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Spectral analysis and source parameter imaging of aeromagnetic anomalies over Ogoja and Bansara areas of lower Benue trough, Nigeria

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Spectral analysis and source parameter imaging of aeromagnetic anomalies over Ogoja and Bansara areas of lower Benue trough, Nigeria

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Qualitative and quantitative interpretations of aeromagnetic anomalies over Ogoja and Bansara areas of Anambra Basin, Lower Benue Trough of Nigeria were carried out using spectral analysis and source parameter imaging methods. The study area which covers an area of approximately 6050 km² lies within latitude 6° 0' to 7° 0' North and longitude 8° 30' to 9° 0' East. The regional anomaly was separated from the total magnetic intensity map to obtain the residual anomaly using first order polynomial fitting technique. The residual data was analyzed spectrally to obtain 18 spectral blocks for sedimentary depth estimates (deep and shallow depths). The edges and causative bodies of the residual anomaly were also sharpened to reduce anomaly complexity as well as fault trend amplification using first, second and horizontal derivatives. The 3-D basement topography map of the study area shows linear depression with deepest sedimentary thickness at the southeastern region of the study area, which implies that the feasibility of hydrocarbon potential will be higher in Bansara area than in Ogoja. The deepest depths obtained from spectral analysis and source parameter imaging are 5437.0 and 5059.9 m, respectively.

Key words: Spectral analysis, source parameter imaging, magnetic anomaly, sedimentary thickness, intrusive bodies, hydrocarbon potentials.

INTRODUCTION

Airborne geophysical survey is an important aspect of modern geophysics that allows faster and usually cheaper coverage of the exploration area. This method of investigating the subsurface geology is based on the magnetic anomalies in the earth’s magnetic field resulting from the magnetic properties of the underlying rocks. Measurements of the horizontal or vertical component or horizontal gradient of the magnetic field may also be made (Biswa et al., 2017). The shape, dimensions, and amplitude of an induced magnetic anomaly 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 (Biswa, 2016, 2017; Biswas and Acharya, 2016). For the exploration purposes, both ground and aero-magnetic data have been used to investigate the presence of mineral deposits in combination with gravity. In the mining industry, both magnetic and gravity method is still widely used as an exploration tool to map subsurface geology and estimate ore reserves for some massive ore bodies (Mandal et al., 2013, 2015; Biswas et al., 2014a, b; Biswas and Sharma, 2016).

Rocks differ in their magnetic mineral content; hence the magnetic intensity map allows a visualization of the geological structures of the upper crust in the subsurface, particularly the spatial geometry of bodies of rock and the presence of faults and folds. The main purpose of magnetic survey is to detect rocks or minerals possessing unusual magnetic properties that reveal themselves by causing disturbances or anomalies in the intensity of the earth’s magnetic field.

As the youth restiveness in the Niger delta continues unabated, the resulting economic losses due to vandalism and the resulting production cut have led to intense search for hydrocarbons in other basins such as the Anambra basin and the Chad basin, with presumed high hydrocarbon potential. The lower Benue Trough of the Anambra basin has been reported to hold high hydrocarbon prospect from previous aeromagnetic studies carried out in the area (Ofoegbu and Onuoha, 1990; Onwumesi, 1997; Obi et al., 2010; Ugwu and Ezema, 2012).

Interpretation of aeromagnetic data can be carried out both quantitatively and qualitatively. Quantitative interpretation involves making numerical estimates of the depth and dimensions of the sources of anomalies, and this often takes the form of modeling of sources which could, in theory, replicate the anomalies recorded in the survey (Biswa, 2015, 2016; Biswas et al., 2017). Spectral analysis has successfully been applied in interpretation of aeromagnetic data (Spector, 1968; Mishra and Naidu, 1974; Hahn et al., 1976). The power spectrum of the surface field has been used to identify average depths of source ensembles (Spector and Grant, 1970). This technique can be used in identification of the characteristic depth of the magnetic basement, on a moving data window basis, merely by selecting the steepest and therefore deepest straight-line segment of the power spectrum, assuming that this part of the spectrum is sourced consistently by basement surface magnetic contrasts. A depth solution is calculated for the power spectrum derived from each grid sub-set, and located at the center of the window. Overlapping the windows creates a regular, comprehensive set of depth estimates.

In the light of the successes of aeromagnetic survey in basement depth estimation, this paper reports the result of the interpretation of aeromagnetic data over Ogoja and Bansara areas of the lower Benue Trough (Anambra basin) using spectral analysis and source parameter imaging methods. This is in order to ascertain the hydrocarbon potentials of the area in terms of its sedimentary thickness (depth to basement) and hence delineate the basement topography of the area.

**Location and geology of the survey area**

The study area is located in the lower Benue Trough of Nigeria. The area lies within latitude 6° 0’ to 7° 0’ North and longitude 8° 30’ to 9° 0’ East. It covers an area of approximately 6050 km². The lower Benue Trough is underlain by a thick sedimentary sequence deposited during the Cretaceous. The oldest sediments belong to the Asu River Group (Figure 1) which uncomfortably overlies the Precambrian basement complex that is made up of granitic and magmatic rocks. The Asu River Group whose type outcrops within Abakaliki has an estimated thickness of 2000 m and is of Albian age (Ofoegbu, 1985). It comprises of argillaceous sandy shale, laminated sandstone, micaceous sandstone and minor limestone, with an inter-fingerling of mafic volcanic (Nwachukwu, 1972). The shales are fissile, highly fractured and are associated with pyroclastic rocks, especially around Abakaliki and Ezil areas (Uzuakpunwa, 1974; Olade, 1975). Deposited on top of these Asu River Group sediments in the area were the Upper Cretaceous Ezelaku shale. This shale consists of nearly 1000 m of calcarceous flaky shale and siltstone, thin shaley limestone and calcareous sandstone (Reymont, 1965). They are Turonian in age and are overlain by younger sediments of the Awgu shales (Coniancian). The Awgu shale consists of marine fossiliferous grey bluish shale, limestones and calcareous sandstone. The Awgu shale is overlain by Nkporo shale (Campanian) which is also marine and has sandstone members. A geological map of the study area is shown in Figure 1.

**MATERIALS AND METHODS**

The materials used in this study include two sheets of aeromagnetic data of Ogoja (sheet 290) and Bansara (sheet 304). Software applications used include, Oasis Montaj, WingLink, Potent O 4.10.07, Microsoft excel and Surfer10. The high resolution aeromagnetic data of Ogoja (sheet 290) and Bansara (sheet 304) used for this study were obtained from the Nigerian Geological Survey Agency (NGSA). Fugro Airborne Surveys Limited carried out the airborne geophysical work in 2008 for NGSA. The survey was flown at 80 m elevation along flight lines spaced 500 m apart. The flight line direction was 135° while the tie line direction was 225°.

**Data processing**

The two digitized sheets were first merged into a single sheet which...
formed the study area (Figure 2). The first step in processing the data was the polynomial fitting in order to remove the regional anomalies from the total magnetic intensity, to obtain the residual anomaly (Figure 3). The first order polynomial fitting was applied on our data. The extracted residual anomaly was used for qualitative interpretation based on visual inspection of the data. Other processing techniques applied include the first vertical derivative, second vertical derivative and horizontal derivative (Biswas et al., 2017).

Spectral analysis

The discrete Fourier transform is the mathematical tool used for spectral analysis and applied to regularly spaced data such as the aeromagnetic data to calculate and interpret the spectrum of the potential field. To perform this analysis, graphs of the natural logarithms of the amplitude against frequency were plotted and the gradient of the linear segments computed in order to obtain the depths to the basement by employing the equations of Spector and Grant (1970):

\[
M_1 = \frac{\Delta y(\log E)}{\Delta x(Freq)}
\]

\[
M_2 = \frac{\Delta y(\log E)}{\Delta x(Freq)}
\]

Where \(M_1\) and \(M_2\) are the slopes of the first and second segments of the plots. The negative sign shows depth to the subsurface while \(D_1\) (deep depth) and \(D_2\) (shallow depth) are the first and second depth segments, respectively.

The merged aeromagnetic sheet was further divided into eighteen different cells using Microsoft Excel sort and filter to select data from smallest to largest or filter out specific values for spectral analysis. Each profile covers a square area of 18.3 km by 18.3 km in order to accommodate longer wavelengths so that depths up to about 6.0 km could be investigated. Each block was then widowed 20 min by 20 min.

Fast Fourier Transform (FFT) technique was used in Microsoft (MS) excel and Oasis Montaj program to transform the magnetic data into the radial energy spectrum for each block. The average radial energy spectrum was calculated and displayed in a logarithm scale of energy versus frequency.

Spector and Grant (1970) has shown that the Log-energy spectrum of the source have a linear gradient whose magnitude is dependent upon the depth of the source. Graphs of radial average energy spectrum were plotted in Microsoft Excel software using Excel chart wizard as Log of energy (FFT magnitude) against frequency in cycles/m. The slope of each of the line segments for
the eighteen spectral blocks were first evaluated. The average depth($D$) of buried ensemble was also calculated. The coordinates and the two depth estimates $D_1$ (deep depth) and $D_2$ (shallow depth) for each of the eighteen spectral blocks were then determined.

**Source parameter imaging (SPI)**

This method utilizes the relationship between source depth and the local wavenumber ($k$) of the observed field, which can be calculated for any point within a grid of data through horizontal and vertical gradients. At peaks in the local wavenumber grid, the source depth is equal to $\frac{n}{n}$, where $n$ depends on the assumed source geometry (analogous to the structural index in Euler deconvolution); for example $n = 1$ for a contact, $n = 2$ for a dyke (Blakely and Simpson, 1986). The assumed geometry for each magnetic body was used to determine the area where we have shallow and deep lying magnetic bodies in the study area. Peaks in the wavenumber grid were identified using a peak tracking algorithm and valid depth estimates were also isolated. Source parameter imaging method was also employed in this work to estimate the depth from the local wavenumber of the analytical signal. The analytical signal $A_1 (x, z)$ is given as (Nabighian, 1972; Biswas et al., 2017):

$$A_1 (x, z) = \frac{\partial M}{\partial x} (x, z) \cdot j \frac{\partial M}{\partial z} (x, z)$$  (5)

Where $M (x, z)$ is the magnitude of the anomalous total magnetic field, $j$ is the imaginary number, $x$ and $z$ are Cartesian coordinates for the vertical and horizontal directions, respectively.

**RESULTS AND DISCUSSION**

Figure 2 shows the total magnetic intensity map (TMI) while Figure 3 shows the residual magnetic field anomaly map of the study area after having removed the regional anomaly from the TMI anomaly. Figures 4 to 6 show the first vertical derivative, second vertical derivative and the horizontal derivative map, respectively after the data reduction techniques.

A summary of the result of the estimates of the depth to basement for the deep ($D_1$) and shallow ($D_2$) depths are presented in Table 1. Six representative plots of log of spectral energy versus frequency for the eighteen spectral blocks are shown in Figure 7. The basement depths (deep depths) presented in Table 1 was used to construct the magnetic basement depth map of the study area (Figure 8). The deep magnetic sources vary from 1.8 to 5.6 km in the study area. The deepest basement
Figure 3. Two dimensional view of residual field of the study area.

depths were found at the southeastern part of the study area (Bansara area). The computed depths to basement were used to construct the 3D surface map for the basement topography of the area (Figure 9). The 3D surface map shows a linear depression with deepest sedimentary thickness (blue color) at the southeastern path (Bansara area) of the study area.

Using the first vertical derivative and horizontal gradient, the depth to basement was also computed using the source parameter imaging method (Figure 10). The negative depth values shown on the SPI legend depicts the depths of buried magnetic bodies, which are deep seated basement rocks to near surface intrusions. The SPI depth result ranges from 0.27 km (shallow magnetic bodies) to 5.10 km (deep lying magnetic bodies). This is in agreement with the depths obtained from the spectral analysis over the study area. Integrating results obtained both from spectral analysis with those from SPI shows that Bansara area with basement depths of about 2.0 to 5.4 km has enough sediment thickness to favour hydrocarbon accumulation, assuming all other conditions are favourable.

Conclusion

The aeromagnetic data of Ogoja and Bansara areas have been interpreted qualitatively and quantitatively. The 2D residual anomaly map of Ogoja and Bansara revealed that the area is magnetically heterogeneous. The areas that have very strong magnetic values (45.5nT to 63.7nT) are probably due to the existence of near surface igneous or metamorphic rocks of high magnetic susceptibility values. The areas between -94.1nT to -0.9nT are most likely due to sedimentary rocks and other non-magnetic sources. The results of spectral analysis and source parameter imaging show clearly the variation along profiles in the surface of magnetic basement across the study area. Based on the highest sedimentary thickness obtained in this work (5.6 km), the possibility of
Figure 4. First vertical derivative map of the study area.

Figure 5. Second vertical derivative map of the study area.
Figure 6. Horizontal derivative map of the study area.

Table 1. Summary of estimates of the first ($D_1$) and second ($D_2$) line segments of the spectral blocks.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Spectral blocks</th>
<th>Co-ordinates (m)</th>
<th>Depth to sources (km)</th>
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<td>Y (Latitude)</td>
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Figure 7. Representative spectral plots of logarithm of energy against frequency for block 1 – 6 of the eighteen spectral blocks.

Hydrocarbon generation in the study area could be feasible around Bansara area.
Figure 8. 2D spectral depth to basement map of the study area (contour interval 0.2 km).

Figure 9. 3D basement topographic map of the study area from spectral depths.
CONFLICT OF INTEREST

The authors have not declared any conflict of interest.

REFERENCES


