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Full Length Research

Determination of hydrocarbon potentials in parts of Sokoto Basin, Northwestern Nigeria using spectral analysis technique

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ABSTRACT: In this work, an attempt was made to estimate the depth to magnetic source and by inference, the thickness of sediments within parts of the Sokoto Basin, Northwestern Nigeria. Aeromagnetic data of Tambuwal (Sheet 50) was acquired, processed and interpreted. The regional field was separated from the total magnetic intensity (TMI) and the magnetic anomaly was obtained. The anomaly map was upward continued and divided into overlapping square grids of 27.5 km x 27.5 km. Spectral depth analysis was then carried out on each grid to infer areas of probable hydrocarbon prospects. The result of the spectral method indicated high sedimentation, generally greater than 2.00 km, trending NE-SW through the central portions. The central, particularly around Dogon Marke town and its environs, have the highest thickness of sediments (2.4 km). In conclusion, the central portion of the study area, particularly around Dogon Marke town and its environs has the highest prospect for hydrocarbon.

Keywords: Depth estimation, magnetic anomaly, power spectrum, sedimentation, upward continuation.

INTRODUCTION

Geophysics involves the application of physical principles and quantitative physical measurements in order to study the earth's interior, atmosphere, and terrestrial space. Detection and analysis of the geophysical signals form the core of geophysical signal processing. Analysis of these results can reveal how various physical properties of the earth (both surface and interior) vary both vertically and laterally, and the interpretations which can reveal meaningful information on the geological structures beneath (Dobrin, 1976).

The Magnetic method is the oldest of all applied geophysical techniques (Milsom, 2003). It involves the investigation of subsurface geology on the basis of anomalies in the earth's magnetic field that results from the magnetic properties of underlying rocks and minerals. The magnetic method can be applied in petroleum exploration and mapping features in igneous and metamorphic rocks, possible faults, dikes, intrusions or other features associated with mineral concentrations. It can be used to estimate depth to basement and to qualitatively and quantitatively describe basement structures. Most sedimentary rocks have very low susceptibility and thus are nearly transparent to magnetism. Accordingly, in petroleum exploration magnetics are used negatively: magnetic anomalies indicate the absence of explorable sedimentary rocks (Likkason, 2014). To ascertain promising areas of possible hydrocarbon deposits within a sedimentary basin, one needs to first determine thickness of sediments or depth to basement within an area. According to Anudu et al. (2012), the minimum sediment thickness required for producing oil usually varies from 2 to 4 km, compared to 3 to 7 km for gas production/formation.

Several magnetic depth measuring techniques exist and have been employed by several authors. However, for the purpose of this study, spectral analysis technique will be used. Therefore, the objective of this research is to determine the thickness of sediments and by that, infer areas suitable for hydrocarbon accumulation and possible exploitation.

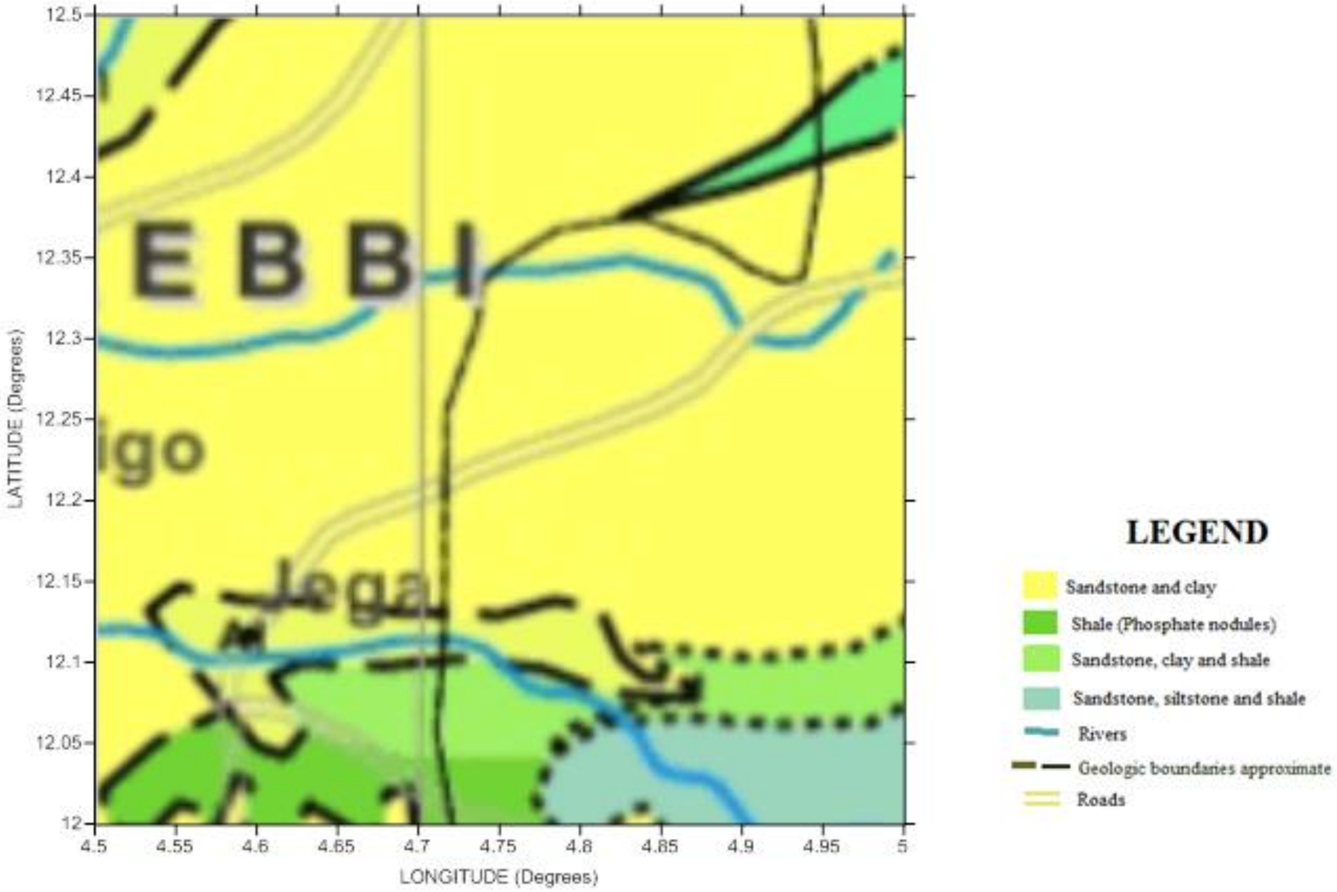

Figure 1. Geologic map of the study area (Extracted from the general geological map of Nigeria by NGSA).

MATERIALS AND METHOD

Location and geologic setting of the study area

The study area falls within Sokoto State, Northwestern Nigeria and is bounded between latitudes 12˚N to 12˚30' N and longitude 4˚30' E to 05˚00' E. It constitutes part of the Nigerian arm of the Lullemmeden Basin; the Sokoto Basin. The Lullemmeden Basin were accumulated during four main phases of deposition: The pre-Maastrichtian Illo and Gundumi Formations consisting of grits and clay; The Maastrichtian Rima group consisting of mudstone and friable sandstone, which forms the Taloka and Wurno Formations, separated by fossiliferous shelly Dukamaje Formation; The Paleocene Sokoto Group which constitute the Dange and Gamba formations and is mainly shales; The post-paleocene continental terminal formed by the Gwandu Formation (Obaje, 2009). As shown in Figure 1, a large portion of the area falls within the Rima Group.

Data acquisition

High-Resolution Aeromagnetic (HRAM) data of Tambuwal (sheet 50), which covers the area under consideration, was obtained from the Nigerian Geologic Survey Agency (NGSA). The map which is on a scale of 1:100,000 and in half-degree sheet, was compiled from the data collected at a flight altitude of 80 m, along NE-SW flight lines spaced approximately 500 m apart. Figure 2 show the total magnetic intensity (TMI) of the study area with field strength ranging from 33041.9 to 33093.7 nT (Figure 2).

Data processing and interpretation techniques

Figure 3 is a flow chart depicting the steps followed in processing the aeromagnetic data. The regional magnetic field data was separated from the residual magnetic data using the polynomial fitting method. Residual magnetic field data were obtained as the deviations of the fitted plane surface from the total magnetic intensity using SURFER 13 software. The regional magnetic field contour map of the study area (Figure 4) shows a NW-SE trend in orientation of deeper sources with an increase in magnetization from NE to SW of the area. Figure 5 is the image map of the residual magnetic intensity (RMI) of the study area. The residual map depicts the presence of high

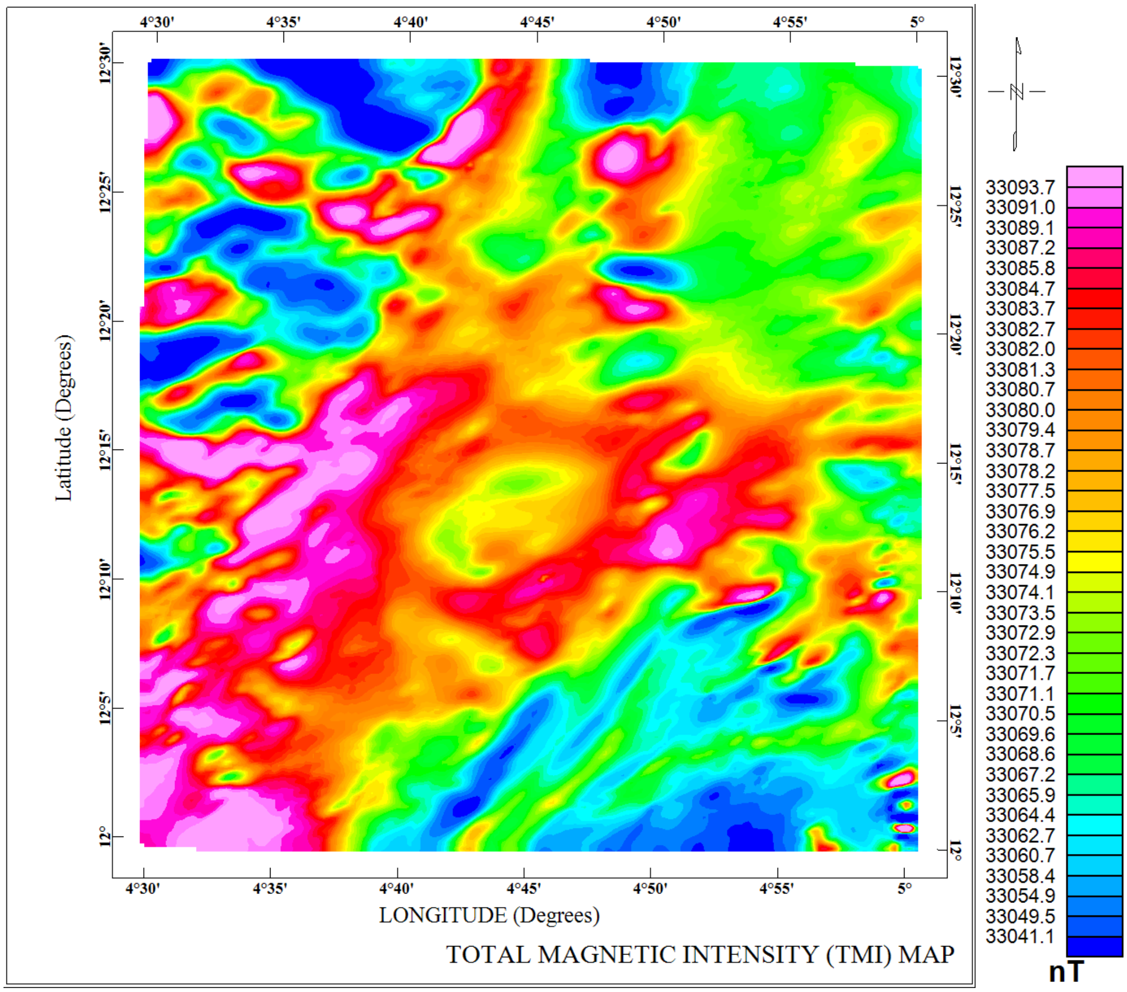

Figure 2. Total magnetic intensity map of the study area.

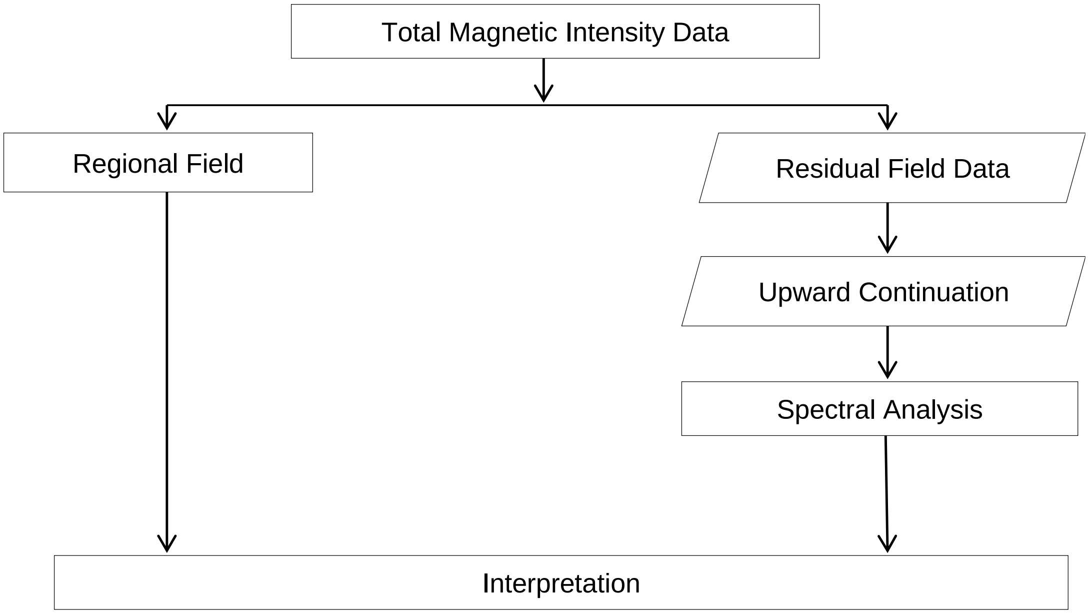

Figure 3. Flow chart showing the process of data processing.

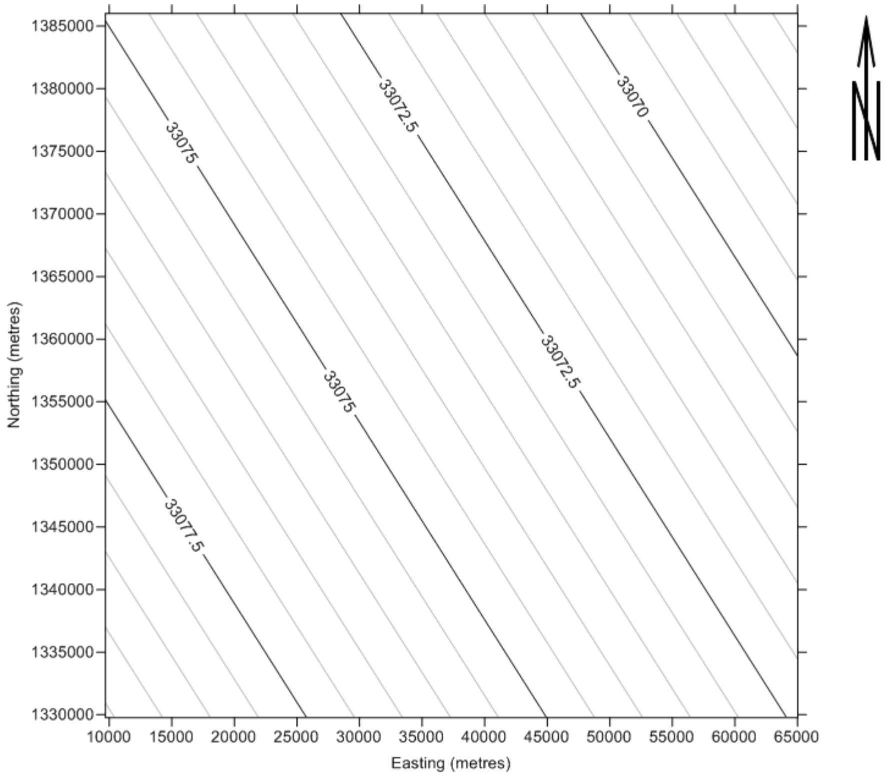

Figure 4. Regional magnetics contour map of the study area.

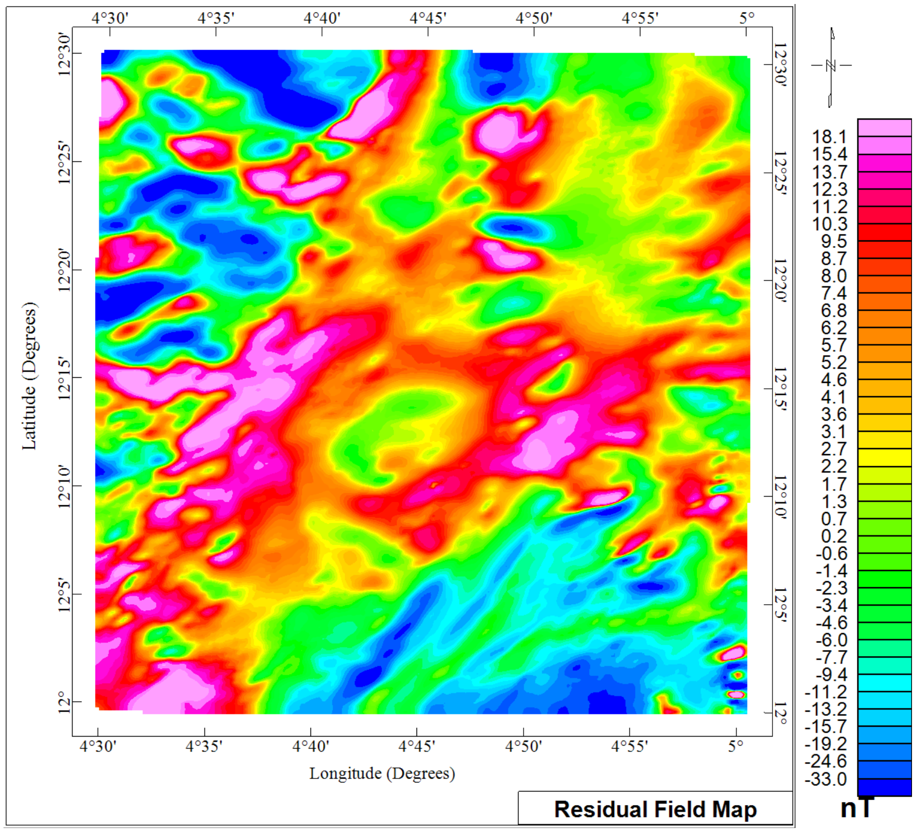

Figure 5. Residual magnetic intensity map of the study area.

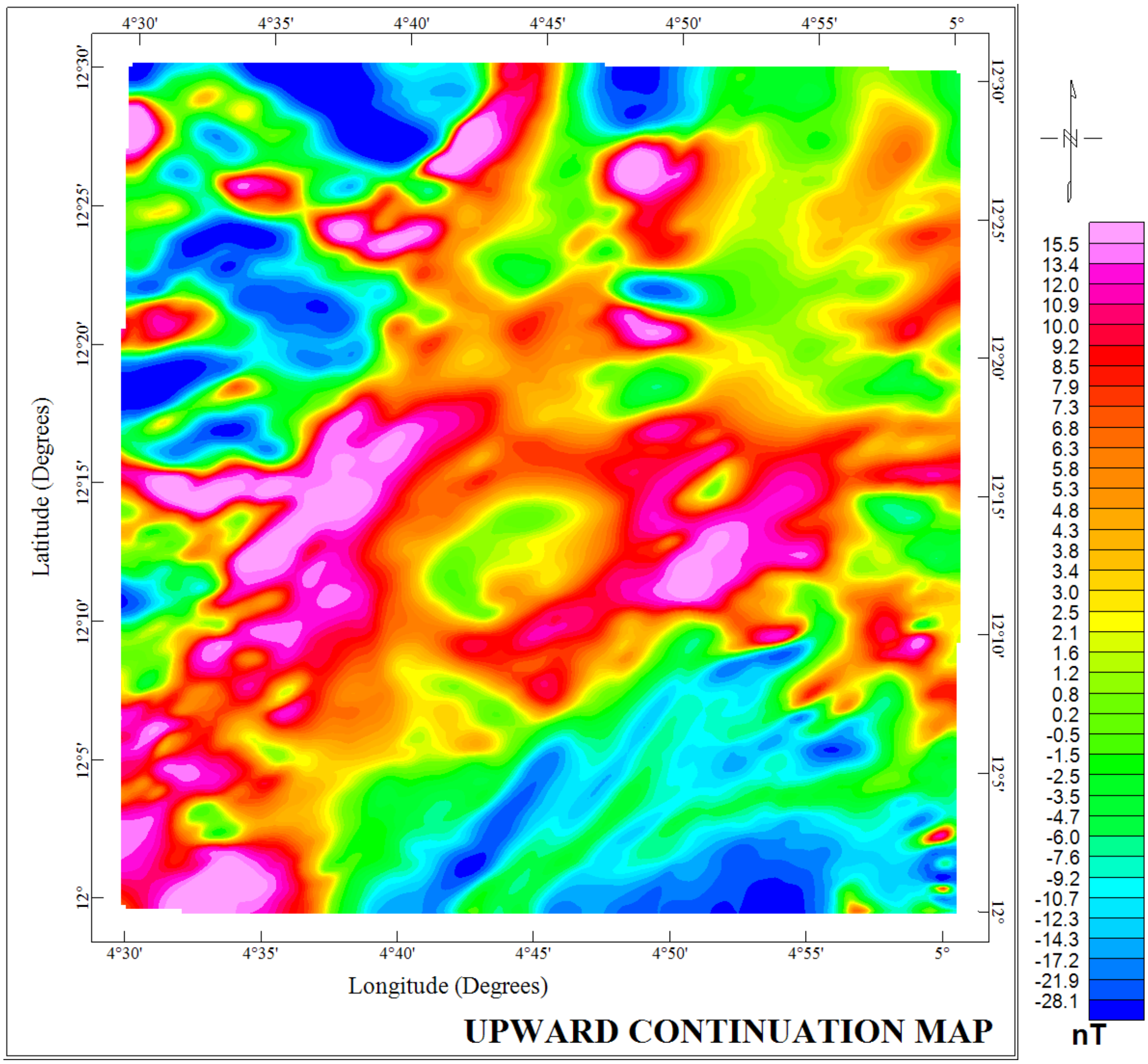

Figure 6. Upward Continuation map of the study area at 250 meters.

magnetic materials in the Southeastern part of the study area decreasing towards the northeast. The Northwestern and Southeastern portions of the study area have relatively low magnetic materials. Various interpretation techniques were applied to the RMI. They include upward continuation and spectral analysis techniques.

Upward continuation

This is a mathematical technique that project potential field data taken at an elevation to a higher elevation. The upward continuation function (Equation 1) tends to accentuate anomalies caused by deep sources at the expense of anomalies caused by shallow sources (Ganiyu et al., 2012).

$$\Delta F(x,y,-h) = \frac{h}{2\pi}\iint \frac{\Delta F(x,y,0)dxdy}{[(x-x_0)^2+(y-y_0)^2+h^2]^{3/2}} \qquad (1)$$

Where: $\Delta F(x,y,-h)$ is the total field at the point P $(x,y,-h)$ above the surface on which $\Delta F(x,y,0)$ is known, h = elevation above surface (Henderson, 1960).

In order to enhance deep-seated anomalies within the study area, the residual magnetic intensity grid was upward continued to a height of 250 m and the result is presented in Figure 6. A comparison of the residual magnetic intensity map (Figure 5) and the upward continuation map (Figure 6) illustrates that the high wavenumber components of the magnetic field in the study area have been removed by the continuation process. The upward continuation has given a clearer view of the anomaly sources.

Spectral analysis and depth estimation

The method to estimate the depth extent of magnetic

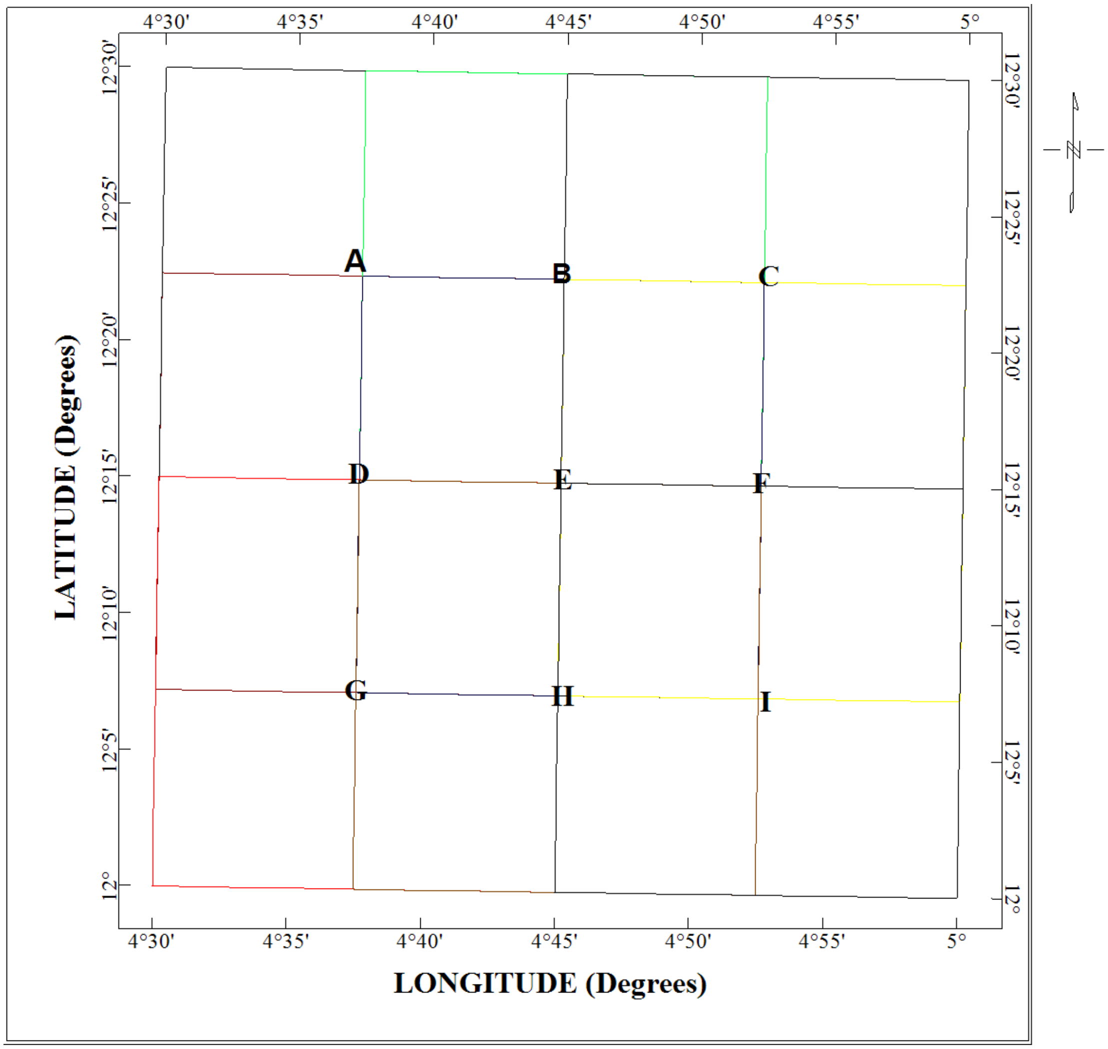

Figure 7. Arrangement of spectral grid sections within the study area.

sources can be classified into two categories: those that examine the shape of isolated magnetic anomalies (Bhattacharyya and Leu, 1975) and those that examine the statistical properties of patterns of magnetic anomalies (Spector and Grant, 1970). Both methods provide the relationship between spectrum of magnetic anomalies and the depth of a magnetic source by transforming the spatial data into frequency domain. However, Shuey et al. (1977) showed that the latter method is more appropriate for regional compilations of magnetic anomalies.

In this research, the entire study area was sectioned into grids. First, 55 km X 55 km (the entire area) and then overlapping square grids, Labeled A to I, of approximately 27.5 km X 27.5 km leading to a total of ten blocks (Figure 7). Radially averaged power spectrum analysis was applied on each grid section using Fast Fourier Transform (FFT) and the log of spectral energy and their corresponding frequencies were obtained.

The depth to the top of the magnetic source was derived from the slope of the high wavenumber portion of a plot of the power spectrum against frequency (Nwankwo and Shehu 2015). The mean depth, *Z*, to magnetic source was computed using $Z = -\frac{m}{4\pi}$, where *m* is the slope (Akanbi and Fakoya, 2015).

RESULTS AND DISCUSSION

Spectral energy plots against respective frequencies of selected blocks are presented in Figures 8(a) and (b) and the results of depth estimates of all the overlapping blocks are presented in Table 1. The result indicates depth values ranging from of 1.5 to 2.4 km and an average sedimentation of 1.92 km. High thicknesses (sedimentation) are observed within the central portion of the study area with blocks E, F, and G having thicknesses of 2.16, 2.09 and 2.26 km respectively. Block D shows the lowest sedimentation (≈1.5 km). The depth estimates of all

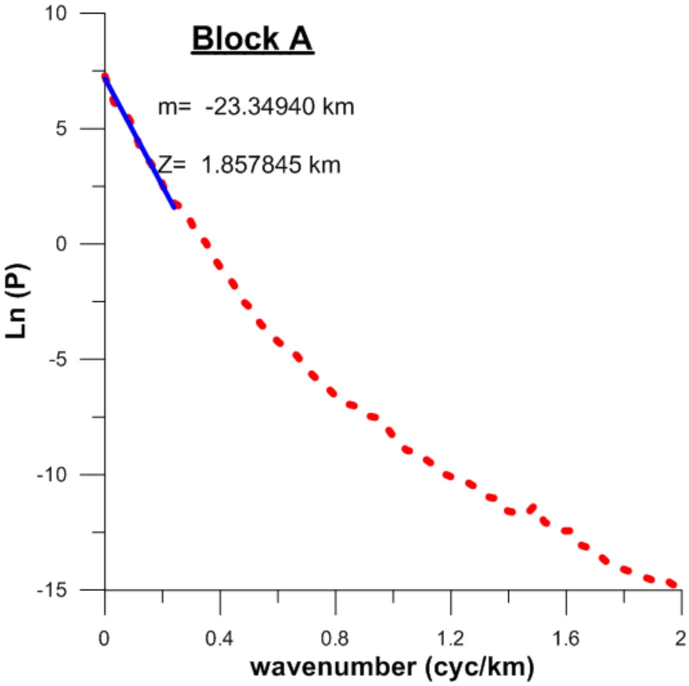

Figure 8(a). Spectral plots of the selected grid (Block A).

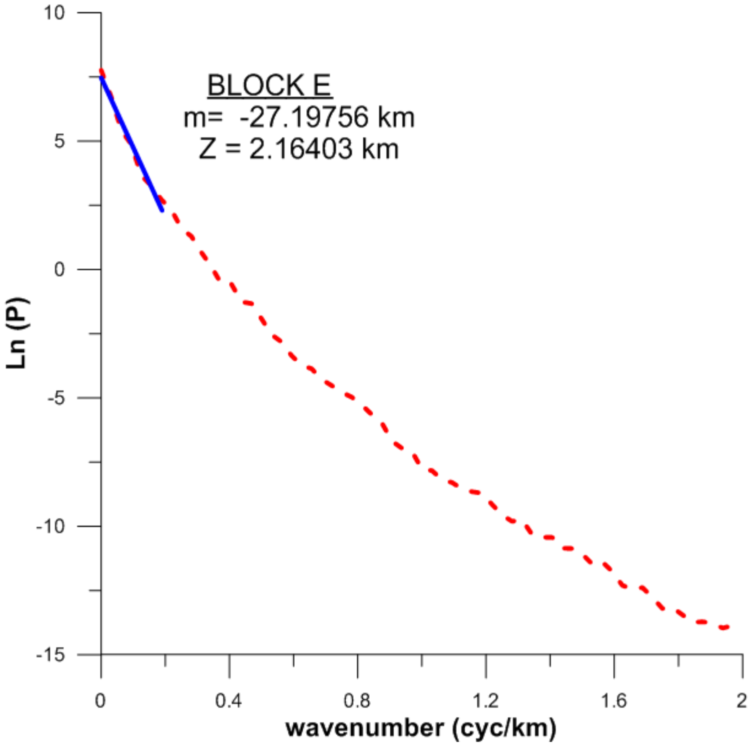

Figure 8(b). Spectral plots of the selected grid (Block E).

the sampling points and notable towns within the study area are superimposed on the upward continued magnetic intensity map and presented in Figure 9. The result further indicates a relatively low sedimentation within the West, Northwestern and Southeastern portions of the study area. Depth estimates obtained in this study correlates with the

Table 1. Result of spectral analysis and depth estimates of the study area.

Block	Longitude (Degrees)	Latitude (Degrees)	Depth/ Thickness of Sediments (km)
Entire Area (X)	4.7524	12.2633	2.4094
A	4.6229	12.3783	1.8578
B	4.7503	12.3780	1.9104
C	4.8742	12.3775	1.9024
D	4.6227	12.2530	1.5136
E	4.7500	12.2515	2.1640
F	4.8738	12.2523	2.0915
G	4.6248	12.1232	2.2664
H	4.7485	12.1227	1.9966
I	4.8735	12.1223	1.6097

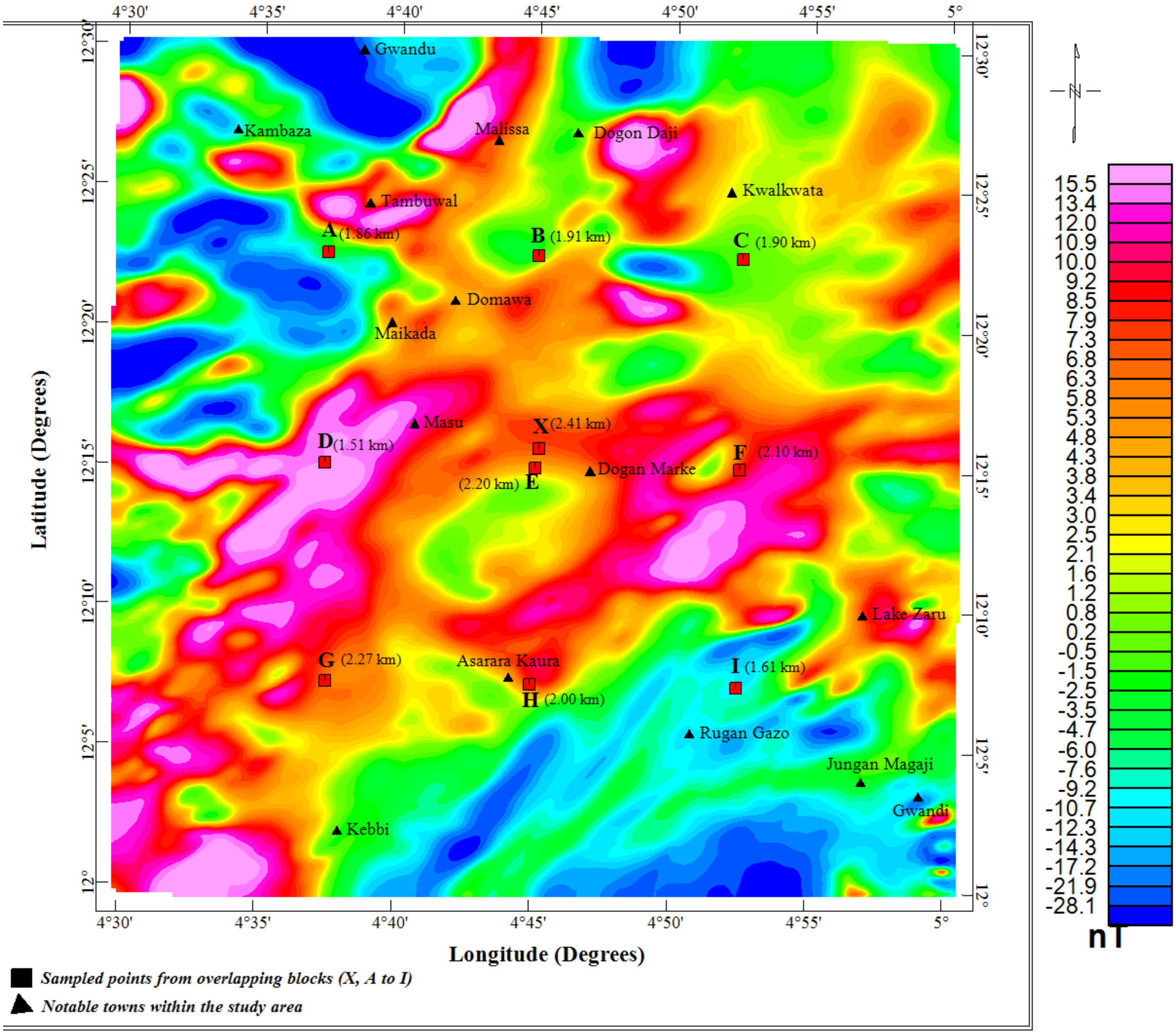

Figure 9. Spectral depth estimates of superimposed on the upward continued map showing some notable towns within the study area.

findings of previous researches carried out within the basin (Bonde et al., 2014; Nwankwo and Shehu, 2015).

Furthermore, high sedimentation, generally greater than 2.00 km, are observed to be trending NE-SW through the central portions. The central portion, particularly around Dogon Marke town, has the highest thickness of sediments (Figure 9) and are likely to have the highest prospect for hydrocarbon (Anudu et al., 2012; Likkason, 2014). These areas are associated mainly with sandstone and clay of the Rima Group as observed from the geological map (Figure 1). The result tends to be in conformity with the work of Bashar et al. (2017).

Conclusion and recommendation

From the result obtained in this study, it can be concluded and inferred that a few portions of the area are probable hosts of hydrocarbon reserve. The central parts, particularly around Dogo Marke town, have the highest possibility to host hydrocarbon reserves within the entire area of study. It is therefore recommended that a detailed ground survey, particularly using the seismic method, should be carried out to further explore the hydrocarbon potentials of the Sokoto Basin.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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