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Original Research Article

Sedimentary Depth Estimation of Southeastern Parts of Sokoto Basin, Northwestern, Nigeria, Using Spectral Analysis

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Abstract

A high resolution aeromagnetic data of southeastern part of Sokoto basin comprising (sheet 28), (sheet 29), (sheet 50) and (sheet 51) was subjected to spectral depth analysis using Oasis Montaj and interpreted in order to determine its hydrocarbon potentials of the area. The study area covered latitudes 12° 00'-13° 00'N and longitudes 4° 30'-5° 30'E with an estimated total area of about 12100 km^2. Qualitative interpretation was done by visual inspection of the total magnetic intensity (TMI) map, regional and residual maps. NW and SE main trends was observed in the TMI. The 3-D surface map also showed a linear depression with sedimentary accumulation trending E-W. Spectral depth estimates revealed two depth sources with the deep sources ranging from 0.76 km to 2.46 km, while the shallow depth sources ranges from 0.450 km - 0.967 km. High sedimentary thickness of over 2.46 km was observed around Shagari and Dange at the Northern part of the study area. The area of maximum sedimentary thickness could serve as a possible reserve for hydrocarbon accumulation.

Keywords: Aeromagnetic data, Spectra Depth, Sedimentary thickness, depth sources.

INTRODUCTION

The search for mineral deposits and hydrocarbon (oil and gas) has been a major business challenge in Nigeria since the pre-colonial era. The bedrock of Nigeria's economy had been the solid mineral before the lucrative oil sector took over due to its high profitability. Over 80 percent of the country's revenue comes from export and domestic sales of oil and gas upon which over 160 million growing population depends on Ugwushi *et al.*, [1]. 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 Sokoto Basin in particular is one of those sedimentary basins, hence the need to ascertain its hydrocarbon potentials. Since most mineral deposits are beneath the surface, their detection depends upon those characteristics that differentiate them from the surrounding media. Methods based upon variations in the elastic properties of rocks have been developed for determining structures associated with oil and gas, such as faults, anticlines and synclines, though these are often thousands of meters below the surface. The Magnetic method is one of the oldest geophysical techniques used to delineate subsurface structures and determine the source of specific anomalies present in an area under investigation [2]. In prospecting for oil, aeromagnetic data can give information from which depths to basement rocks can be determined and thus locate and define the extent of sedimentary basin [3]. Mukhtar and Congjiao [4] stated that, in Nigeria there are seven (7) basins in which active petroleum exploration activities can be carried out.

The present study intends to use some spectral analysis techniques of data management and interpretation to evaluate the magnetic anomalies of the southeastern parts of the Sokoto basin, northwestern Nigeria, which can help predict the hydrocarbon potentials of the area.

Location of the Study Area

The study area lies between Latitude 4°30'N–5°30'N and Longitude 12°00'E–13°00'E covering an approximate area of about 12,100 km^2 within the southeastern parts of the Sokoto sedimentary basin of Nigeria.

The Sokoto basin also known as the southern part of the IuIIemenden basin, is located in northwestern Nigeria. It consists predominantly of a great undulating plain with an average

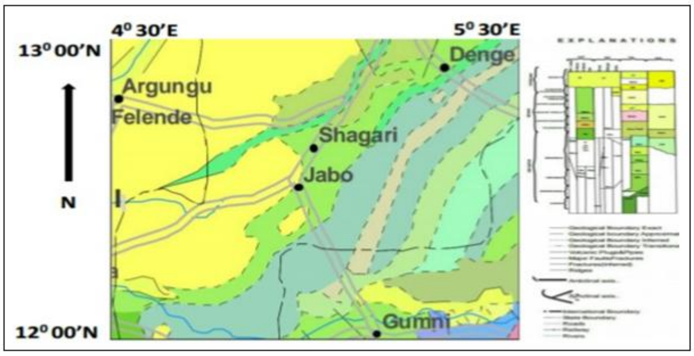

Fig-1: Geological Map of the Study area (Modified after Obaje, 2004) [5]

MATERIALS AND METHODS

Four aeromagnetic data used for this study was obtained from the Nigerian Geological Survey Agency (NGSA). The aeromagnetic data were acquired using a 3 x Scintrex CS2 caesium vapour magnetometer. Fugro Airborne Surveys carried out the airborne geophysical survey in 2009 across the nation. The survey was conducted along NW-SE flight lines and tie line along NE-SW direction with 500m flight line spacing. Terrain clearance of 80m and line spacing of 2km were used. The magnetic data recording interval during the survey was 0.1 seconds. All grid data were saved and delivered in Oasis Montaj Geosoft raster file format. Each 1:100,000 topographical sheet covers an area of about 3025 km^2 (i.e. 55 km x 55 km) totaling a superficial area of 12,100 km^2.

Regional-Residual Separation

Polynomial fitting was applied to remove of the regional anomalies from the total magnetic intensity data in order to obtain the residual anomalies. The residual component is due to relatively local near surface masses while the regional component is that component of the total field arising from larger and deeper structures beneath the earth surface. The extracted residual anomalies are often useful for structural mapping or qualitative interpretation based on visual inspection of the data. Regional - residual separation was carried out by fitting a plane surface to the data using multi- regression least squares analysis. This is an analytical method in which matching of the regional by a polynomial surface of low order exposes the residual features as random errors. The surface linear equation used on the data is:

$$P(x, y) = a + bx + cy \qquad (1)$$

Where: a, b and c are constants; x and y are distances in x and y – directions (independent variables); P (x, y) is the magnetic value at x and y co-ordinates (dependent variable). If the regional surface is expressed as the function.

$$Z = a + bx + cy \qquad (2)$$

Then the residual anomaly function R, for the observed magnetic intensity M is given as:

$$R = M - Z \qquad (3)$$

SPECTRAL ANALYSIS

Spectral analysis of potential field data has been used extensively over the years to derive depth to certain geological features Alagbe and Sunmonu [6], Spector & Grant [7].

Hahn *et al.,* [8] Spectral analysis is the process of calculating and interpreting the spectrum of the potential field data. The spectral depth method is based on the principle that a magnetic field measured at the surface can be considered as an integral of magnetic signature from all depths. The Discrete Fourier Transform is the mathematical tool for spectral analysis and applied to regularly spaced data such as the aeromagnetic data. A Fast Fourier Transform (FFT) algorithm computes the Discrete Fourier Transform (DFT) of a sequence, or it's inverse. The Fourier Transform is represented mathematically [7] as:

$$Y_i(x) = \sum_{n=1}^{N} \left[a_n \sin(\frac{2\pi n x_i}{L}) + b_n \sin(\frac{2\pi n x_i}{L}) \right] \qquad (4)$$

Where $Y_i(x)$is the reading at x_i position, L is length of the cross-section of the anomaly, n is harmonic number of the partial wave number, N is number of data points, a_n is real part of the amplitude spectrum and b_n is imaginary part of the amplitude spectrum; for i = 0,1,2,3, … , n.

Estimation of Depth to Basement from Spectral Analysis

The study area is subdivided into equal spectral blocks using the filtering tool of the Microsoft excel software. Microsoft (MS) excel program employing the Fast Fourier Transform (FFT) technique transforms the magnetic data into the radial energy spectrum for each block. The average radial energy spectrum will be calculated and displayed in a logarithm figure of energy versus frequency. Two linear segments are drawn from each graph; and their gradients (m) are used to estimate the deep depth (D1) and the shallow depth (D2) using equations (5), (6) and (7) respectively,

$$slope(m_1 m_2) = \frac{\text{Log}\, Energy}{Frequency} \quad (5)$$

$$D_1 = -\frac{m_1}{2\pi} \quad (6)$$

$$D_2 = -\frac{m_2}{2\pi} \quad (7)$$

Where m_1 and m_2 are slopes of the first and second segment of the plot and the negative sign (-) indicates depth to the subsurface.

RESULTS AND DISCUSSIONS

The composite Total Magnetic Intensity map (TMI) of the study area produced using Oasis Montaj as shown in Figure-2. The TMI map can be divided into three main sections; The northeastern (NE), northwestern (NW) and parts of the southwest (SW) are characterized by high magnetic intensity values represented by pink color. Whereas majority of the southwestern (SW) and northwestern (NW) parts are dominated by low magnetic intensity values indicated by green-blue colour. The negative value imply areas that are magnetically subdued or quiet while the positive values are areas magnetically responsive. The magnetically subdued areas are the magnetic lows of the study area and this is typical of a sedimentary terrain while the magnetic responsive areas are the magnetic highs regions. These high magnetic intensity values, which dominate the northeastern and southwestern parts of the study area are caused probably by near surface igneous rocks of high values of magnetic susceptibilities. The low amplitudes are most likely due to sedimentary rocks and other non-magnetic sources. In general, high magnetic values arise from igneous and crystalline basement rocks, metamorphic rocks, deep seated volcanic rocks or even crustal boundaries.

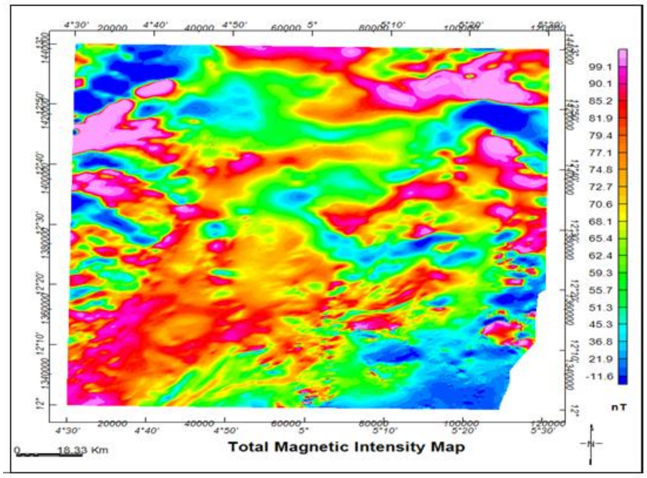

Fig-2: Total magnetic intensity (TMI) map of the study area (33000nT must be added to the data so as to get the actual value at any point)

Residual Magnetic Intensity

The 2D residual map (Figure-3) of the study area revealed that the magnetic field intensity values ranges from -64.7 nT (minimum) to 35.9 nT (maximum). This indicates that the study area is characterized with low (blue colour) and high (pink colour) magnetic signature. The positive residual anomalies were obtained in areas where they could be related to the surface rocks (outcrops) and/or with measured magnetic values. Similarly, negative residual anomalies were obtained where the observed field produced definite magnetic lows.

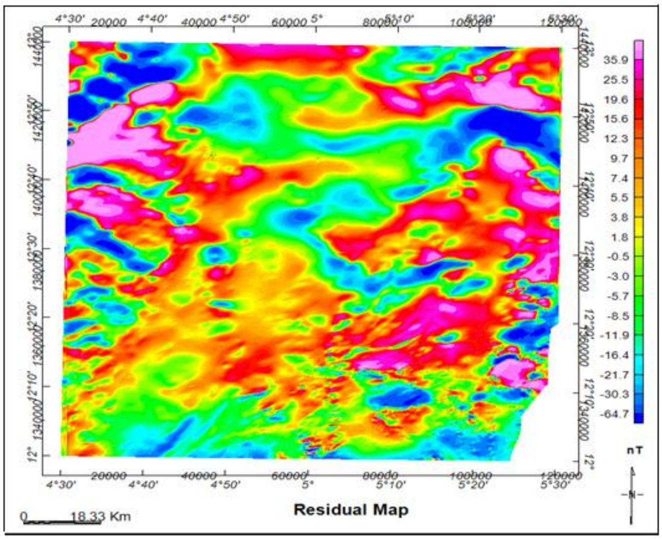

Fig-3: Residual magnetic map of the study area

Regional Map

Fig-4 is the regional magnetic intensity map of the study area with magnetic values ranging from 50.0 nT to 73.2 nT. The values increases from southeastern to northwestern parts indicating there is a fill of sediments more in the southeastern parts than in the northwestern parts of the study area. The regional anomalies trends majorly in the NW-SE direction.

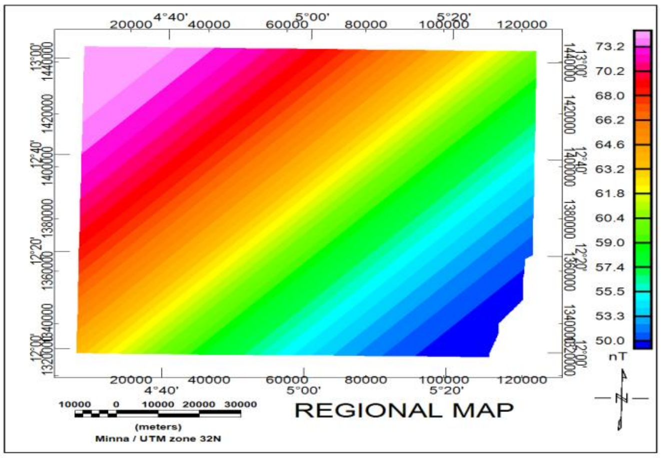

Fig-4: Regional magnetic map of the study area

SPECTRAL ANALYSIS RESULT

The Residual map of the study area was divided into 18 spectral cells (blocks) to allow for an in-depth analysis. Block A-L (36.67 km x 36.67 km), Block J-M (55 km x 55 km), Block N-O (110 km x 55 km), Block P-Q (55 km x 110 km and Block R (110 km x 110 km). The divisions of residual map into spectral sections or blocks were done with Oasis Montaj and Microsoft excel. The analysis was carried out using a spectral program plot (SPP) developed with MATLAB. A graph of the logarithm of the energy against frequency was plotted for each of the spectral block and the slope was calculated. Employing equation (6) and (7), the depths were calculated. Z_1 and Z_2 in Figure 7 (A-R) is the slope for the deep depth and slope for the shallow depth of magnetic anomalous source respectively. Z_1 ranges from 0.76km - 2.46km while Z_2 ranges from 0.450 km - 0.967 km as shown likewise in (Table-1).

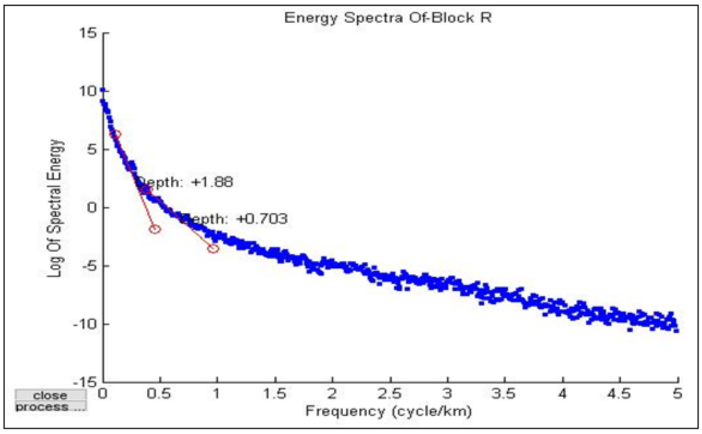

Fig-7: Plot of Log of Spectral Energy against Frequency for Block M - R in (radian per metre)

Table-1: Depths of the eighteen (18) spectral cells

BLOCK	LONGITUDE (Degrees)	LONGITUDE AVERAGE (Degrees)	LATITUDE (Degree)	LATITUDE AVERAGE (Degree)	Depth to top Z1 (Km)	Shallow Depth Z2(Km)
A	4.5-4.83	4.67	12.66-13.00	12.83	1.69	0.616
B	4.83-5.17	5.00	12.66-13.00	12.83	2.46	0.967
C	5.17-5.50	5.34	12.66-13.00	12.83	1.73	0.516
D	4.50-4.85	4.68	12.33-12.66	12.48	1.13	0.744
E	4.83-5.17	5.00	12.33-12.66	12.48	2.06	0.765
F	5.17-5.50	5.34	12.33-12.66	12.48	1.31	0.774
G	4.50-4.83	4.67	12.00-12.33	12.16	1.21	0.472
H	4.83-5.17	5.00	12.00-12.33	12.16	1.14	0.461
I	5.17-5.50	5.34	12.00-12.33	12.16	0.76	0.465
J	4.50-5.00	4.75	12.50-13.00	12.75	1.91	0.694
K	5.00-5.50	5.25	12.50-13.00	12.75	1.58	0.846
L	4.50-5.00	4.75	12.00-12.50	12.25	1.27	0.452
M	5.00-5.50	5.25	12.00-12.50	12.25	1.26	0.590
N	4.50-5.50	5.00	12.50-13.00	12.75	1.97	0.782
O	4.50-5.50	5.00	12.00-12.50	12.25	1.11	0.450
P	4.50-5.00	5.00	12.00-13.00	12.50	1.42	0.542
Q	5.00-5.50	5.25	12.00-13.00	12.50	1.26	0.452
R	4.50-55.50	5.00	12.00-13.00	12.50	1.88	0.703

Magnetic Basement Depth map

From the computed values (Table-1), the magnetic basement depth was plotted and contoured using surfer 13 software. The deep magnetic sources vary from 0.7 to 2.5 km approximately, whereas the shallow magnetic source varies from 0.42 to 0.96 km. The deep magnetic sources suggests depth to precambrian basement while the shallow magnetic sources depict depths to basic intrusive and/or magnetised bodies. The deep depth to basement (sedimentary thicknesses) is shallowest (Red colour) in the southeastern part of the study area, while it is deepest (Blue colour) in the northern part. This disagrees with the result from the analytic signal which suggests otherwise.

Basement Topography

The computed deep depths to basement were used to construct the 3D surface map for the basement topography of the area. The 3D surface map shows a linear depression with thickest sediments at the north-central region of the study area and an elevation with shallowest sediments at the southeastern part of the study area.

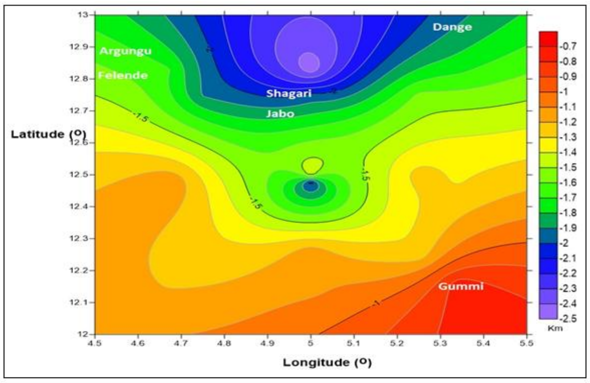

Fig-8: Deep depth to basement map of the study area

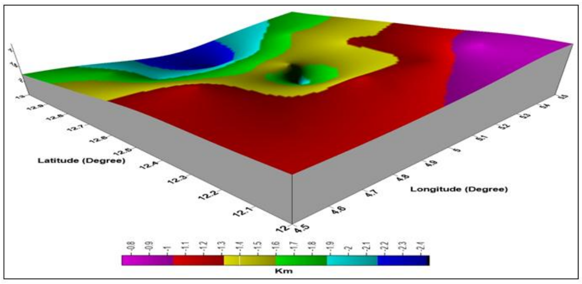

Fig-9: 3D Deep depth to basement map of the study area

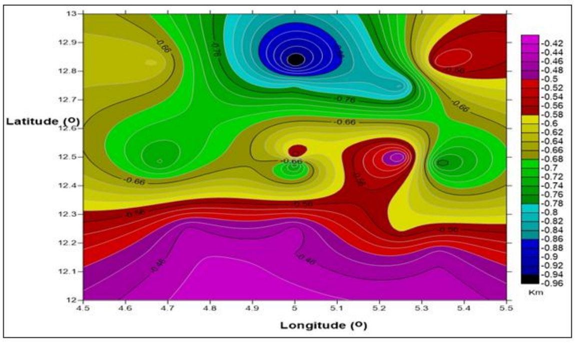

Fig-10: Shallow depth map of the study area

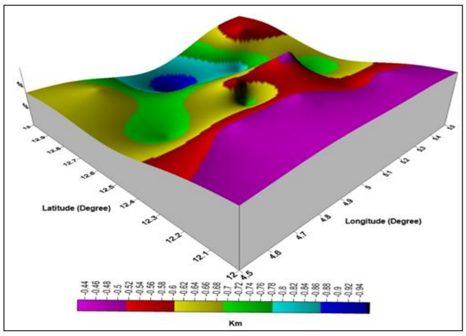

Fig-11: 3D Shallow depth map of the study area

DISCUSSION

The Total Magnetic Intensity (TMI) values of the study area range from -11.6 nT to 99.1 nT while the residual magnetic intensity ranges from -64.7 nT to 35.9 nT. These values show that the study area is magnetically heterogeneous. The Total Magnetic Intensity map, TMI (Figure-1) and the Residual magnetic intensity map (Figure-2) shows variation of highs and lows in magnetic signature. About one third of the map can be seen to be greenish (featureless), the pink coloration depicts high magnetic signature while blue depicts low magnetic signature and yellow indicates intermediary. The negative values imply areas that are magnetically subdued or quiet while the positive values are magnetically responsive. The magnetically subdued areas are the magnetic lows of the study area and this is typical of a sedimentary terrain while the magnetic responsive areas are the magnetic highs regions which are assumed to be due to the likely presence of outcrops of crystalline igneous or metamorphic rocks, deep seated volcanic rocks or even crustal boundaries.

The result from the Spectral analysis shows that the deep depth to the magnetic sources varies from 0.76 km to 2.46 km approximately, whereas the shallow magnetic source varies from 0.45 km to 0.967 km. The deep magnetic sources could suggest depth to Precambrian basement while the shallow magnetic sources depict depths to basic intrusive and/or magnetized bodies. The deep depth to basement (sedimentary thicknesses) is shallowest in the Southeastern part of the study area around Gummi, while it is deepest in the Northern part around Shagari and Dange. These depths are found to be within the range of depths predicted by earlier researchers that worked on the Sokoto basin Onwuemesi [9], Kamba *et al.,* [10] and Bonde [11].

The 3D basement topographic map presents irregular nature of the basement which is possibly associated with faults that aids the migration and entrapment of hydrocarbon and other mineralized deposits. The 3D surface map (Figure-5) shows a linear depression with thickest sediments at the Northern region of the study area and an elevation with shallowest sediments at the southwest (SW) to southeastern (SE) part of the study area.

CONCLUSION

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 better striking features owing to the high resolution nature of the 2009 data more than the 1970s in terms of terrain clearance, line spacing and improvement of technology. This work will help to ascertain better geophysical details of the southeastern parts of the Sokoto Basin, and further enhanced the full coverage of the whole basin in the exploration activity.

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