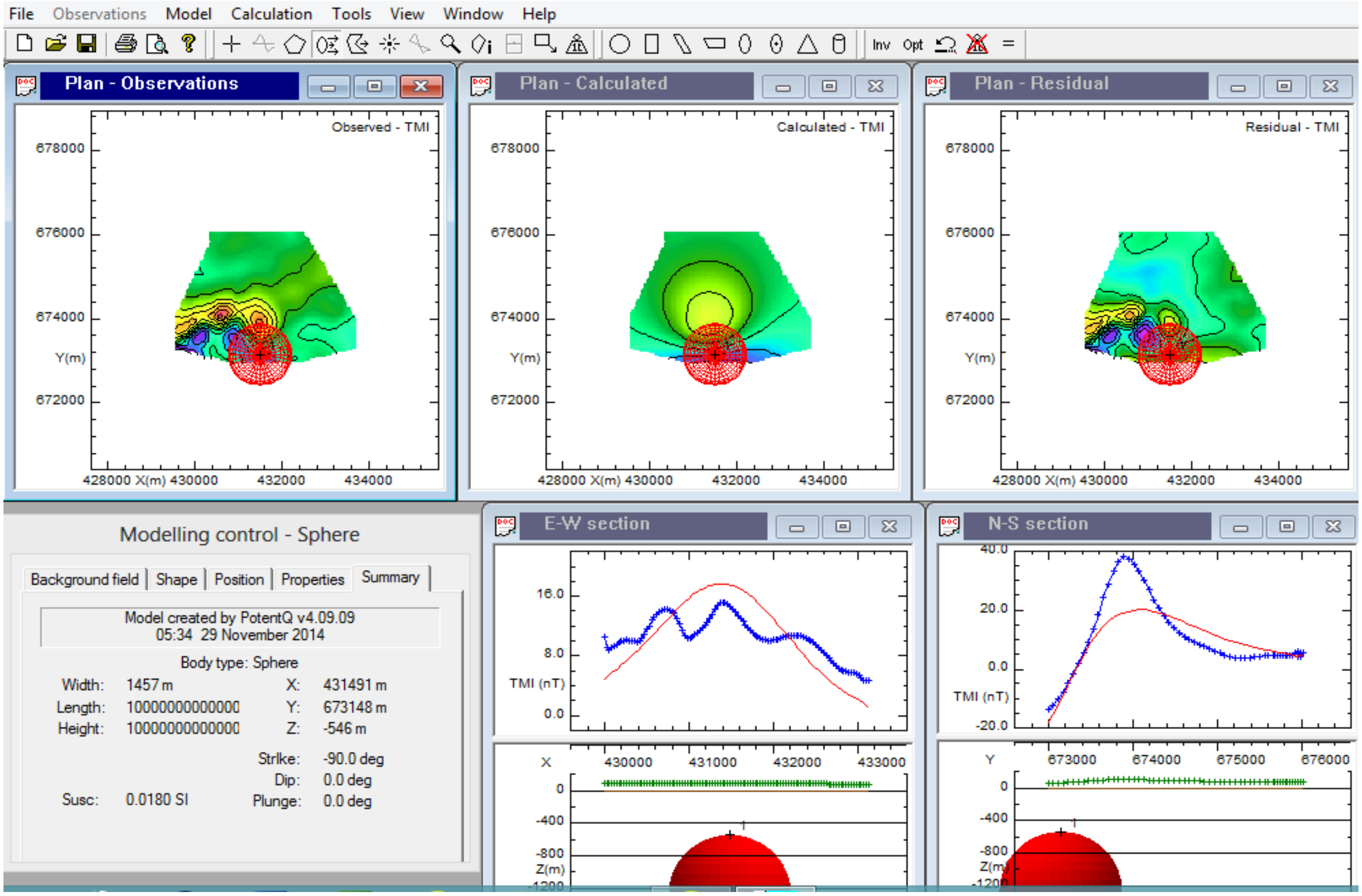


Figure 8. Grid map showing modeled areas (M implies model).

used in the grid. Figure 11a to c shows the Euler solution for the structural indices (1, 2 and 3) used. Table 2 summarizes the result of the Euler depth estimation.

Comparing the results of this study with the results from previous studies that employed different methods in the area, Ugbor and Okeke (2010) carried out land gravity survey in Abakaliki area using worden gravimeter.

Table 3 shows the summary of their results (Z is depth



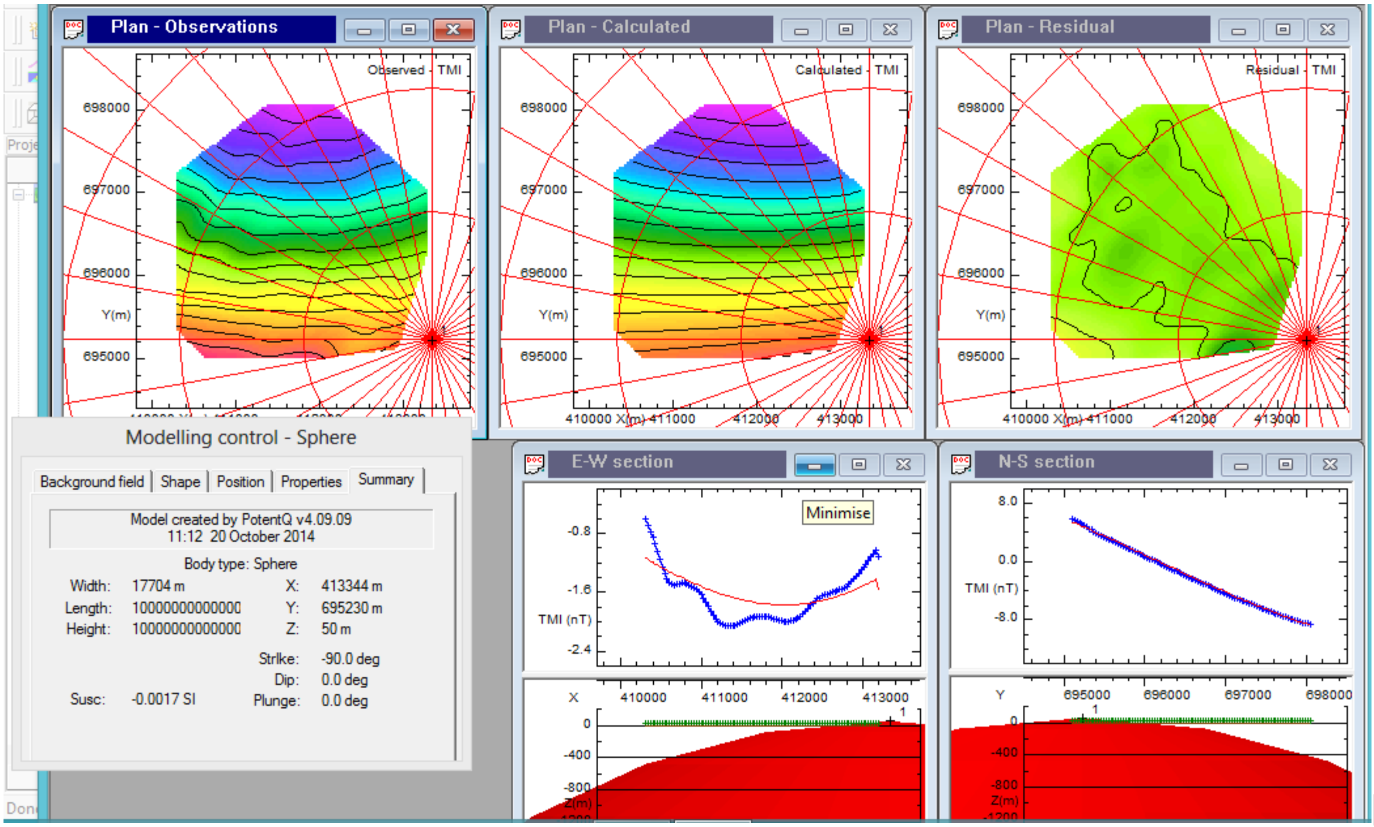
Modelling control - Sphere

Model created by PotentQ v4.09.09
05:34 29 November 2014

Body type: Sphere

Width:	1457 m	X:	431491 m
Length:	10000000000000	Y:	673148 m
Height:	10000000000000	Z:	-546 m
		Strike:	-90.0 deg
		Dip:	0.0 deg
Susc:	0.0180 SI	Plunge:	0.0 deg

A



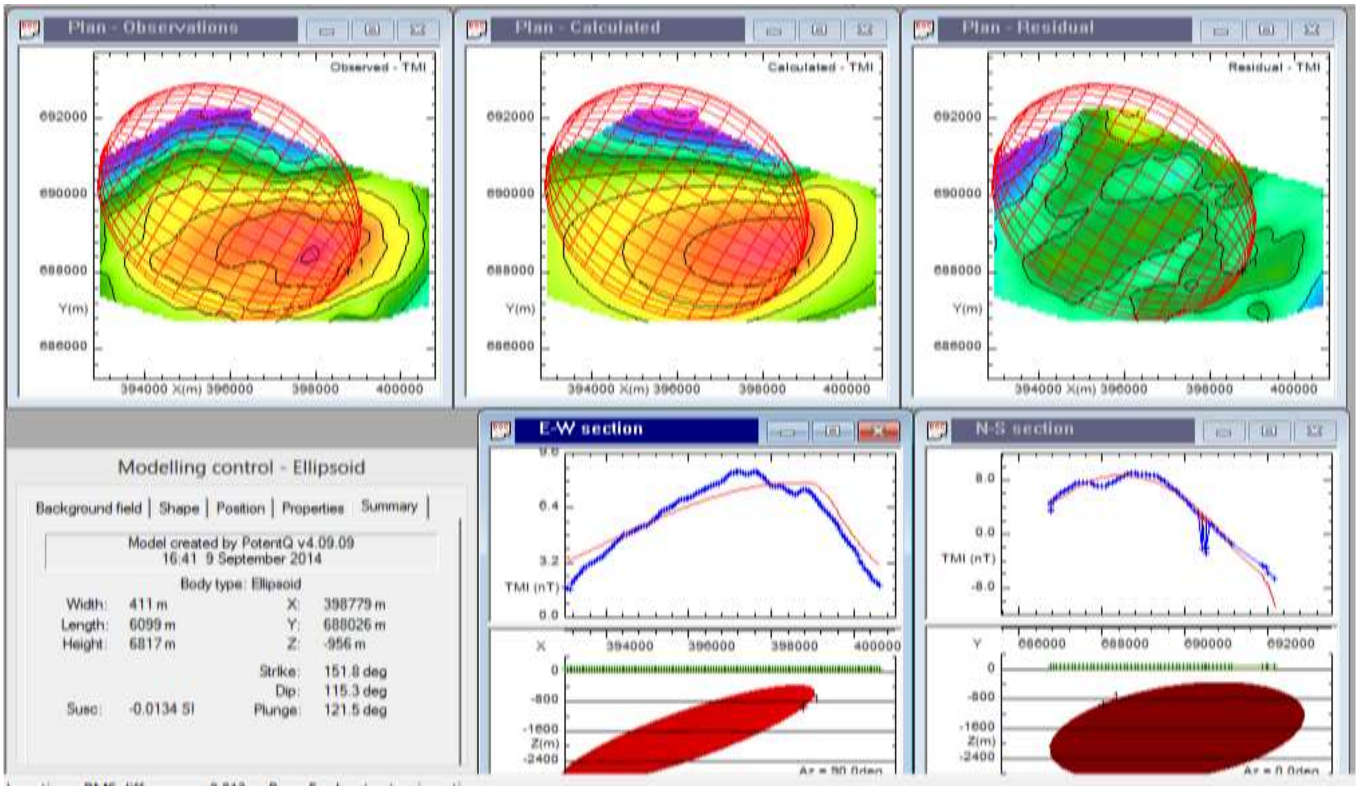
Modelling control - Sphere

Model created by PotentQ v4.09.09
11:12 20 October 2014

Body type: Sphere

Width:	17704 m	X:	413344 m
Length:	10000000000000	Y:	695230 m
Height:	10000000000000	Z:	50 m
		Strike:	-90.0 deg
		Dip:	0.0 deg
Susc:	-0.0017 SI	Plunge:	0.0 deg

B



Modelling control - Ellipsoid

Background field | Shape | Position | Properties | Summary

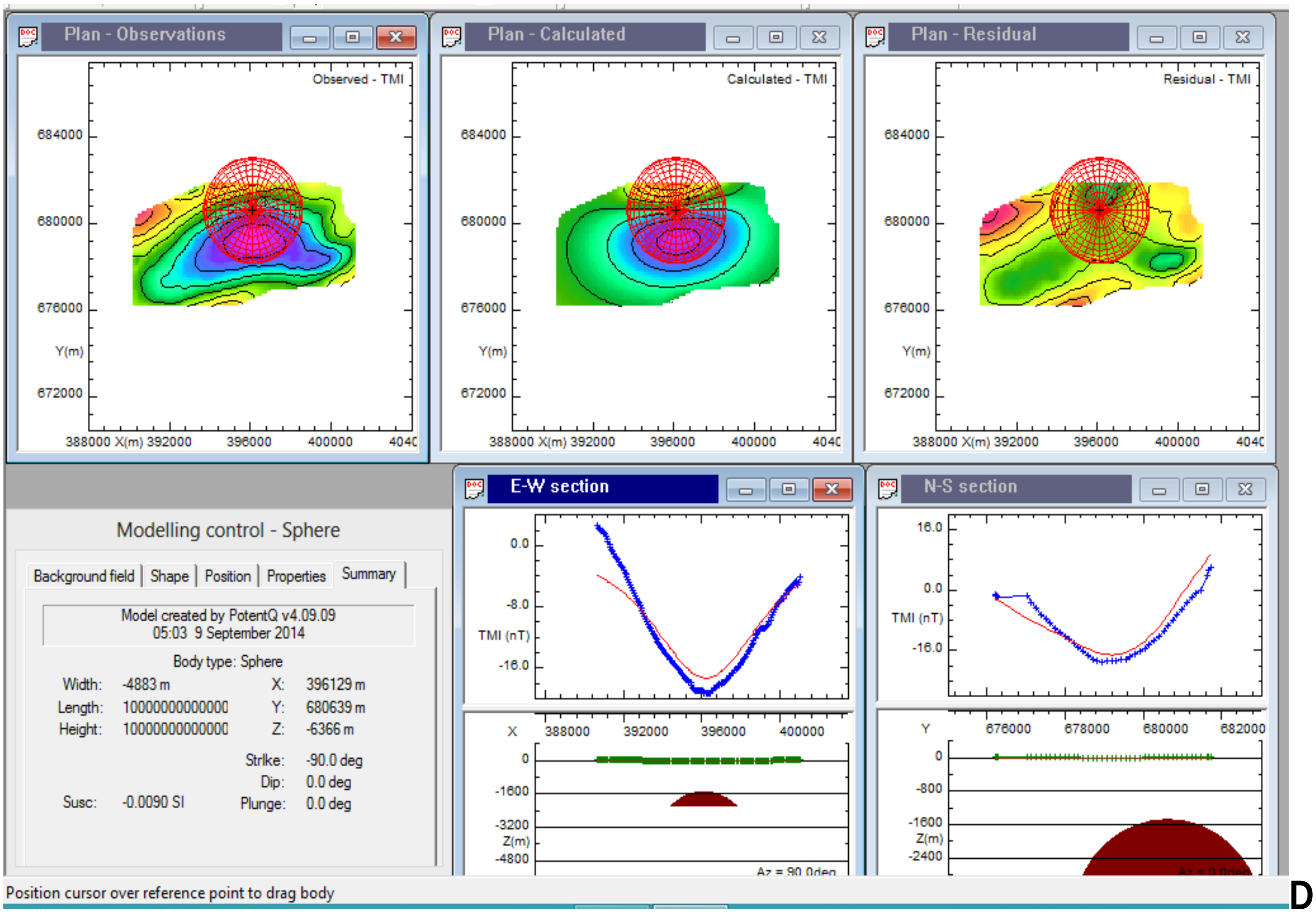
Model created by PotentQ v4.09.09
16:41 9 September 2014

Body type: Ellipsoid

Width: 411 m X: 398779 m
Length: 6099 m Y: 688026 m
Height: 6817 m Z: -956 m

Strike: 151.8 deg
Dip: 115.3 deg
Susc: -0.0134 SI Plunge: 121.5 deg

C



Modelling control - Sphere

Background field | Shape | Position | Properties | Summary

Model created by PotentQ v4.09.09
05:03 9 September 2014

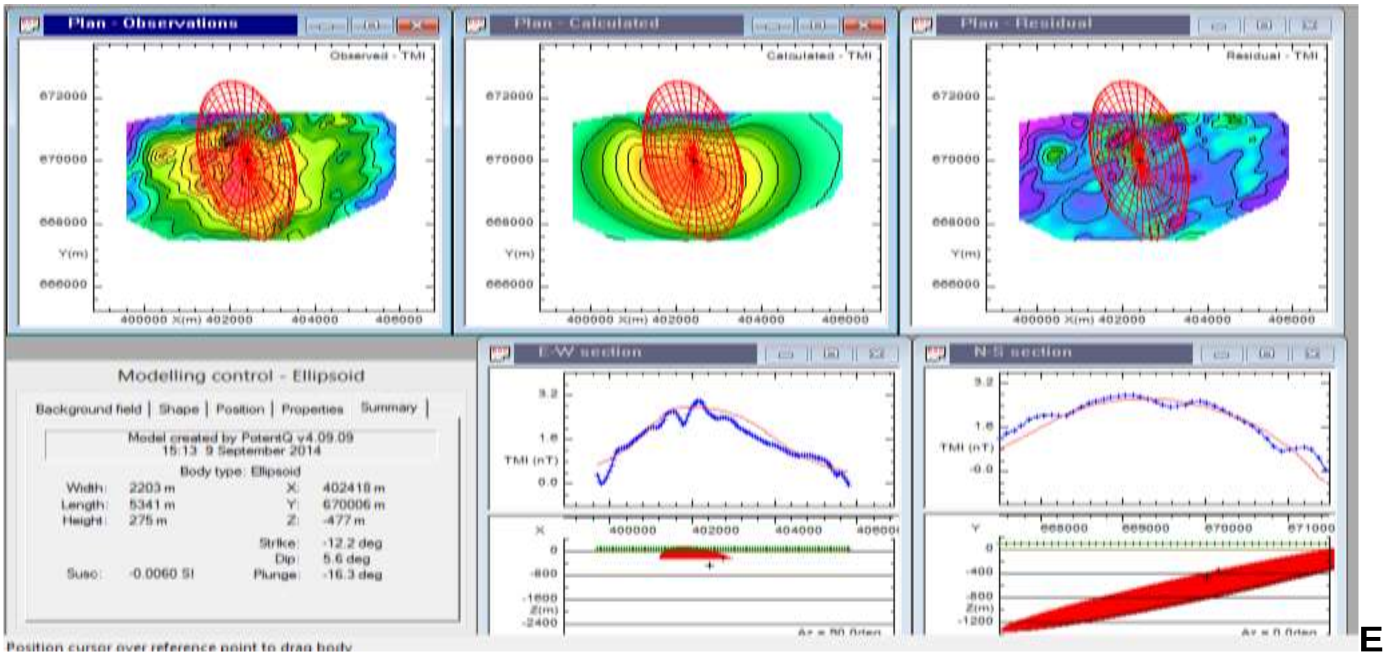
Body type: Sphere

Width: -4883 m X: 396129 m
Length: 10000000000000 Y: 680639 m
Height: 10000000000000 Z: -6366 m

Strike: -90.0 deg
Dip: 0.0 deg
Susc: -0.0090 SI Plunge: 0.0 deg

Position cursor over reference point to drag body

D



Modelling control - Ellipsoid

Background field | Shape | Position | Properties | Summary |

Model created by PotentQ v4.09.09
15:13 9 September 2014

Body type: Ellipsoid

Width: 2203 m
Length: 5341 m
Height: 275 m
X: 402418 m
Y: 670006 m
Z: -477 m
Strike: -12.2 deg
Dip: 5.6 deg
Susc: -0.0060 SI
Plunge: -16.3 deg

Position cursor over reference point to drag body

Figure 9. (A) Model A, (B) Model B, (C) Model C, (D) Model D, (E) Model E.

Table 1. Summary of modeling result.

Model	X (m)	Y (m)	Depth (m)	Dip (°)	Plunge (°)	Strike (°)	Body shape	k value (SI)	Probable mineral
A	431491	673148	-546	0.0	0.0	-90.0	Sphere	0.0180	Limestone
B	413344	695230	50	0.0	0.0	-90.0	Sphere	-0.0017	Calcite
C	398779	688026	-956	115.3	121.5	151.8	Ellipsoid	-0.0134	Rock salt
D	396129	680639	-6366	0.0	0.0	-90.0	Sphere	-0.009	Quartz
E	402418	670006	-477	5.6	-16.3	-12.2	Ellipsoid	-0.006	Calcite

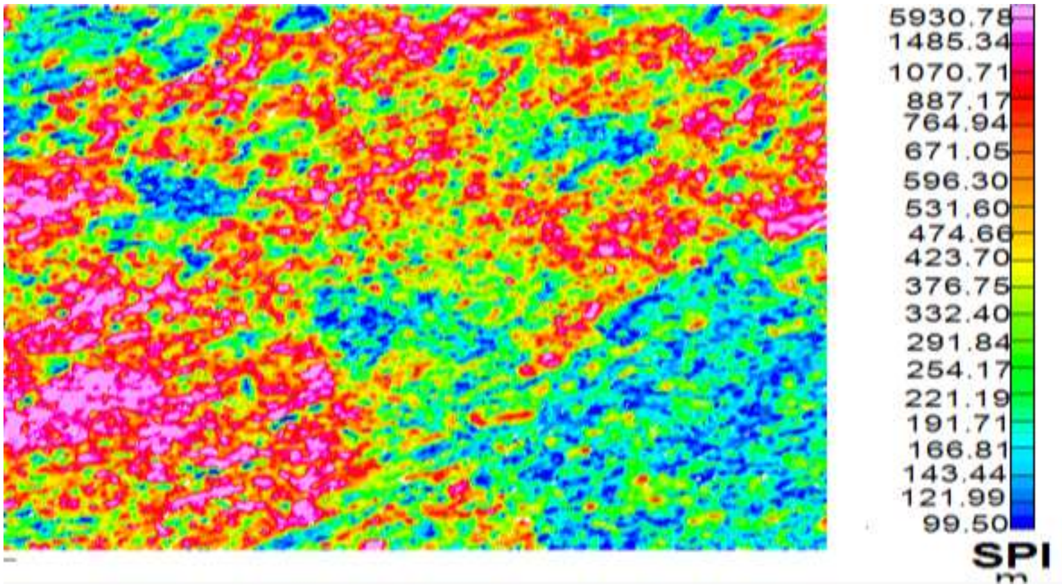


Figure 10. Source parameter imaging (SPI).

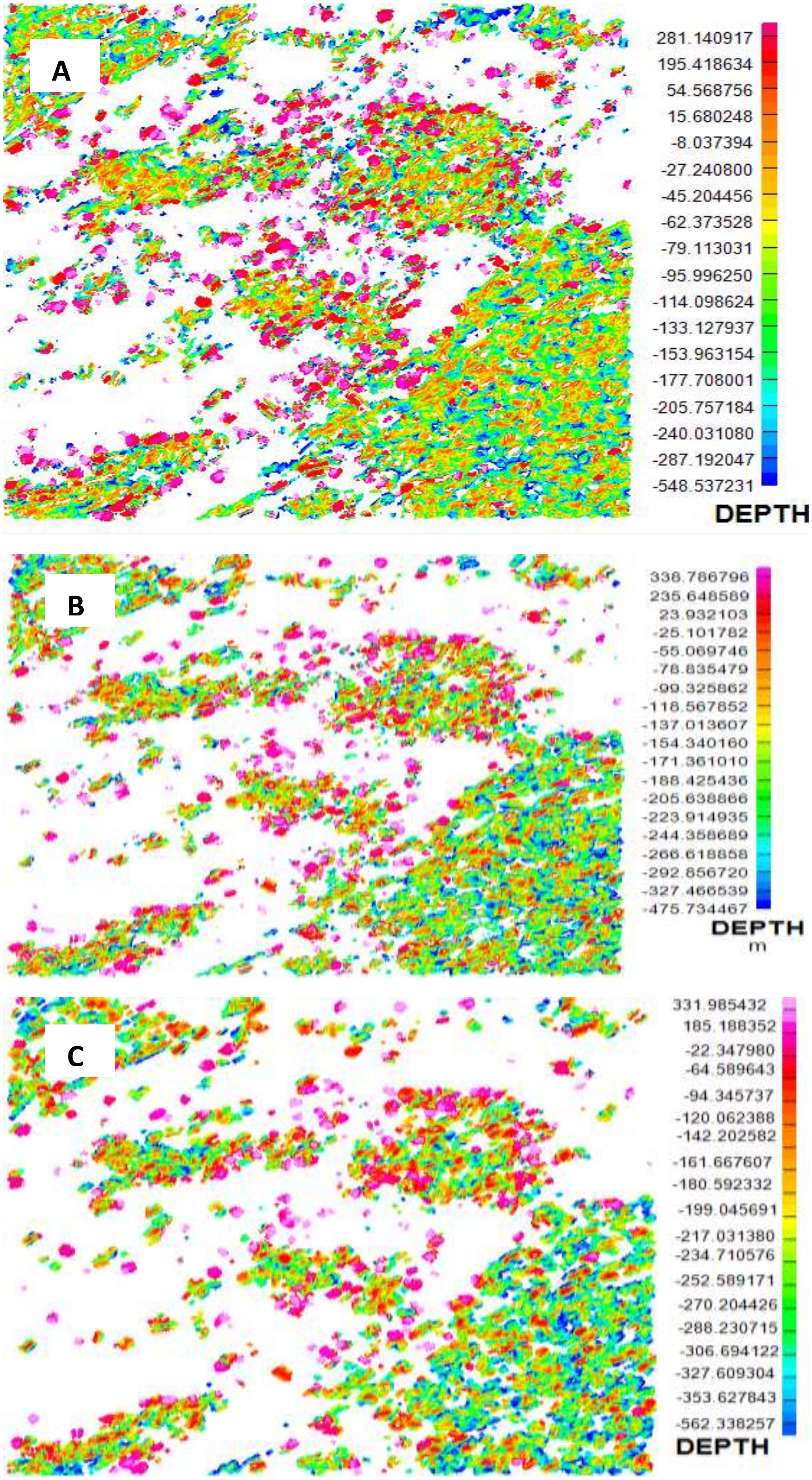


Figure 11. (A) Euler 3D (SI=1), (B) Euler 3D (SI=2), (C) Euler 3D (SI=3).

Table 2. Euler 3D result.

SI	Depth range (m)	
	From	To
1	8.037	548.537
2	25.102	475.734
3	22.348	562.338

Table 3. Interpretation results of land gravity survey (Ugbor and Okeke, 2010).

Profile	Z(m)	R(m)	T(m)	M(kg)
AA'	3132.00	1432.64	1699.36	2.8945×10^{13}
BB'	1931.40	1063.14	868.26	1.1828×10^{13}
CC'	2479.50	1133.88	1345.64	1.4350×10^{13}
DD'	2061.90	1100.13	961.77	1.3107×10^{13}
EE'	4280.40	1661.95	2618.45	4.5187×10^{13}
FF'	2283.75	1188.80	1094.95	1.6538×10^{13}
GG'	1794.38	1012.24	782.14	1.021×10^{13}

from surface to centre of anomaly, R is radius of anomaly, T is depth to surface of anomaly and M is mass of anomaly). They observed low Bouguer gravity anomaly which its cause might be accredited to a big and enormous anomalous low-density material whose depths of intrusion from surface to top range from 782 to 2618 m, with radii and masses ranging from 1012 to 1661 m and $1\cdot02\times10^{13}kg$ to $4\cdot52\times10^{13}kg$, respectively. This proposes a region of basic to intermediate igneous intrusions, deep basement and crustal thinning. The low-density anomalous body which indicated existence of salt dome, concealed at a depth between 868 and 2618 m suggests occurrence of oil or/and Uranium in the area. Its diameter and mass ranged between 2126 and 3322 m and $1\cdot18\times10^{13}kg$ to $4\cdot52\times10^{13}kg$, respectively. The depth to anomalous bodies estimated by Ugbor and Okeke (2010) agrees with the depths from this work especially as could be seen from SPI depth results.

The total magnetic intensity grid (TMI) of the study area shows fault zone which trends NE-SW part of the study area. The circular contour pattern is evident of granitic as well as basic intrusives such as dyke, lacolyte or batholyte which agrees with the interpretation of aeromagnetic anomalies over the lower and Upper Benue Trough by Ofoegbu (1985b), where he opined that the anomalies occur mainly as basic intrusives within the cretaceous sediments. The gravity work of Cratchley and Jones (1965) who interpreted the positive anomaly over Amar in terms of zone of basic intrusive also agrees with this result. From the model results, model B signifies outcrop, and gravity work in the lower Benue trough by Cratchley and Jones (1965) suggested that further positive anomalies flank the elongated negative anomalies on either side. The positive anomalies could be due to additional basic intrusive bodies within either the basement or sedimentary rocks which agree with the present work. The outcrop also conforms to the gravity work of Adighije (1981) on the Benue Trough who explained the central positive gravity anomaly in terms of an intrusive body with density of about 2.90 gcm^{-3}.

Aeromagnetic data of Abakaliki and Nkalagu areas were interpreted by Ugwu and Ezema (2012), using forward and inverse modeling method. The magnetic susceptibility values they got from their modeling results depict that most of the anomalous bodies are igneous rocks. The mineralization in the study area is due to igneous intrusions in the area. Though depth ranges of 10 to 22 km which they obtained for some anomalies could be favourable sites for buildup of hydrocarbons, they held that the existence of huge amount of intrusions makes this portion of the Benue Trough incapable of holding any substantial hydrocarbon potentials, since the existence of a great amount of igneous intrusions in the area designates an exceptionally high temperature history capable of destroying any hydrocarbons that might have been formed in the area. However, the works of Obi et al. (2010) and Igwesi and Umego (2013) did not rule out the possibility of hydrocarbon accumulation in the area. Igwesi and Umego (2013) employed spectral techniques in analyzing aeromagnetic data of some parts of Lower Benue Trough in order to estimate the average depth to magnetic sources in the area. Their results showed deeper magnetic sources situated at depths which fluctuate between 1.16 and 6.13 km, with an average depth of 3.03 km, representing magnetic basement surface. Their shallower magnetic sources vary from depths of 0.06 to 0.37 km, with an average depth of 0.22 km displaying the presence of magnetic intrusive bodies within the sediments. The profiles taken from the area show that the topography of the basement is undulating with an anticlinal structure over Abakaliki area. The average depth to basement of 3.03 km to the magnetic source recommends sufficient sedimentary thickness for hydrocarbon accumulation. The undulating of the basement surface probably offers traps for hydrocarbon. The work of Igwesi and Umego (2013) agrees with the present work. Ezema et al. (2014) interpreted aeromagnetic data of Abakaliki using forward and inverse modeling method and spectral analysis. Their results disclosed five intrusive bodies comprising granulites, pyrite and basalt. The intrusive depths range from 2.4 to 6.32 km. Their spectral analysis indicates maximum depths of 4.96 to 9.8 km with minimum depths ranging from 0.12 to 0.71 km. Their results also showed availability of mineral (pyrite), granulites and salt at Mfuma which according to them agrees with the work of Ehinola (2010). They observed that the main source of magnetic anomalies in Abakaliki arises from the existence of intrusive and basic igneous in the sedimentary terrain. They agreed with Obi et al. (2010) who believed in the possibility of hydrocarbon potential in Abakaliki. The works of Ezema et al. (2014) and Anyanwu and Mamah (2013) fairly agree with the present work. The results of the 2-D spectral analysis of Anyanwu and Mamah (2013) showed a two depth models: the shallower magnetic source bodies which range in depth from 0.035 to 1.285 km with an average depth of 0.656 km while the deeper magnetic source bodies range in depth from 1.585 to 4.136 km with an average depth of 3.096 km. They believed that their average sedimentary thickness of 3.096 km estimated in their study area may favor hydrocarbon generation which fairly agrees with our work. Ofoegbu and Onuoha (1991) who employed spectral analysis on aeromagnetic data of Abakaliki estimated a shallow sediment thickness that ranges from 1.2 to 2.5 km, which is in fair agreement with this work.

There is a good correlation between the depths estimated by source parameter imaging and depth estimated by forward and inverse modeling in this study. The shallow depths obtained by source parameter imaging, forward and inverse modeling and Euler 3D deconvolution also correlate.

Conclusion

The results of this study suggest that the magnetic anomalies over the study area are caused by intrusive bodies of basic composition with different thicknesses and fault zone in the sedimentary area. The result of qualitative analysis shows that the magnetic anomalies are predominant in the southeastern part of the study area. It also showed the presence of intrusive like dyke, lacolyte or batholyte. From quantitative interpretation, the presence of mineral deposits was deduced such as limestone, calcite, quartz, and rock salt in the study area. This correlates with the mineralization in the Lower Benue Trough and agrees with the works of Ehinola (2010), Ugwu et al. (2013) and Ezema et al. (2014). The forward and inverse modeling results revealed the presence of out crop in the area which correlates well with the work of Ofoegbu (1985a, b). Depth obtained by source parameter imaging (SPI) ranges from 99.50 to 5930.78 m, while depth obtained by forward and inverse modeling ranges from 477 to 6366 m. The depth range makes the study area good for hydrocarbon accumulation, but the intrusive bodies that dominate the area at variable depths make the chance of hydrocarbon generation and accumulation rare.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors thank Dr. Paul O. Ezema and Dr. Josiah U. Chukudebelu for their encouragement and guidance. They are also grateful to the Editor, Editorial Board members and the reviewers for wonderful work.

REFERENCES

Adighije C (1981). A gravity interpretation of Benue Trough, Nigeria. Tectonophysics 79:109-128.

Anyanwu G, Mamah L (2013). Structural Interpretation of Abakiliki – Ugep, using Airborne Magnetic and Landsat Thematic Mapper (TM) Data. Journal of Natural Science Research 3(9):137-148.

Benkhelil J (1982). Benue Trough and Benue Chain. Geological Magazine 119: 155-168.

Benkhelil J (1988). Structure et evolution géodynamiqué du bassin intracontinéntal de la Bénoué (Nigéria). Bull centre Rech. Explor prod. ELF Aquaintaine 12:29-128.

Biswas A, Parija MP, Kumar S (2017). Global nonlinear optimization for the interpretation of source parameters from total gradient of gravity and magnetic anomalies caused by thin dyke. Annals of Geophysics 60(2):G0218: 1-17.

Biswas A (2016). Interpretation of gravity and magnetic anomaly over thin sheet-type structure using very fast simulated annealing global optimization technique. Modeling Earth Systems and Environment 2(1):30.

Biswas A, Sharma SP (2016). Integrated geophysical studies to elicit the structure associated with Uranium mineralization around South Purulia Shear Zone, India: A Review. Ore Geology Reviews 72: 307-1326.

Biswas A, Mandal A, Sharma SP, Mohanty WK (2014a). Delineation of subsurface structure using self-potential, gravity and resistivity surveys from South Purulia Shear Zone, India: Implication to uranium mineralization. Interpretation 2(2):T103-T110.

Biswas A, Mandal A, Sharma SP, Mohanty WK (2014b). Integrating apparent conductance in resistivity sounding to constrain 2D Gravity modeling for subsurface structure associated with uranium mineralization across South Purulia Shear Zone. International Journal of Geophysics, Article ID 691521: 1-8.

Burke K, Dessauvagie TFJ, White AJ (1971). Opening of the Gulf of

Guinea and geological history of Benue Depression and Niger Delta. Nature Physical Science 233:51-55.

Cratchley CR, Jones GP (1965). An interpretation of the geology and gravity anomalies of the Benue Valley, Nigeria. Overseas Geology, Survey and Geophysics 9:1-28.

Ehinola EO (2010). Biostratigraphy and Depositional Environment of the Oil Shale Deposit in the Abakaliki Fold Belt, South East-Nigeria. Oil Shale 27(2):99-125.

Ezema PO, Ezeh ID, Ugwu GZ, Abudullahi UA (2014). Hydrocarbon and Mineral Exploration in Abakaliki, Southeastern Nigeria. International Journal of Engineering Science 3(1):24-30.

Igwesi ID, Umego NM (2013). Interpretation of Aeromagnetic anomalies over some parts of the Lower Benue Trough using spectral analysis Technique. International Journal of Science and Technology Research 2:153-165.

Lowrie W (2004). Fundamentals of Geophysics. Cambridge University Press, New York.

Mamah LI, Ezepue MC, Ezeigbo HI (2000). Integration of geology and geophysics in mineral exploration in the Benue Trough, Nigeria: the Onuahia lead-zinc deposit - a case study. Global Journal of Pure and Applied Science 6:255-262.

Mandal A. Mohanty WK, Sharma SP, Biswas A, Sen J. Bhatt AK (2015). Geophysical signatures of uranium mineralization and its subsurface validation at Beldih, Purulia District, West Bengal, India: A case study. Geophysical Prospecting 63:713-726.

Nwachukwu SO (1972). The Tectonic Evolution of the Southern Portion of the Benue Trough, Nigeria. Geological Magazine 109:411-419.

Obaje NG (2009). Geology and Mineral Resources of Nigeria. Springer- Verlag, New York.

Obi DA, Okereke OS, Obei BC, George AM (2010). Aeromagnetic Modeling of subsurface intrusives and its implication on hydrocarbon evaluation of the Lower Benue Trough Nigeria. European Journal of Scientific Research 47:347-361.

Ofoegbu CO (1985a). A review of the Geology of the Benue Trough, Nigeria. Journal of African Earth Science 3:283-291.

Ofoegbu CO (1985b). Interpretation of an aeromagnetic profile across the Benue Trough of Nigeria. Journal of African Earth Science 3:293-296.

Ofoegbu CO, Onuoha KM (1990). A Review of Geophysical Investigations in the Benue Trough. In Ofoegbu CO (Ed) The Benue Trough Structure and Evolution pp. 171-201.

Ofoegbu CO, Onuoha KM (1991). Analysis of Magnetic Data over the Abakaliki Antilinorium of the Lower Benue Trough, Nigeria. Marine and Petroleum Geology 8:174-183.

Ojoh KA (1992). The Southern part of the Benue Trough (Nigeria) Cretaceous stratigraphy, basin analysis, paleooceanography and geodynamic evolution in the equatorial domain of the south Atlantic. NAPE Bulletin 7:131-152.

Olade MA (1975). Evolution of Nigeria’s Benue Trough (Aulacogen): A Tectonic Model. Geological Magazine 112:575-583.

Parasnis DS (1986). Principles of Applied Geophysics. Chapman and Hall, New York.

Petters WS (1978). Stratigraphic Evolution of the Benue Trough and its implications for the Upper Cretaceous Paleogeography of West Africa. Journal of Geology 86:311-322.

Petters SW (1982). Central West African Cretaceous-Tertiary Benthic Foraminifera and strat Stratigraphy. Palaeogeographica 179:1-104.

Reeves C (2005). Aeromagnetic Surveys; Principles, Practice and Interpretation. e-Published by GEOSOFT (http://www.geosoft.com/knowledge).

Reford S (1962). The Geology of Egypt. Elsevier publication, Amsterdam, New York.

Reid AB, Allsop JM, Granser H, Millett AJ, Somerton LW (1990). Magnetic interpretation in three Dimensions using Euler Deconvolution. Geophysics 55:80-91

Selley RC (1998). Elements of Petroleum Geology, 2nd Edition. Academic Press, London.

Smith RS, Thurston JG, Dai TF, Macleod IN (1998). Spi-the improved Source Parameter Imaging Method. Geophysics Prospects 46:141-151.

Steenland NC (1965). Oil fields and aeromagnetic anomalies. Geophysics 30:206-239.

United States Geological survey (USGS) (1997). Introduction to Potential Fields: Magnetic. pubs.usgs.gov/fs/fs-0236-95/fs-236-95.pdf.

Telford WM, Geldart LP, Sheriff RE (1990). Applied Geophysics, second edition. Cambridge University Press, Cambridge.

Ugbor DO, Okeke FN (2010). Geophysical investigation in the lower Benue Trough of Nigeria, using gravity method. International Journal of Physical Science 5:757-1769.

Ugwu GZ, Ezema PO (2012). Forward and inverse modeling of aeromagnetic anomalies over Abakaliki and Nkalagu areas of the Lower Benue Trough, Nigeria. International Research Journal of Geology and Mining 2:222-229.

Ugwu GZ, Ezema PO, Ezeh CC (2013). Interpretation of aeromagnetic data over Okigwe and Afikpo areas of lower Benue trough, Nigeria. International Research Journal of Geology and Mining, 3:1-8.

Ukaegbu VU, Akpabio IO (2009). Geology and Stratigraphy Northeast of Afikpo Basin, Lower Benue Trough, Nigeria. Pacific Journal of Science and Technology 10:518-527.

Vol. 10(6), pp. 72-80, August 2018
DOI: 10.5897/JGMR2018.0293
Article Number: 223F51C57902
ISSN: 2006-9766

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Full Length Research Paper

Interpretation of high resolution aeromagnetic data to determine sedimentary thickness over part of Bida Basin, North Central Nigeria

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Received 11 May, 2018; Accepted 9 July, 2018

This study focuses on the quantitative interpretation of aeromagnetic data to estimate the thickness of sediments over part of Bida Basin so as to identify possible areas of hydrocarbon potential. The study area covers an area of 24,200 km^2 located between latitude 8° 30'N and 9° 30'N and longitudes 5° 00'E and 7° 00'E. Aeromagnetic data in grid format containing eight sheets were analysed and interpreted. Polynomial fitting was used in regional/residual separation and this result to the residual field data that corresponds to the target source for further processing. Three depth estimating methods were employed in this study; Euler deconvolution, source parameter imaging and spectral depth analysis. Euler depth determination method reveals a maximum depth of 3.56 km around Mokwa and Batati areas. Shallow sources also exist around Pategi, Paiko, Izom and Lapai areas with an average depth ranging from 107.74 m to about 514.82 m. Source parameter imaging shows a deeper sedimentary thickness of 4.2 km in the same area with Euler deconvolution. Spectral depth analysis also showed a maximum sedimentary thickness of 3.50 km. It was found in the study that the maximum depths obtained might probably be sufficient enough for hydrocarbon maturation and gas accumulation. Further research using seismic reflection might be carried out in the areas where maximum depth was obtained.

Key words: Aeromagnetic data, polynomial fitting, spectral analysis, euler deconvolution source parameter imaging.

INTRODUCTION

Magnetic airborne survey has been a useful tool in mapping geological feature, in exploration of mineral and for other geological purposes. This method investigates the subsurface geology on the basis of the magnetic disturbances measured in the magnetic field of the earth subsequent from the magnetic properties of the causal

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rocks. The shape dimensions, and amplitude of an induced magnetic signature is a function of the orientation, geometry, size, depth, and magnetic susceptibility of the body as well as the intensity and inclination of the earth's magnetic field in the survey area (Biswas, 2018, 2016; Biswas and Acharya, 2016).

The present work focuses on the analysis of a total-field aeromagnetic data over parts of Bida Basin to estimated depth to magnetic basement rock for hydrocarbon maturation. The outcome of this analysis will provide more information on the geophysical and other linear features of the area and add to the geophysical history of the area. The new high resolution aeromagnetic data obtained in the year 2009 were used for this analysis which reveal more structural features that could not be captured using the old data, and so this study throw more light on this peculiarity and further provide base-line information for further studies and correlation.

This study is relevant to the national need because it will further provide information (geophysical) through the processed total field aeromagnetic data on the structural styles of the area.

Recently, the Nigerian National Petroleum Corporation disclosed the intention of Indonesia a South East Asian country, indicating their interest to buy more crude oil from Nigeria above the current 18% they use to buy. As a result of this demand which is a welcome development to the country economy, it is of necessity to explore other sedimentary basins in Nigeria presume to be rich in hydrocarbon, as this will boast the economy of the nation and pave way for business opportunities in the country.

Euler deconvolution, SPI and spectral depth analysis were employed in this study to determine the sedimentary thickness of the area for hydrocarbon potential.

Location and the geology of the study area

The area of study (Bida Basin) is located between latitude 8° 30'N to 9° 30'N and longitudes 5° 00'E to 7° 00'E covering an area of 24,200 km^2 (Figure 1). The Bida Basin is a NW–SE trending intracratonic sedimentary basin extending from Kontagora in Niger State of Nigeria to areas slightly beyond Lokoja in the south (Figure 2). It is delimited in the northeast and southwest by the basement complex while it merges with Anambra and Sokoto basins in sedimentary fill comprising post orogenic molasse facies and a few thin unfolded marine sediments (Obaje, 2009). The entire basin is bounded by latitude 8° 00'N to 10° 30'N and longitudes 4° 30'E to 7° 30'E with an estimated area of about 90,760 km^2. The basin is a gentle down-warped shallow trough filled with Campanian-Maastrichtian marine to fluviatle strata believed to be more than 300 m thick (Bemsen et al., 2013) The Basin might be regarded as north-western extension of Anambra basin, which is found in the southeast, both of which were major depocenters during the second major sedimentary cycle of southern Nigeria in the Upper Cretaceous time (Obaje, 2009). Although the hydrocarbon potential of the basin has not been fully tested with seismic data and the basin remains undrilled, both ground and aeromagnetic studies by several workers have outlined the basin's configuration (Udensi et al., 2004). Often, experts working in the area have divided the basin geographically into northern and southern Bida basins probably due to rapid facies changes across the basins. The northern and southern Bida basins comprise of about 3 km thick Campanian to Maastrichtian continental to shallow marine sediments. The southern Bida Basin comprises of the basal Campanian Lokoja formation (mainly conglomerate and sandstone), Maastrichtian Patti formation (shale, claystone and sandstone) and the youngest Agbaja formation (Ironstone). Their lateral stratigraphic equivalents in the northern Bida Basin consist of the basal Bida formation (conglomerate, sandstone), Enagi formation (siltstone, claystone and sandstone) and Batati formation (Ironstone) (Ojo et al., 2011).

MATERIALS AND METHODS

The high resolution aeromagnetic data used for the analysis of this study were part of the data collected from the aero-magnetic survey carried out in the year 2009 Fugro. The collections of the data were sponsored by Nigerian Geological Survey Agency. Below are the technical details of the survey/ flight parameters:

Flight line spacing: 500 m
Terrain clearance: 100 m (Ogun state), 80 m (Phases I and II)
Flight direction: NW - SE
Tie lines spacing: 2 km
Tie lines direction: NE - SW

The data were knitted and re-gridded to produce the total magnetic field map (TMI) of the area of investigation (Figure 3).

Theory of method

Euler depth determination method

A formulation of the method given by Reid et al. (1990) shows that:

$$(x-x_0)\frac{\delta T}{\delta x}+(y-y_0)\frac{\delta T}{\delta x}+(z-z_0)\frac{\delta T}{\delta z}=N(B-T) \tag{1}$$

where *(x_o,y_o* and *zo)* are the positions of the magnetic source whose total magnetic intensity field T is detected at *(x,y,z).* The total field has a regional value of B. N is a structural index which is equal to three for a point dipole and two for a vertical pipe. More complicated bodies, which are, in effect, assemblages of dipoles, have indices ranging from zero to three. An index of one appears to work for dykes and contacts approximated by lines of poles. Reid et al. (1990) automated the solution of this linear equation for gridded data to produce solutions for the positions and depths of magnetic sources. By using field and computed derivative values at more points than necessary, they obtained an over-determined set of equations and were able to use least square inversion techniques

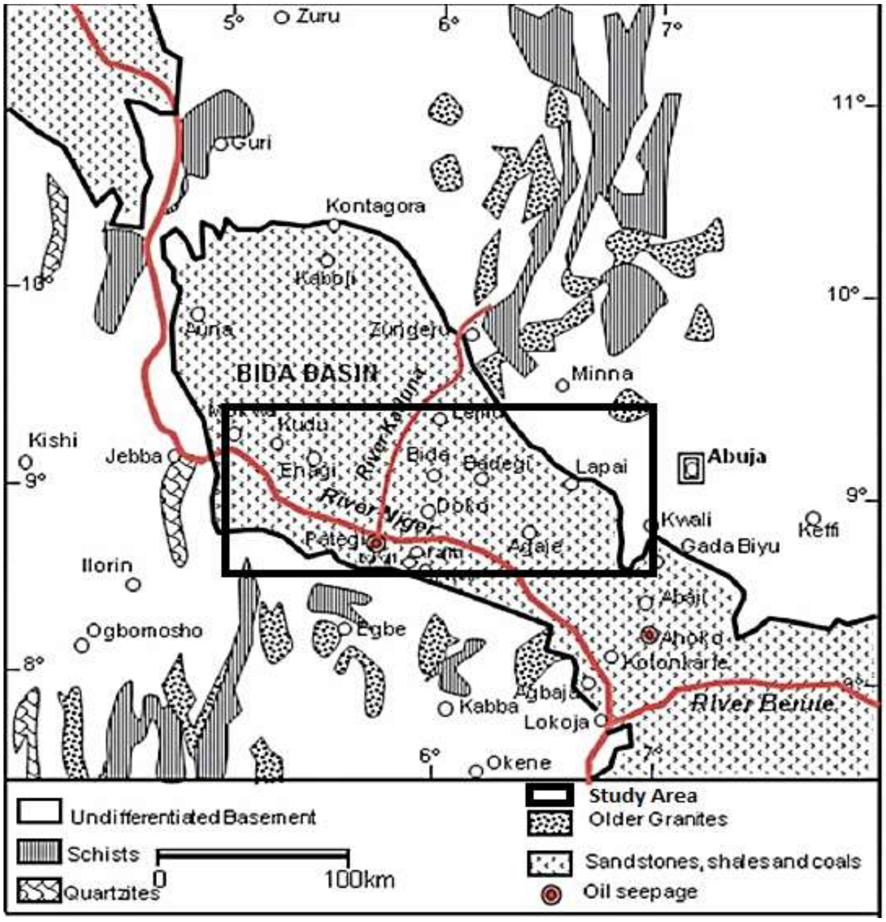

Figure 1. Location map of the study area (after Obaje et al., 2011).

to solve for the unknowns. The solutions are typically displayed as a series of circles, with the centre of the circle indicating the position of the source and the diameter of the circle indicating the source depth. The method has proved useful for identifying source positions and boundaries and for giving generalised indications of source depth part of the problem in obtaining accurate depths using the Euler method may relate to the difficulty of computing accurate derivatives on which to base the depth estimates.

Source parameter imaging: This method is one of the depths estimating method developed by Thurston and Smith (1997). It differentiates and characterise regions of sedimentary thickening from those of uplifted or shallow basement and also to estimate the depths to the magnetic sources. It uses a procedure for automatic calculation of source depths from gridded magnetic data. The results could be used to ascertain areas with hydrocarbon potential and mineral deposits concentration.

SPI assumes a step-type source model. For a step, the following formula holds:

$$Depth = {}^{1}\!/\!_{K_{\max}} \tag{2}$$

where K_{max} is the peak value of the local wavenumber K over the step source.

$$K = \sqrt{\left(\frac{dA}{dx}\right)^2 + \left(\frac{dA}{dy}\right)^2 + \left(\frac{dA}{dz}\right)^2} \tag{3}$$

$$\text{Tilt derivative A} = \tan^{-1}\left(\frac{\frac{dT}{dz}}{\sqrt{\left(\frac{dT}{dx}\right)^2 + \left(\frac{dT}{dy}\right)^2}}\right) \tag{4}$$

T = the total magnetic field anomaly grid

Spectral depth analysis

The Fourier transform of the potential field as result of prismatic body has a wide spectrum whose upper location is a function of the depth to the up and down surfaces and whose maximum displacement is calculated by its density or magnetization (Salako and Udensi, 2013).

The peak wave number (ϖ) can be related to the geometry of the body according to the following expression.

$$W' = \frac{In\left({}^{h_b}/_{h_t}\right)}{h_b - h_t} \tag{5}$$

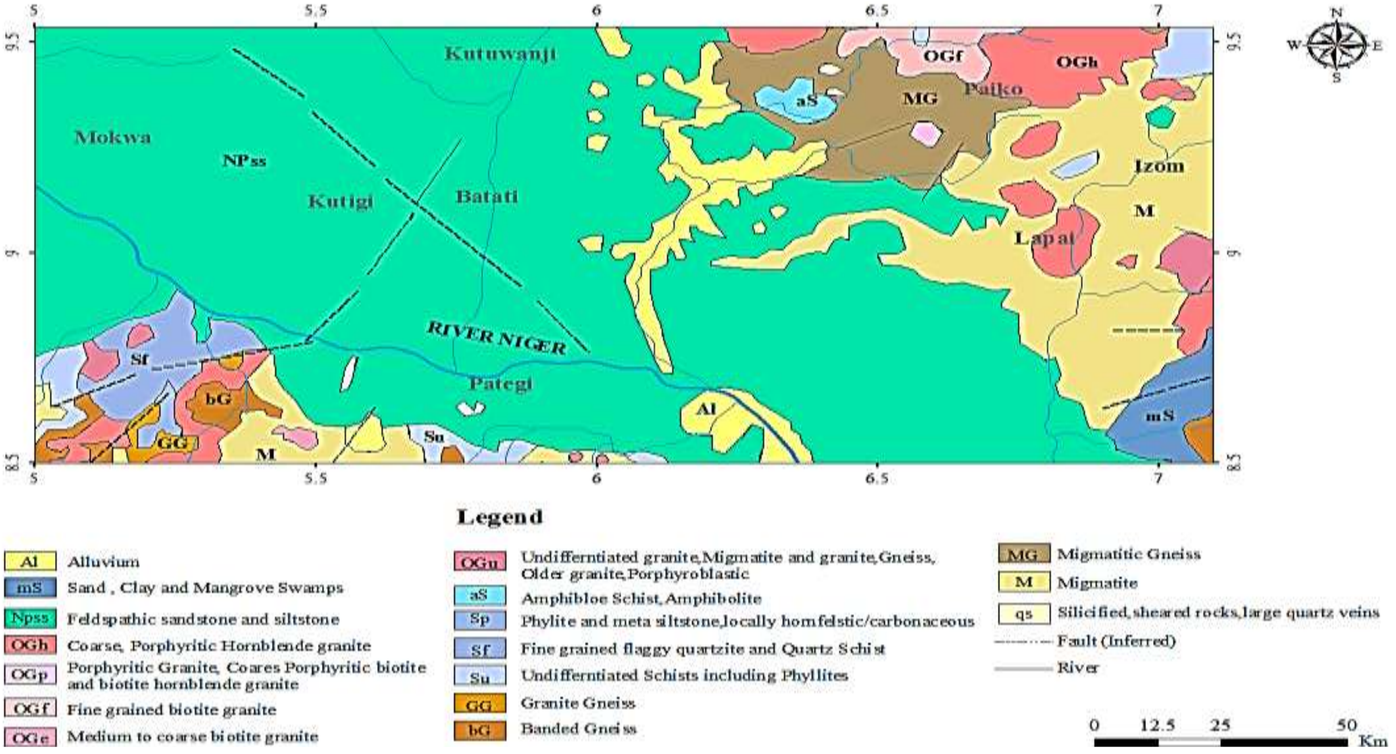

Figure 2. Geological map of the study area (NGSA).

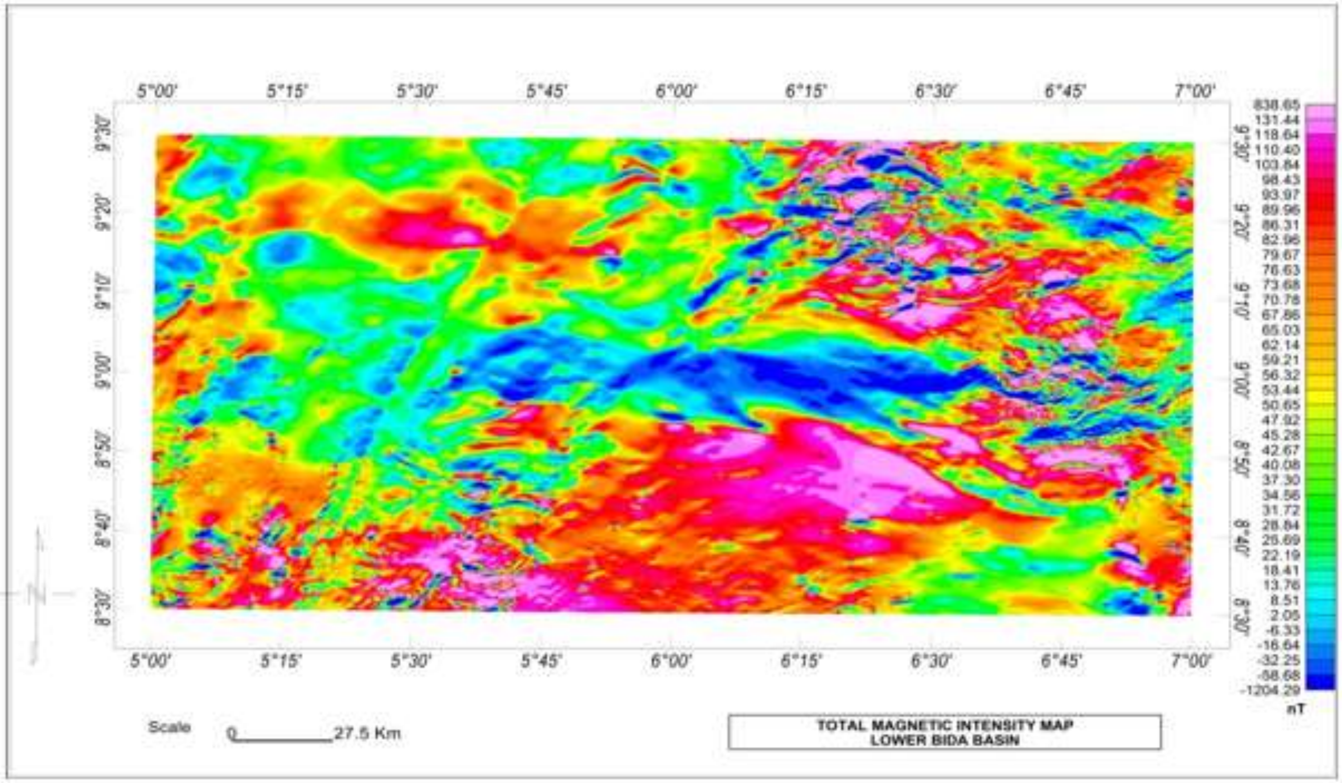

Figure 3. IGRF filtered total magnetic intensity map of the study area. 33,000 nT must be added to the values shown in the key to get the real value at any position.

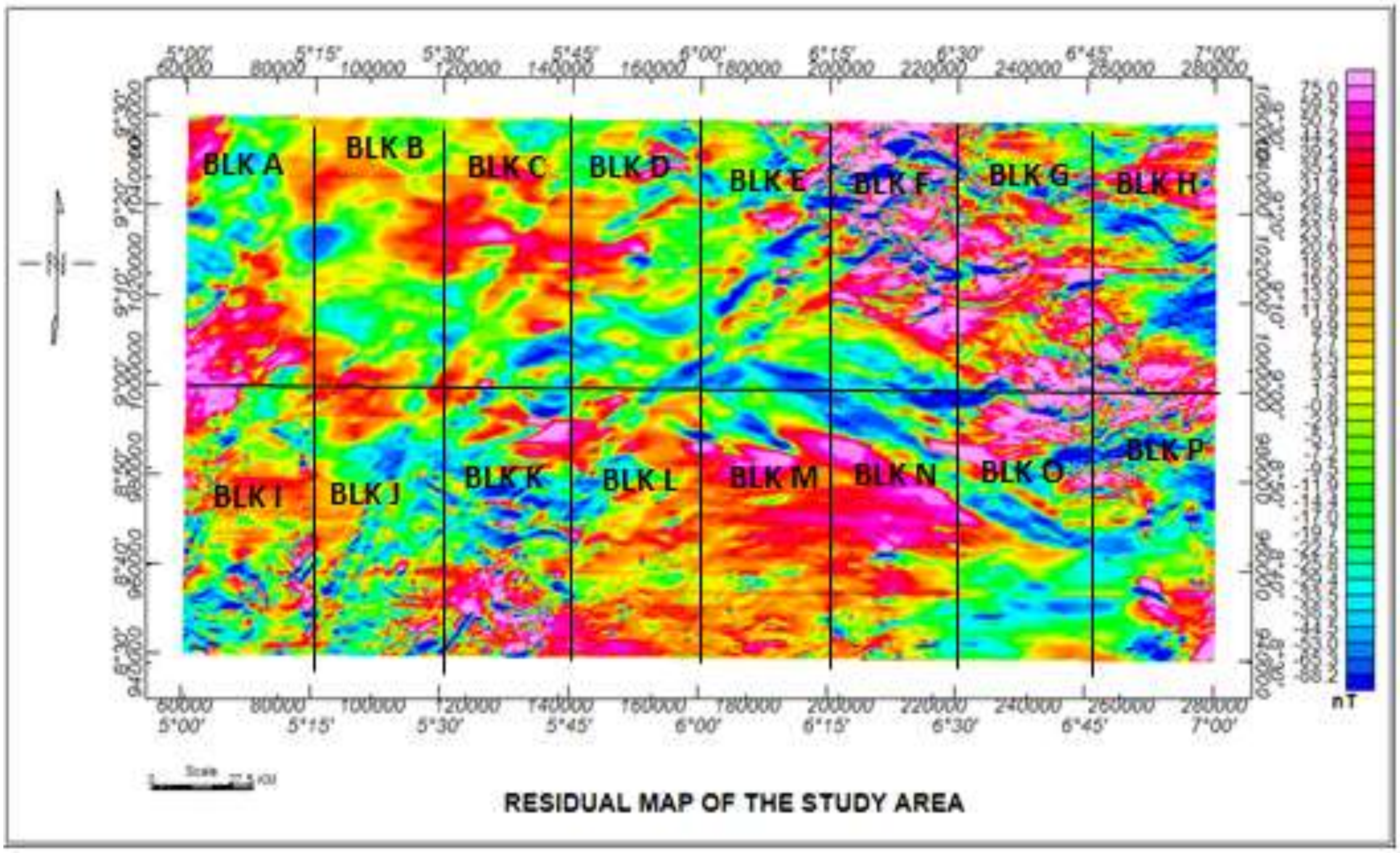

Figure 4. Residual map of the study area showing spectral blocks.

where W' is the peak wave number in radian / ground – unit, h_t the depth to the top and h_b is the depth to the bottom.

$$f(\varpi) = e^{-h\omega} \tag{6}$$

Where, ϖ = angular wave number in radians/ground-unit; h = depth to the top of the prism. For a prism with up and down surface, the spectrum is:

$$f(\varpi) = e^{-h_t\omega} - e^{-h_b\omega} \tag{7}$$

where h_t and h_b are the depths to top and bottom surface respectively.

The log spectrum of this data can be used to determine the depth to the top of a statistical ensemble of sources using the relationship.

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

where, *h*= depth in ground – units, and K = wavenumber in cycles / ground – unit.

Dividing the slope of the energy (power) spectrum by 2π gives the depth of an'ensemble'; a deep source depth; a shallow source depth and a noise component. A Matlab program was used to obtain the graph of energy against frequency in cycle/km of the sixteen blocks (A-P).

RESULT AND DISCUSSION

The TMI map (Figure 3) is produced in different colours, with pink to red colour depicting high anomalies while green to blue depicts low anomalies. The total magnetic intensity map of the study area exhibits both high and low anomalies ranging from 31,796 to 33,839 nT. The lower part of the area is predominantly of high anomaly while the middle portion is dominated by low magnetic anomalies. The North-eastern corner down to the eastern flank is dominated by short wavelength anomalies which are high in frequency of occurrence. Major structures observed on the map trend E-W.

The regional/residual separation was carried out using polynomial fitting with order one which results to the residual field data that corresponds to the target source for further processing. The residual map (Figure 4) shows high and low magnetic field values and which ranges from -1204.29 to 838.65 nT.

The Euler deconvolution method of depth determination is an automatic technique used for locating source of potential field based on amplitudes and gradients; it windows the area and locates structures and evaluate the depth to which those structures exist by writing equations

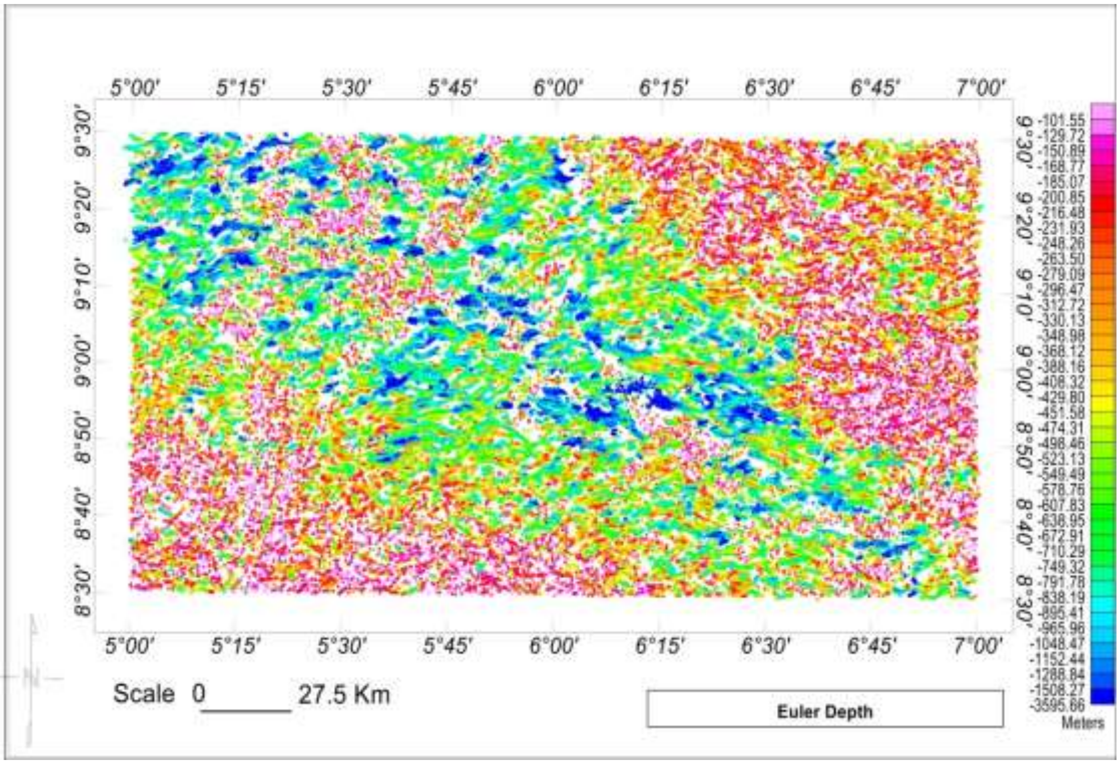

Figure 5a. Map of Euler depth of the study area.

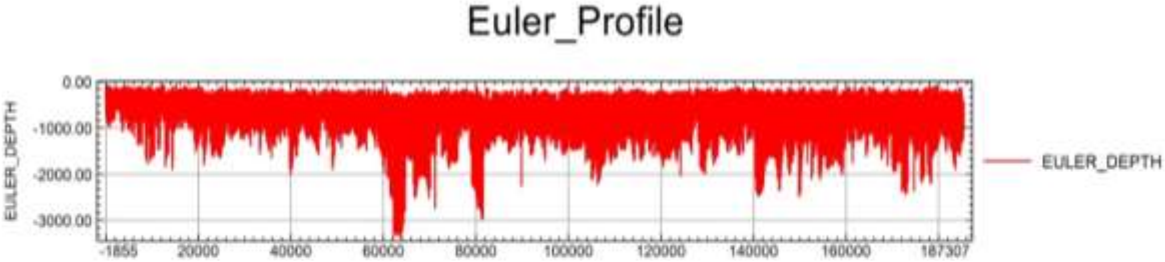

Figure 5b. Euler depth profile of the study area.

for the structures. Its degree of accuracy depends on the structures having a perfect shape and that the structure or anomaly falls on the center of the window. Figures 5a and b represent the maps for the Euler depth and the profile respectively. The Euler Depth map shows that the depth to magnetic sources (anomalies) ranges from 101.55 to 3595.66 m, while the Euler profile estimates the maximum depth of the located anomalies to be about 3.5 km around Mokwa and Batati areas and this result is sufficient enough for hydrocarbon maturation or accommodation. The shallow sources also exist around Pategi, Paiko, Izom and Lapai areas with an average depth ranging from 107.74 m to about 514.82 m.

The source parameter imaging (SPI) is one of the depth estimating techniques that gives a better depth to top of magnetic rocks within the area of investigation. Result from SPI (Figure 6a) shows that the depth to magnetic body ranges from 107.74 to 4972.94 m. The map (Figure 6a) shows that the Pategi, Paiko, Izom and Lapai areas have the shallowest range of depths to the top of magnetic sources which ranges from 107.74 m to about 514.82 m. Batati and Mokwa areas have the maximum estimated depths to magnetic sources and become shallower towards Kutigi and Kutuwanji. The SPI profile (Figures 6b) estimates the maximum depth of the sedimentary units to be about 4200 m (4.2 km) because the isolated values beyond this depth cannot be correlated and this depth occurs around Mokwa and Batati areas.

Figure 4 (residual map) was divided into sixteen (16)

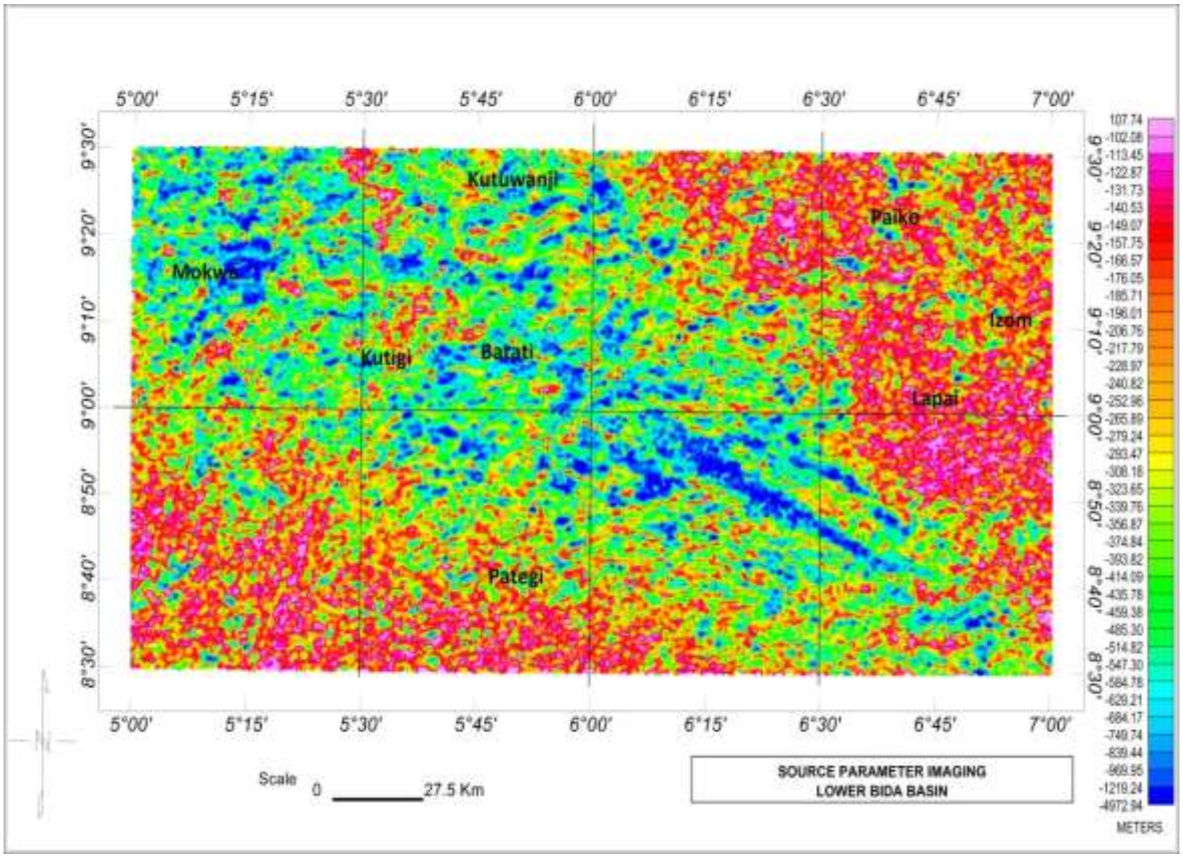

Figure 6a. Source parameter imaging (SPI) map.

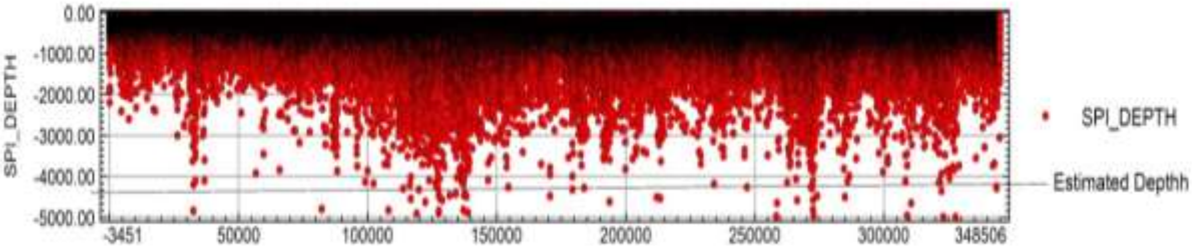

Figure 6b. Source parameter imaging (SPI) profile.

overlapping magnetic sections (A-P) using an algorithm in Oasis Montaj. Energy spectrum of each section was plotted against frequency wave number) with a Matlab program designed to estimate the deep and shallow magnetic source depth using the following equation:

$$Z_1 = -\frac{m_1}{4\pi} \quad (9)$$

$$Z_2 = -\frac{m_2}{4\pi} \quad (10)$$

where m_1 and m_2 are gradients of the first and second segment of the plot, and Z_1 and Z_2 are first and second depths respectively (Table 1).

From Figure 7a, maximum depth of 3.50 km was obtained which agrees with the result of Euler deconvolution depth with minimum depth of 1.08 km. Likewise from Figure 7b to d, maximum depth of 3.0, 2.22 and 1.54 km were also obtained with minimum depth of0.83, 0.42 and 0.7 km respectively. Figure 8 is the contour map of first depth to magnetic source. Deeper depths of 3.5 km and 3.0 km are more noticeable at the extreme Northwestern part of the study area and this relate to Mokwa and Batati town respectively. The Shallow sources also exist around Pategi, Paiko, Izom and Lapai areas with an average depth ranging from 107.74 m to about 514.82 m.

Aeromagnetic data (HR) of Bida Basin had been

Table 1. Calculated depths of maximum and minimum magnetic source in Km of Bida Basin.

Spectral section	Long. (x) (Deg.)	Lat.(y) (Deg.)	Z_1 (km)	Z_2 (km)
A	5.12	9.25	3.50	1.08
B	5.37	9.25	3.02	0.83
C	5.62	9.25	2.22	0.46
D	5.87	9.25	1.54	0.72
E	6.12	9.25	1.03	0.60
F	6.37	9.25	0.82	0.56
G	6.62	9.25	0.66	0.43
H	6.87	9.25	0.6	0.45
I	5.12	8.75	0.55	0.36
J	5.37	8.75	0.52	0.46
K	5.62	8.75	0.59	0.44
L	5.87	8.75	0.84	0.45
M	6.12	8.75	0.97	0.50
N	6.37	8.75	0.92	0.29
O	6.62	8.75	0.67	0.48
P	6.87	8.75	0.57	0.49

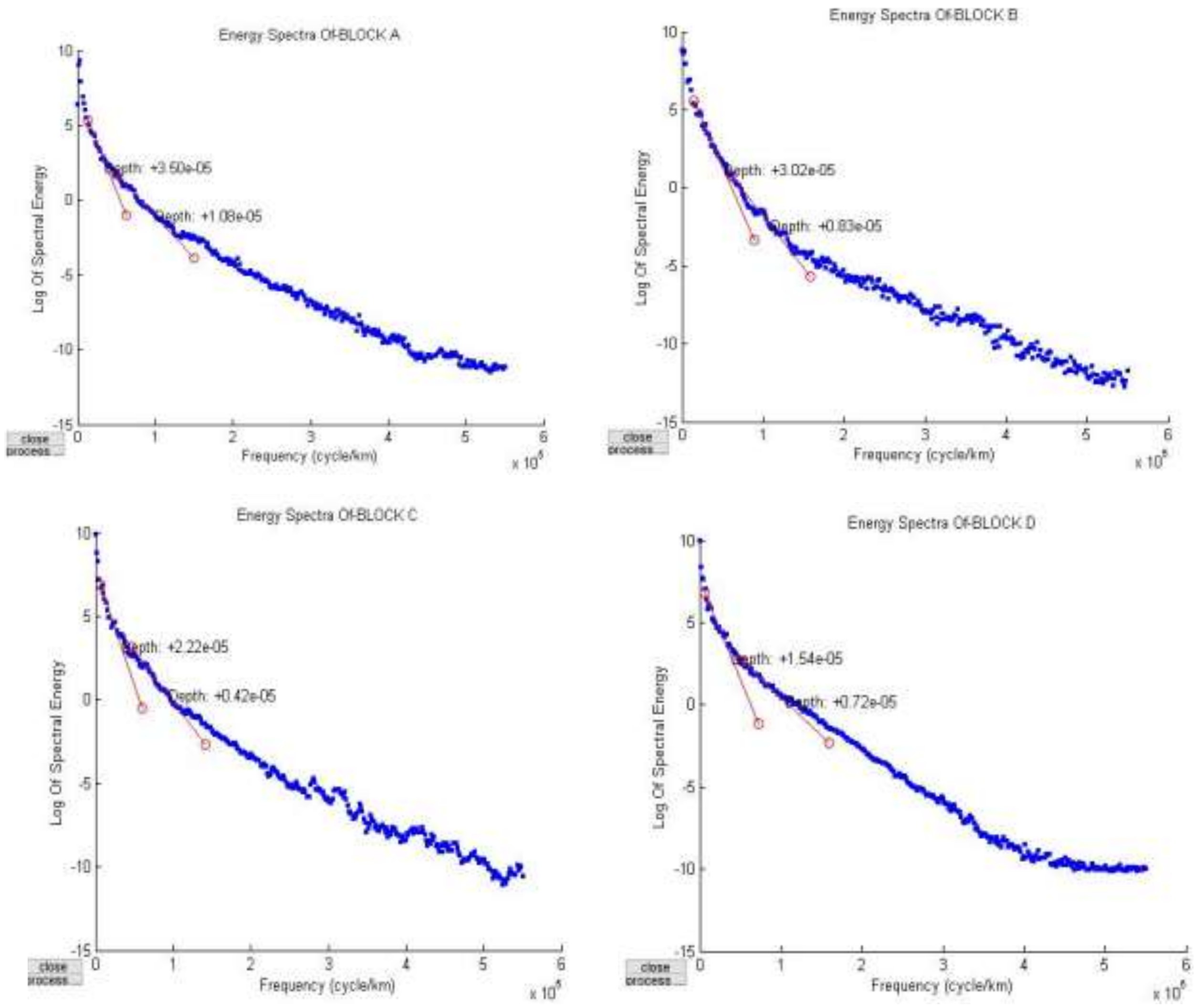

Figure 7. Typical plots of energy spectrum against frequency (Section A-D).

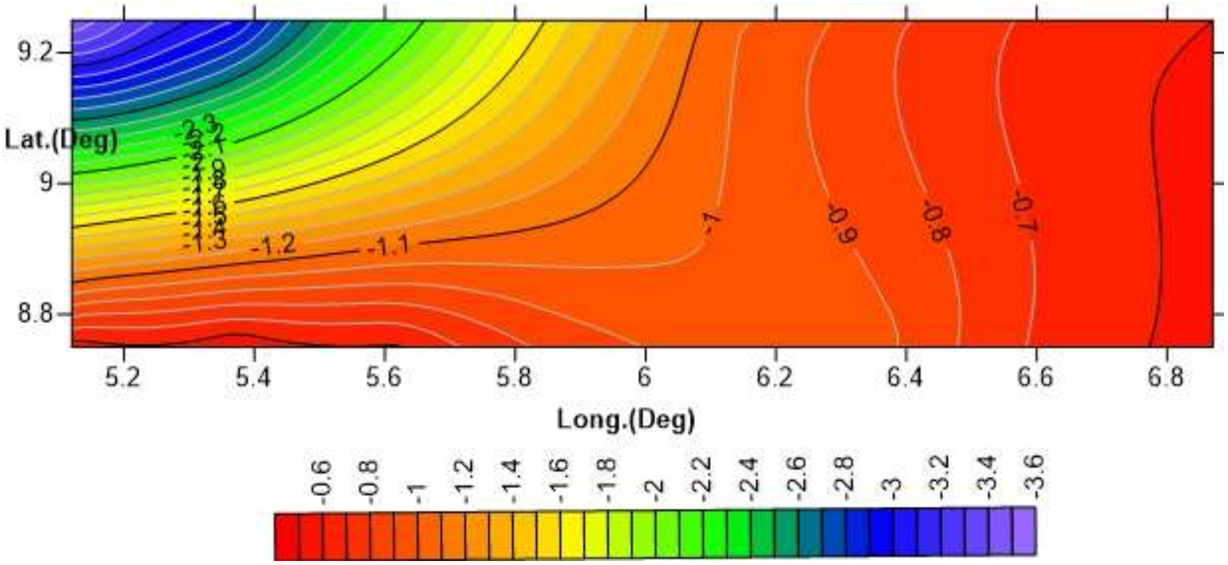

Figure 8. Depth to top of magnetic source contour map.

interpreted with the aim of estimating the thickness of sediments for hydrocarbon potential. Three depth estimating methods were employed; Euler deconvolution, SPI and spectral analysis to estimate the thickness of sediments in the area of investigation for hydrocarbon potential. The result from Euler deconvolution and spectral analysis reveal maximum sedimentary thickness of 3.56 and 3.50 km respectively while the result of the SPI shows a maximum sedimentary thickness of 4.20 km. Previous research works on sedimentary thickness for hydrocarbon maturation showed that the sufficient sedimentary thickness for hydrocarbon maturation is about 3 km and above (Bemsen et al., 2013; Salako and Udensi, 2013; Adewumi et al., 2017; Lawal and Nwankwo, 2014). The result from this study is ample enough to accommodate oil and gas accumulation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Biswas A (2018). Inversion of source parameters from magnetic anomalies for mineral /ore deposits exploration using global optimization technique and analysis of uncertainty. Natural Resources Research 27(1):77-107.

Biswas A (2016). Interpretation of gravity and magnetic anomaly over thin sheet-type structure using very fast simulated annealing global optimization technique. Modeling Earth Systems and Environment 2(1):30.

Biswas A, Acharya T (2016). A Very Fast Simulated Annealing method for inversion of magnetic anomaly over semi-infinite vertical rod-type structure. Modeling Earth Systems and Environment 2(4):198.

Biswas A, Mandal,A, Sharma SP, Mohanty WK (2014). Integrating apparent conductance in resistivity sounding to constrain 2D Gravity modeling for subsurface structure associated with uranium mineralization across South Purulia Shear Zone. International Journal of Geophysics, 2014, Article ID 691521, 1–8. (DOI:10.1155/2014/691521).

Obaje NG, Moumouni A, Goki NG, Chaanda MS (2011). Stratigraphy, Paleogeography and Hydrocarbon Resource Potentials of the Bida Basin in North-Central Nigeria. Journal of Mining and Geology 47:97-114.

Obaje NG (2009). Geology and mineral resources of Nigeria. Dordrecht Heidelberg London New York: Springer-Verlag.

Bemsen IE, Onwuemesi AG, Anakwuba EK, Chinwuko AI, Usman AO, Okonkwo CC (2013). Spectral Analysis of Aeromagnetic Data over Part of the Southern Bida basin, West-Central Nigeria. International Journal of Fundamental Physical Sciences 3:27-31.

Udensi EE, Osazuwa IB (2004). Spectral determination of depths to magnetic rocks under the Nupe Basin, Nigeria. Nigerian Association of Petroleum Explorationists Bulletin 17:22-27.

Reid AB, Allsop JM, Granser H, Millet AJ, Somerton IW (1990). Magnetic interpretation in three dimensions using Euler deconvolution. Geophysics 55:80-91.

Salako KA, Udensi EE (2013). Spectral Depth Analysis of part of upper Benue Trough and Bornu Basin, Northeast Nigeria, using Aeromagnetic data. International Journal of Science and Research 2(8).

Adewumi T, Salako KA, Salami MK, Mohammed MA, Udensi EE (2017). Sedimentary Thickness using Spectral analysis of Aermagnetic data over part of Bornu Basin, Northeast, Nigeria. Asian Journal of Physical and Chemical Science 2(1):1-8.

Lawal TO, Nwankwo LI (2014). Wavelet analysis of high resolution aeromagnetic data over part of Chad Basin, Nigeria. Ilorin Journal of Science 1:110-120.

Thurston JB, Smith RS (1997). Automatic conversion of magnetic data to depth dip, and susceptibility contrast using the SPI^{TM} method. Geophysics 62:807-813.

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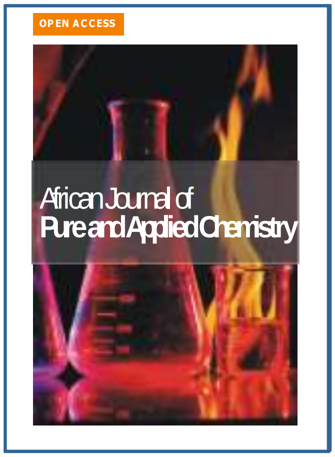

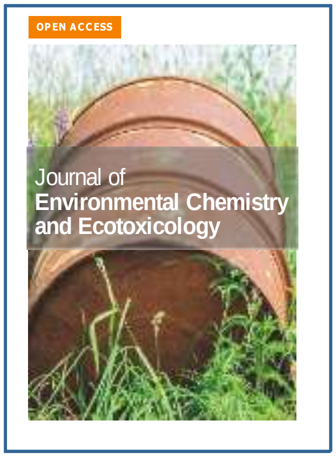

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