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Estimation of Sedimentary Thickness Using Spectral Analysis of Aeromagnetic Data over Part of Bornu Basin, Northeast, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author TA wrote the manuscript and analyzed the data. Author KAS designed the study. Author MKS checked the protocol of the study and managed the literature searches. Author MAM appraised data quality. Author EEU checked the grammar and language. All authors read and approved the final manuscript.

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ABSTRACT

The aeromagnetic data (High resolution) over part of Bornu Basin NE was interpreted using spectral analysis to estimate the sedimentary thickness of the study area. The study area is covered by four aeromagnetic data sheets covering latitude 12°N and 13°N and Longitude 12°E and 13°E with an estimated total area of 12, 100 km^2. Polynomial fitting method was adopted for the regional-residual separation of the total magnetic intensity. The residual map was divided into nine spectral sections. The result of the study shows a sedimentary thickness that ranges between 0.29 km and 3.35 km. The sedimentary thickness of over 3 km could be found around the South-eastern part of the study area which corresponds to Gubio town while the minimum sedimentary thickness could be found around North-western part of the study area which also corresponds to Borgo town area. The maximum sedimentary thickness of 3.35 km may be sufficient for hydrocarbon presence.

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Keywords: Aeromagnetic data; spectral analysis; polynomial fitting; sedimentary thickness; hydrocarbon maturation.

1. INTRODUCTION

Over the years, searching for earth embedded minerals and hydrocarbon (oil and gas) has become a bone of contention in the economy of Nigeria. The bigger part of the nation's income (80%) is gotten from hydrocarbon (oil and gas) profit whereupon more than 160 million overflowing populace relies on upon. As the hydrocarbon potential of the prolific Niger delta becomes depleted or exhausted in the nearest future due to continuous exploitation and inherent crises in the Niger delta region which had led to excessive reduction in oil production for export and domestic use, it is of necessity to shift attention to other sedimentary Basins. In particular, the Bornu Basin which is one of the inland Basins in Nigeria presumed to have high hydrocarbon potential aside other earth minerals with high economic values [1]. The Nigerian government have directed one of its Oil-regulating Agency (NNPC) to heighten hydrocarbon prospecting in the Northeast (Bornu Basin). As this will expand Nigeria's oil and gas holds, add qualities to the hydrocarbon potentials of the Nigerian inland basins, in this way, give speculation open doors, help the economy of the nation and also provide many new employments to lessen unemployment definitely in Nigeria. This research will be very useful on a reconnaissance basis for oil and mineral prospecting in the area.

Spectral analysis of aeromagnetic data over the area would be used to determine the sedimentary thickness of the study area. The result from the spectral analysis could be used to suggest areas of potential hydrocarbon presence.

2. GEOLOGY OF THE STUDY AREA

The area of study is part of the Nigerian sector of the Chad Basin, known locally as the Bornu Basin (Fig. 1). It is one of the Nigerian inland Basins occupying the north-eastern part of the country. It represents about one-tenth of the total area extent of the Chad Basin, which is a regional large structural depression common to five countries, namely, Cameroon, Central African Republic, Niger, Chad, and Nigeria [2]. The Bornu Basin (Study area) falls between latitudes 12°N and 13°N and longitudes 12°E and 13°E with an estimated area of 12,100 km^2. The Borno State where the area of study is located is endowed with rock mineral base resources such as clay, salt, limestone, kaolin, iron ore, uranium and mica.

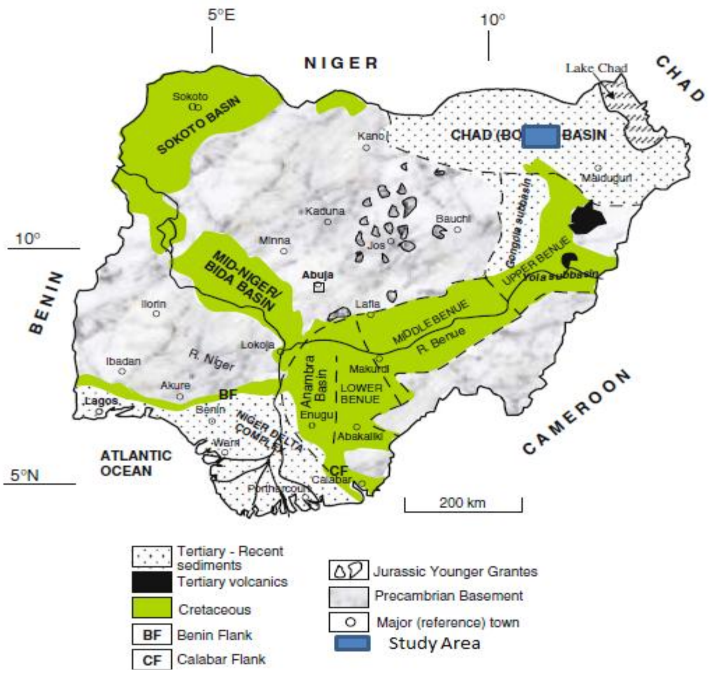

Fig. 1. Geological Map of Nigeria showing the study area
(Adapted from [2])

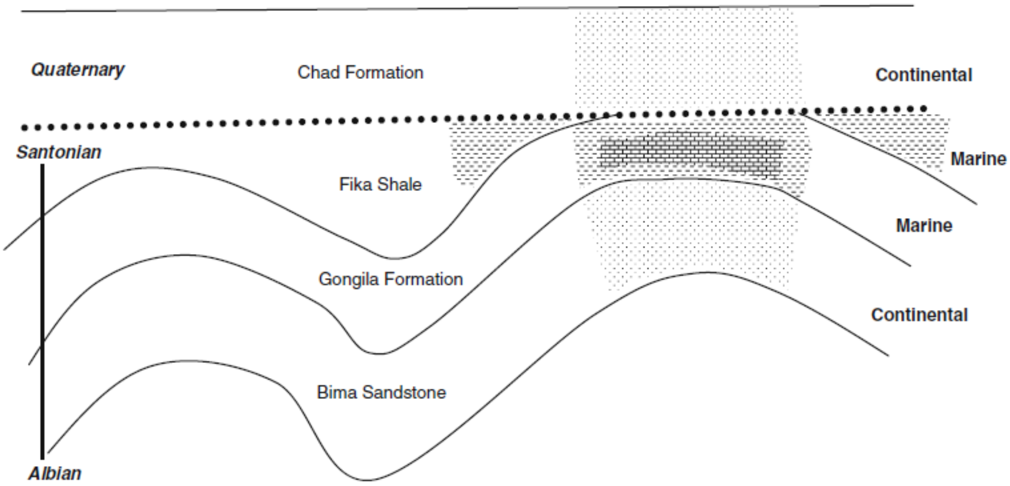

Fig. 2. Generalized stratigraphic sequence of Bornu Basin, Nigeria
(Adapted from [2])

Geologically, the Bornu basin has been explained as a broad sediment-filled broad depression straddling North-eastern Nigeria and adjoining parts of the Republic of Chad. The sedimentary rocks of the area have a cumulative thickness of over 3.6 km and rocks consist of thick basal continental sequence overlaid by transitional beds followed by a thick succession of Quaternary Limnic, fluviatile and eolian sand and clays [3]. The stratigraphy sequence (above Fig. 2) shows that Chad, Kerri-Kerri and Gombe Formations have an average thickness of 130 to 400 m. Below this formations are the Fika shale with a dark grey to black in colour, with an average thickness of 430 m. Others are Gongila and Bima Formations with an average thickness of 320 m and 3,500 m, respectively [4,5] and [6].

3. MATERIALS AND METHODS

The study area covers four aeromagnetic data sheets of total-field intensity in 1/2° by 1/2° procured from Nigerian Geological Survey agency (NGSA). The sheets are 43 (Borgo), 44 (Bazabure), 65 (Chungulbulturi) and 66 (Gubio). The sheets were merged together to generate the study area using Oasis Montaj 6.4 software. The aeromagnetic data were obtained as part of the aeromagnetic survey carried out between 2003 and 2009 sponsored by Geological survey of Nigeria. The data were obtained at an altitude of 100 m along a flight line spacing of 500 m oriented in NW-SE and a tie line spacing of 2000 m. The maps are on a scale of 1:100,000 and half-degree sheets contoured mostly at 10nT intervals. The geomagnetic gradient was removed from the data using the International geomagnetic Reference Field (IGRF). The total area covered was about 12,100 km^2.

The actual magnetic intensity value was reduced by 33,000 nT for handling before the contour map was plotted. As a result, 33,000 nT must be added to the data so as to get the actual magnetic intensity at a given point. The total magnetic intensity was contoured and colour filled to show the high and low total magnetic intensity of the study area (Fig. 3). Polynomial fitting (order one) method was used for the regional-residual separation, Figs. 4 and 5 shows the contoured and colour filled regional map and residual map respectively. The magnetic values found on Fig. 4 trend northeast-southwest and the lines observed indicate faults.

3.1 Spectral Analysis

The statistical spectral analysis of the residual field data was used to determine the depths to the buried magnetic sources within the subsurface of the study area. Spector and Grant (1970) developed a 2-D spectral depth determination method [7]. Their model assumes that an uncorrelated distribution of magnetic sources exists at a number of depth intervals in a geologic column. The Fourier transform of the potential filed due to a prismatic body has a broad spectrum whose peak location is a function of the depth to the top and bottom surfaces and whose amplitude is determined by its density or magnetization [7].

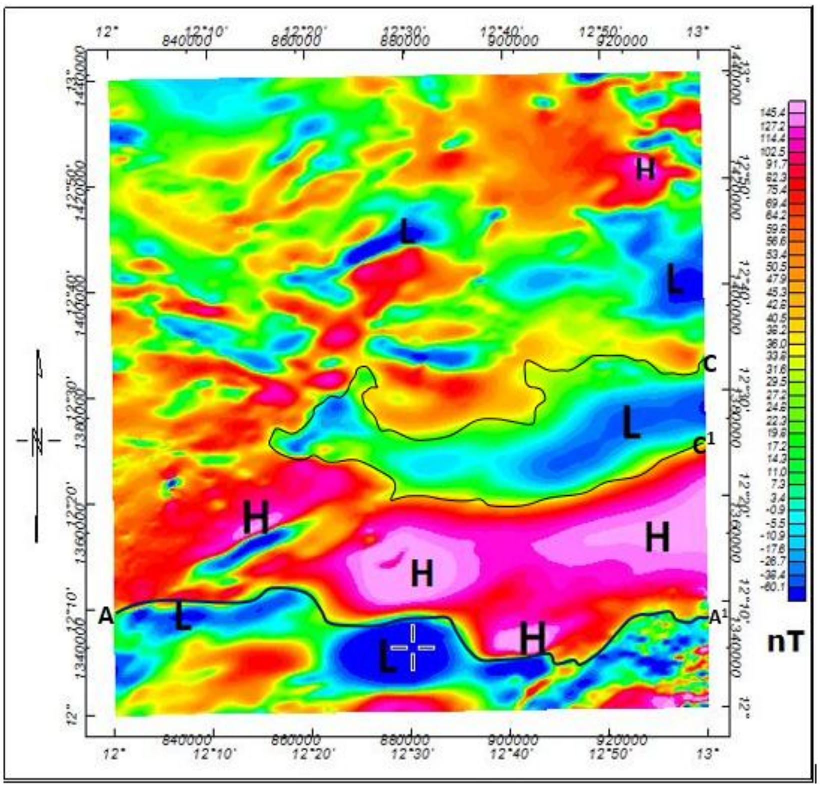

Fig. 3. Total magnetic intensity map over part of Bornu basin. Magnetic ‘lows’ are represented by ‘L’ and magnetic ‘highs’ are represented by ‘H’. AA^1 and CC^1 are the identified paleo-structures in the study area

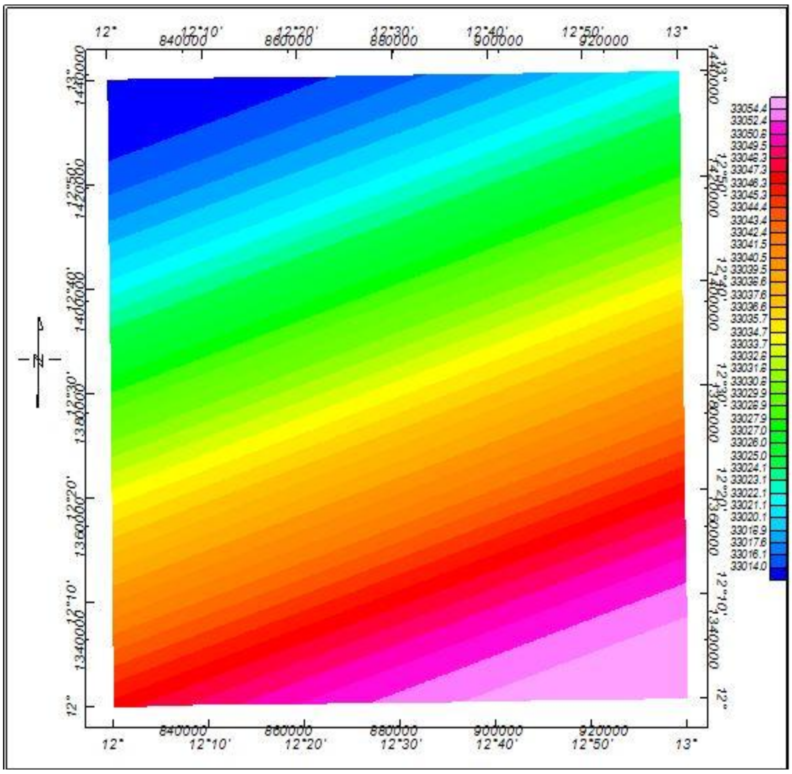

Fig. 4. Regional map of the study area

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

$$W' = \frac{In\left(h_b/h_t\right)}{h_b - h_t} \quad (1)$$

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.

For a bottomless prism, the spectrum peak at the zero wave number according to the expression:

$$f(\varpi) = e^{-h\omega} \quad (2)$$

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

$$f(\varpi) = e^{-h_t\omega} - e^{-h_b\omega} \quad (3)$$

Where h_t and h_b are the depths to top and bottom surface respectively. As the prism bottom moves closer to the observation point at surface, the peak moves to a higher wave number. When looking at the spectrum, it is important to note that the amplitude of a deep prism does not exceed the amplitude of the same prism at shallow depth at any wavenumber. The effect of increasing the depth is to shift the peak to lower wavenumbers. Because of this characteristic, there is no way to separate the effect of deep sources from shallow sources of the same type by using wavenumber filters. The sources can only be distinguished if the deep sources have greater amplitude or if the shallow sources have less depth extent. When considering a line that is long enough to include many sources, 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.

$$Log\ E(k) = 4\pi hk \quad (4)$$

Where *h* is the depth in ground – units and k is the wavenumber in cycles / ground – unit. The depth of an‘ensemble’ of source can be determined by measuring the slope of the energy (power) spectrum and dividing by 4π. A typical energy spectrum for magnetic data may exhibit three parts – a deep source component, a shallow source component and a noise component.

In this study, the graph of each energy spectral was obtained with Matlab software purposely designed to accept the longitude and latitude values alongside with its respective magnetic values for each of the nine spectral sections label (A –I) where the log of spectral energy plotted against frequency.

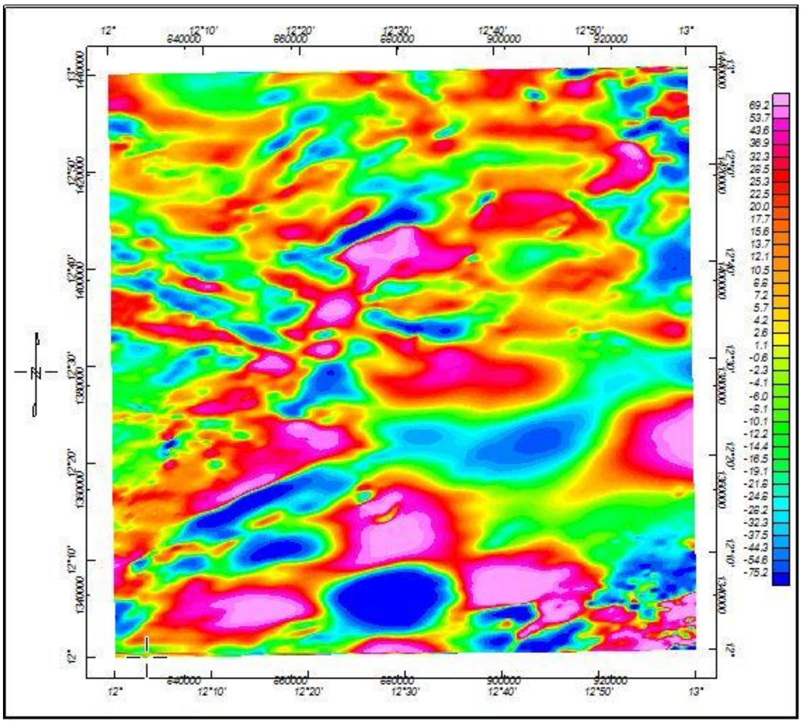

Fig. 5. Residual map of the study area

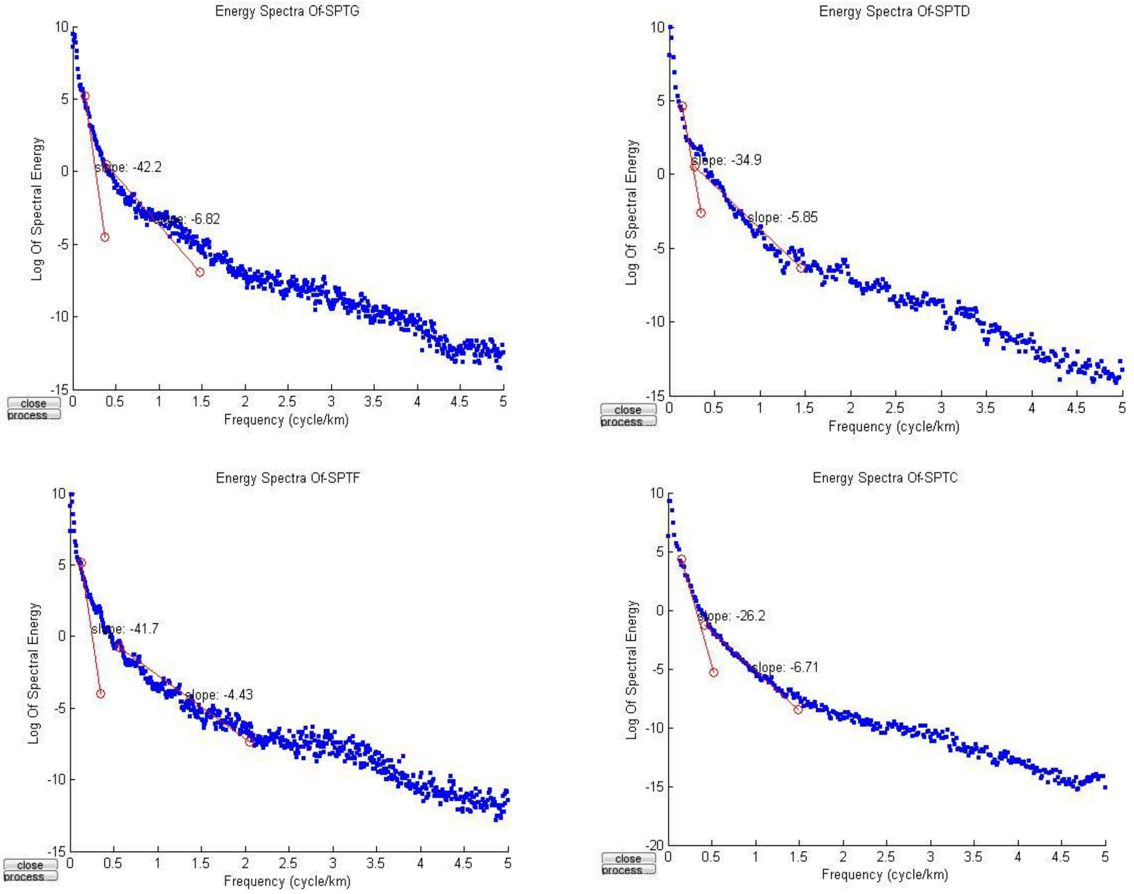

Fig. 6. Typical plots of energy spectrum against frequency

4. RESULTS AND DISCUSSION

The residual map (Fig. 4) produced from this study was divided into nine (9) blocks (A-I) of overlapping magnetic sections. Six of the divisions (section SPTA, SPTB, SPTC, SPTD, SPTE, and SPTF) covered 55km^2 and three others (SPTH, SPTG, and SPTI) covered 110km^2. The divisions of residual map into nine (9) spectral sections was done with Oasis Montaj (Version 6.4) and the spectral energies were plotted, the *.SPC file obtained were later exported into Microsoft Excel worksheets one after the other until the total number of nine (9) spectral (*.SPC) energy files were later used as an input file into a spectral program plot (SPP) developed with Matlab. The total number of nine (9) spectral energies were plotted in Matlab with the developed program. A typical plots of energy against frequency (wavenumber) is shown in Fig. 6 above.

The program has been designed to determine the first slope (m_1) and the second slope to calculate for the first and second magnetic depth source using the equations below.

$$Z_1 = -\frac{m_1}{4\pi} \tag{5}$$

$$Z_2 = -\frac{m_2}{4\pi} \tag{6}$$

Where m_1 and m_2 are slopes of the first and second segment of the plot while Z_1 and Z_2 are first and second depths respectively (Table 1).

Substituting form$_1$ = -42.2 and m_2 = -6.82 (Fig. 6) into the equation (5 & 6).

Therefore,

$$Z_1 = -(-42.2/4 * 3.142) = 3.35 \text{ Km}$$

Similarly,

$$Z_2 = -(-6.82/4 * 3.124) = 0.54 \text{ Km}$$

Fig. 6 shows a typical plot of energy spectrum against frequency of section SPTG, two layers can be observed with their respective depths and magnitude values. The minimum depth is 0.54 km while the maximum depth source is 3.35 km (Fig. 6). Table 1 shows that the shallow depth source (Z_2) ranges from 0.39 km to 0.64 km while the deeper depth source (Z_1) ranges from 1.32 km to 3.35 km. Figs. 7 and 8 shows that the maximum sedimentary thickness of 3.35 km is more pronounced around Gubio town.

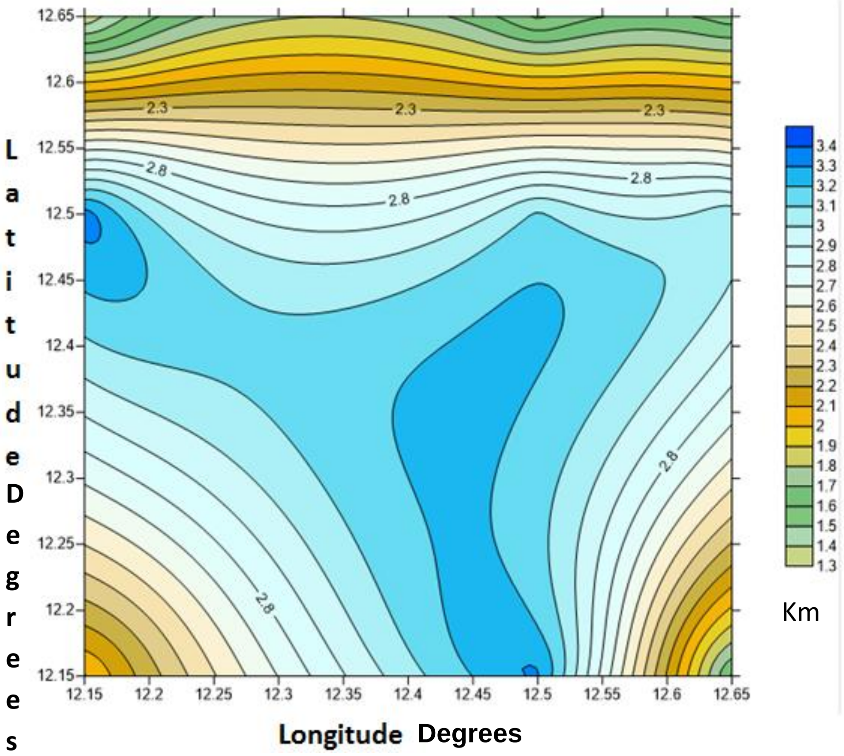

Fig. 7. Contour map of spectral magnetic depth to top of basement over part of Bornu Basin

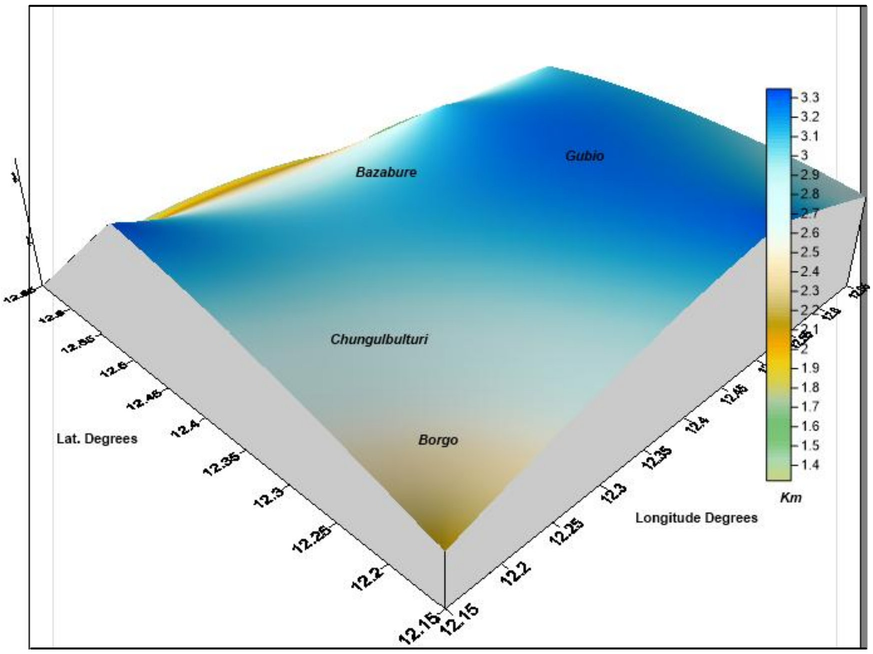

Fig. 8. 3D surface map of magnetic depth to top of basement over part of Bornu Basin

Table 1. Estimated depth to deeper magnetic and shallow source in Km

S/N	Sections	Longitude (Degrees)	Latitude (Degrees)	Depth Z1 (Km)	Depth Z2 (Km)
1	SPTA	12.15	12.65	1.32	0.39
2	SPTB	12.65	12.65	1.54	0.53
3	SPTC	12.15	12.15	2.10	0.54
4	SPTD	12.65	12.15	2.77	0.47
5	SPTE	12.5	12.65	1.48	0.29
6	SPTF	12.5	12.15	3.32	0.35
7	SPTG	12.15	12.5	3.35	0.54
8	SPTH	12.65	12.5	3.06	0.46
9	SPTI	12.5	12.5	3.12	0.64

5. CONCLUSION

The highest sedimentary thickness of 3.35 km from spectral analysis is sufficient enough for hydrocarbon maturation and the results also concur with those obtained by other researchers in some part of the Bornu Basin; notably are results of studies by [8] and [9].

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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