

Interpretation of Aeromagnetic Anomalies over parts of Upper Benue Trough and Southern Chad Basin, Nigeria

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ABSTRACT

A detailed interpretation of the aeromagnetic data has been carried out over parts of Upper Benue Trough and Southern Chad Basin, Nigeria. The magnetic properties of rock were used to determine the depth to magnetic basement, model prominent magnetic anomaly, determine the basement topography and also determine various temperatures at depth in the study area. Two depth source models were interpreted using Discrete Fourier Transform method. Depth to the deeper magnetic sources ranges from 1.5 to 2.5 km, representing the sedimentary cover in the study area. The depth to the shallower magnetic source model which ranges from 0.5-1.4 km, represents intrusive bodies within the area. Based on the sedimentary thickness of 1.5 - 2.5 km and the temperature at depth of 81-115^oC, the possibility of hydrocarbon generation towards the northeastern part of the study area is feasible.

Keywords: Aeromagnetic data, Fourier transform, sedimentary cover, Benue Trough and Chad Basin.

INTRODUCTION

Aeromagnetic survey is one of the most important tools used in modern geological mapping. It is a rapid and cost effective technique for locating both hidden ores and structures associated with mineral deposits. Roughly about 60% of magnetic surveys are carried out for regional geological mapping and mineral exploration purposes while the remainder being mainly for petroleum exploration [1]. However, the present study is concerned with the interpretation of the aeromagnetic data over parts of the Upper Benue Trough and Southern Chad Basin, Nigeria. The total area studied spans a territory of 12100 km², extending from Latitude 10^o30'N to 11^o30'N and Longitude 12^o00'E to 13^o 00'E. The study area houses sedimentary rock sequence comprising sandstones, clay, siltstones, limestones and shales. Hence, the petroleum potentials of the study area is a matter of great interest and the determination of sediment thickness above the basement and the delineation of major geological structures, are essential steps towards the assessment of the petroleum potential of this area. The objectives of this research include: determination of the variation in sedimentary thickness of the area using Fourier Transform method and modeling of prominent magnetic anomalies in the area. The study further attempts the delineation of the basement topography and structural features such as faults and possibly infer the hydrocarbon potential zone within the study area.

GEOLOGICAL SETTING

The study area falls within two of the Nigeria inland basins namely; Benue Trough and Chad Basin (Fig.1). The Benue Trough is the most interesting sedimentary basins chiefly because of the folding movements that affected the marine and continental sediments within it. Similarly, the Chad Basin is an elongate depression that extends well beyond Lake Chad. Certainly, Benue Trough is widely held to have originated as a tectonic trough whose origin was

closely linked with the separation of African and South American Continents during the Mesozoic [2, 3]. Several geological studies have been carried out by various workers [4, 5, 6, 7, 8, 9, etc.] in the study area and its environs. Thus, the earliest documented sedimentary deposit in the area was in the Paleocene – Albian period when fluvio – classic sediments of Bima Formation were laid unconformably on the basement in the fitted wrench – fault basin. Consequently, this transgression episode caused the deposition of Yolde, Dukul, Jessu, Sekule and Numanha sedimentary formations, which are found in the Upper Benue Trough. In addition, the Southern Chad Basin is poorly exposed in Nigeria and merges with the Upper Benue Trough. A sub-surface basement high, the Zambuk Ridge separates the Southern Chad Basin from the Upper Benue Trough. Three major sediment packages – the Bima Formation, Gongila-Fika Shale and the Chad Formation have been identified in the Nigerian sector of the basin [9, 10]. The Gongila Formation at the base and the Fika Shale at the top constitutes the marine and transitional deposits which extend from the Upper Benue into the Southern Chad Basin. Both Gongila and Fika Formations thicken towards the northeast, away from the ridge. The Chad Formation which is of Tertiary Formation is very thick. This is an area that was subjected to prolonged continental and lake sedimentation as a result of the downwarp of the Chad Basin.

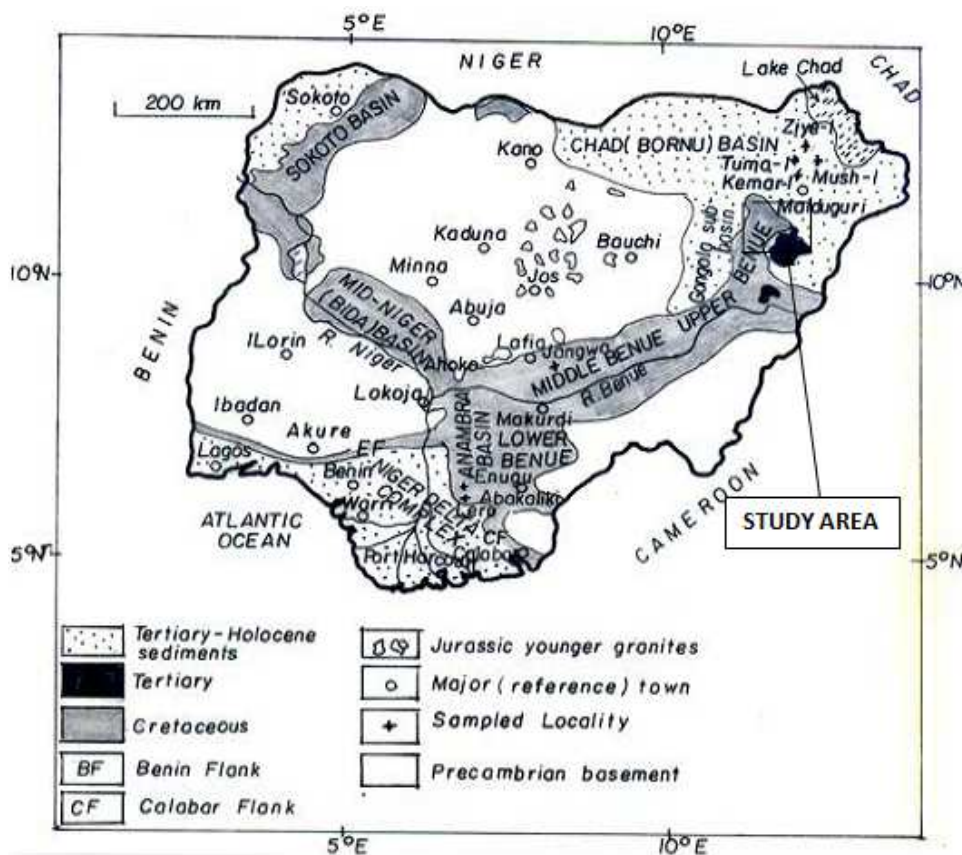


Fig. 1: Geologic map of Nigeria showing the study area [11]

DATA AND METHODOLOGY

Four aeromagnetic maps (Sheets 111, 112, 133 and 134) were acquired, assembled and interpreted. These maps were obtained as part of the nationwide aeromagnetic survey sponsored by Geological survey of Nigeria. The data were acquired along a series of NW – SE flight lines with a spacing of 2 km and an average flight elevation of about 150 m while tie lines occur at about 20 km interval. The geomagnetic gradient was removed from the data using the International Geomagnetic Reference Field (IGRF). The data were made available in the form of contoured maps on a scale of 1:100,000.

The procedures involved in this study include digitization of the aeromagnetic maps, separation of magnetic data, production of magnetic anomaly map and analysis of magnetic anomaly data amongst others. The four maps

obtained were digitized at 1 km interval so as to pick more details. Moreso, the contour digitized data which is referred to as the total magnetic field intensity of the study area contains both the regional and residual anomaly.

A linear trend surface was fitted on to the digitized aeromagnetic data by a multiple regression technique for the purpose of removing the regional magnetic gradient. The linear surface so fitted was removed from the digitized data to obtain the residual anomaly data that would be interpreted. The surface linear equation on the data can be given by:

$$P(x, y) = a + bx - cy \tag{1}$$

Where,

a, b and c are constants; x and y are distances in x and y – directions (axes); P(x, y) is the magnetic value at x and y co-ordinates.

The Least Squares method of statistical analysis was used to obtain the constants (a, b and c) and the trend surface equation (regional gradient) then becomes:

$$P(x, y) = 7989.73 - 0.4573x - 1.8019y \tag{2}$$

Furthermore, the trend surface equation was then subtracted from the aeromagnetic (observed) data and the resultant residual anomaly was obtained.

The resultant residual anomaly was contoured and five profiles were selected for the actual interpretation of the geophysical anomalies in the study area (Fig. 2).

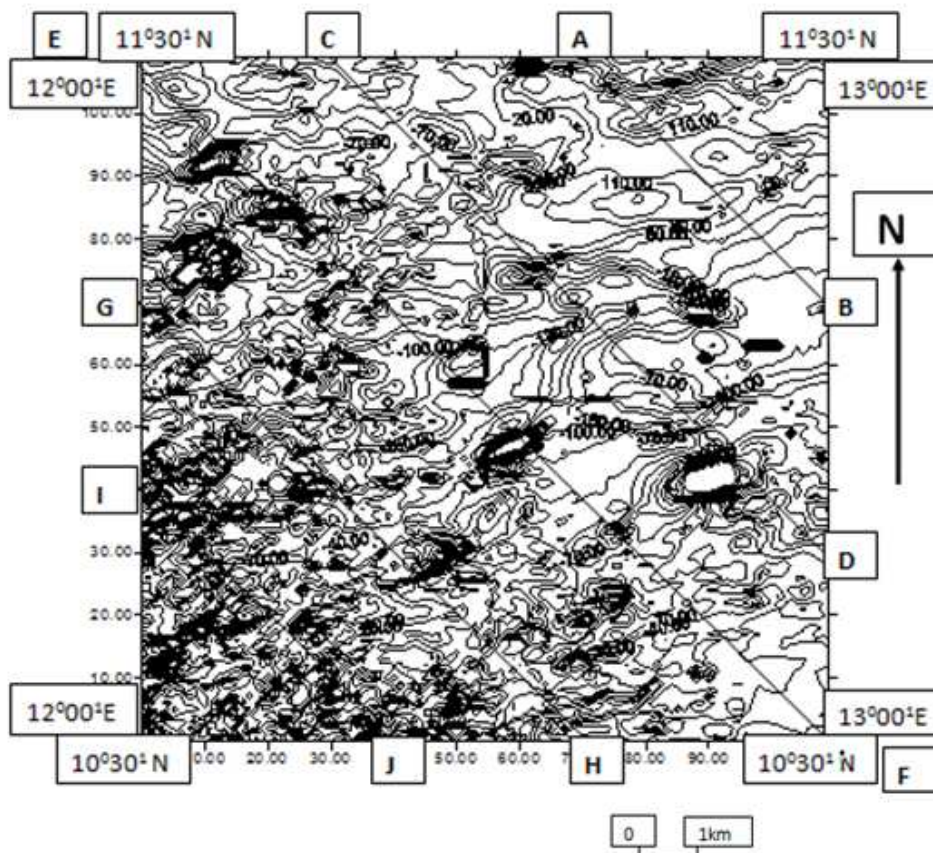


Fig.2: Digitized residual anomaly profiles of the study area (Contour Interval ~ 30nT)

The anomalies in these profiles were then subjected to the spectral analysis. The application of spectral analysis in the interpretation of aeromagnetic data has been discussed extensively [12, 13, 14, 15, 16, 17]. The Discrete Fourier Transform method was used in this study because it is capable of filtering all the noises away from the data more than any other published methods. The method can be represented mathematically as shown below:

$$Y(x) = \sum_{n=0}^{n-1} a_n \cos \left(2\pi \frac{nxi}{L} \right) + \sum_{n=0}^{n-1} b_n \sin \left(2\pi \frac{nxi}{L} \right) \tag{3}$$

where:

- Y(x) = Reading at Xi position
 - L = length of the cross-section of the anomaly
 - n = harmonic number of the partial wave
 - N = number of data point
 - a_n = real path Partial
 - b_n = imaginary path of the amplitude spectrum
- } Main Amplitude

Graphs of the logarithm of the amplitude (A_n) against frequency (n) were plotted and the linear segments from the low frequency portion of the spectra were drawn from the graphs. The gradient of the linear segments were also evaluated and the depths to the basement were calculated using the equation of Spector and Grant, (1970);

$$Z = ML/2\pi \tag{4}$$

where,

Z = depth to basement; M = gradient of the linear segment

L = length of the cross section of the anomaly

RESULTS AND DISCUSSION

Graphs of the logarithms of the amplitude against frequencies for the selected profiles are shown in Fig. 3. The gradients of these graphs were used in estimating the depth to magnetic sources. The depth to magnetic sources ranges from 0.5 to 2.5 km. Geological model sections generated for all the profiles are shown in Fig. 4. More so, the depths computed were used to construct the map showing the basement topography of the study area (Fig. 5). The map shows a gradual increase in the sedimentary thickness towards the north.

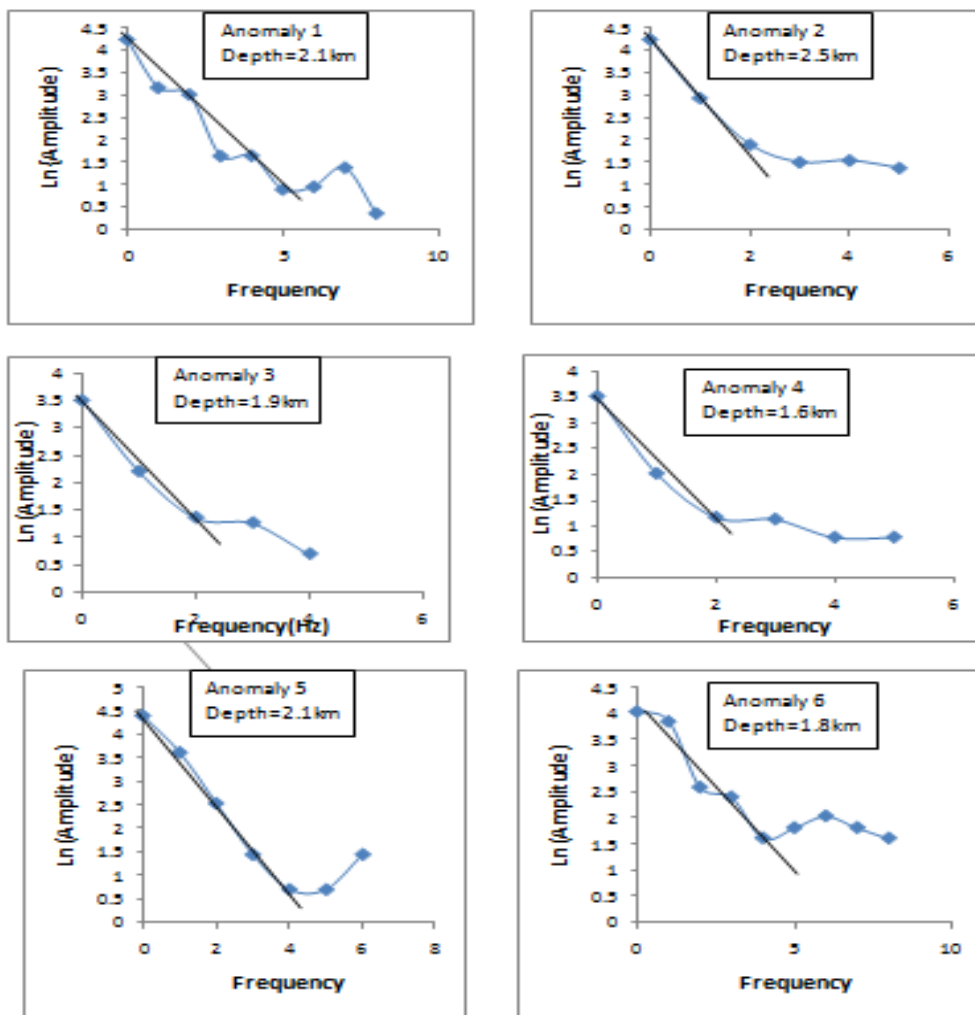


Fig. 3: Amplitude spectral along some profiles

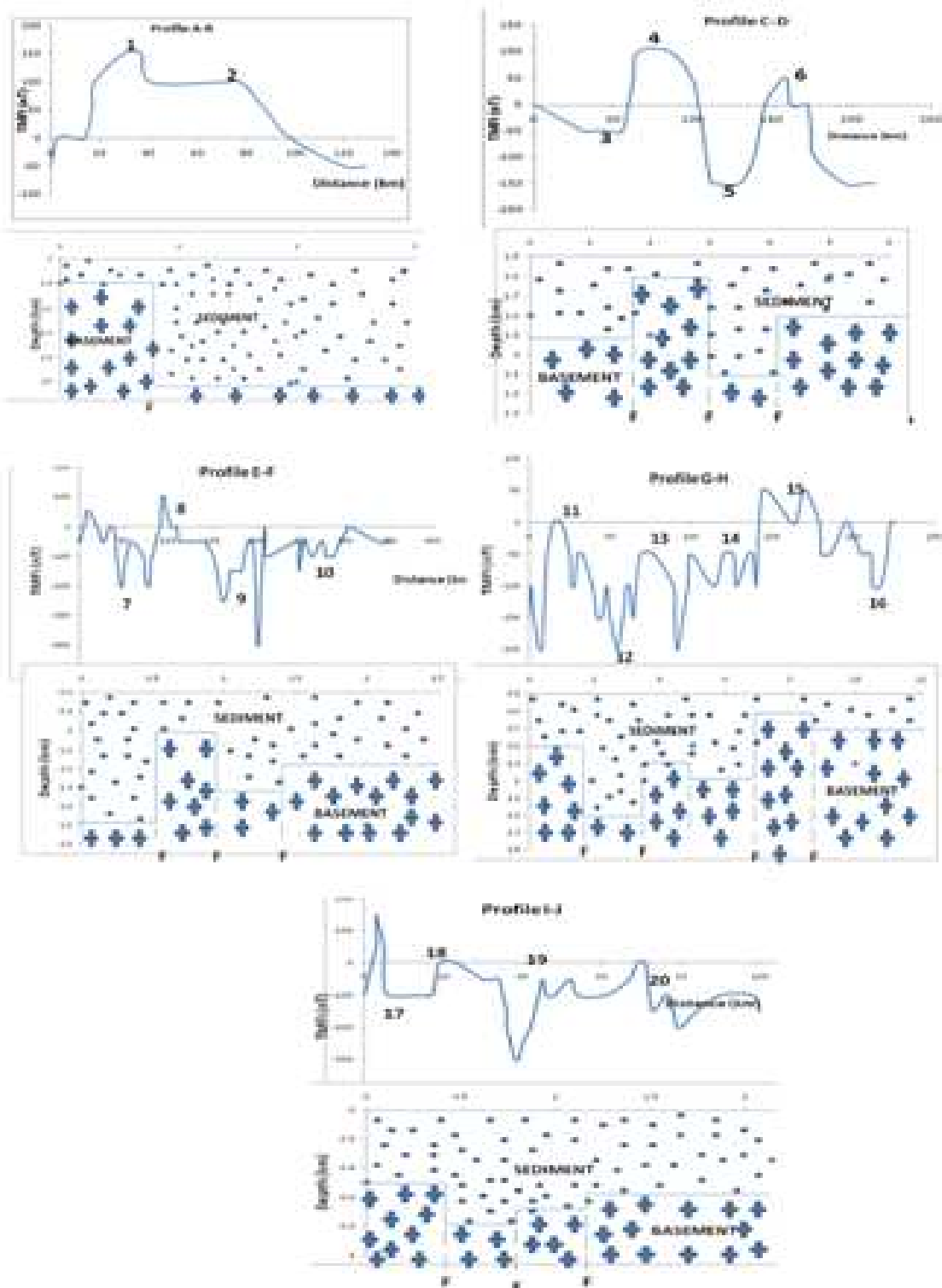


Fig. 4: Geological model section for some anomaly

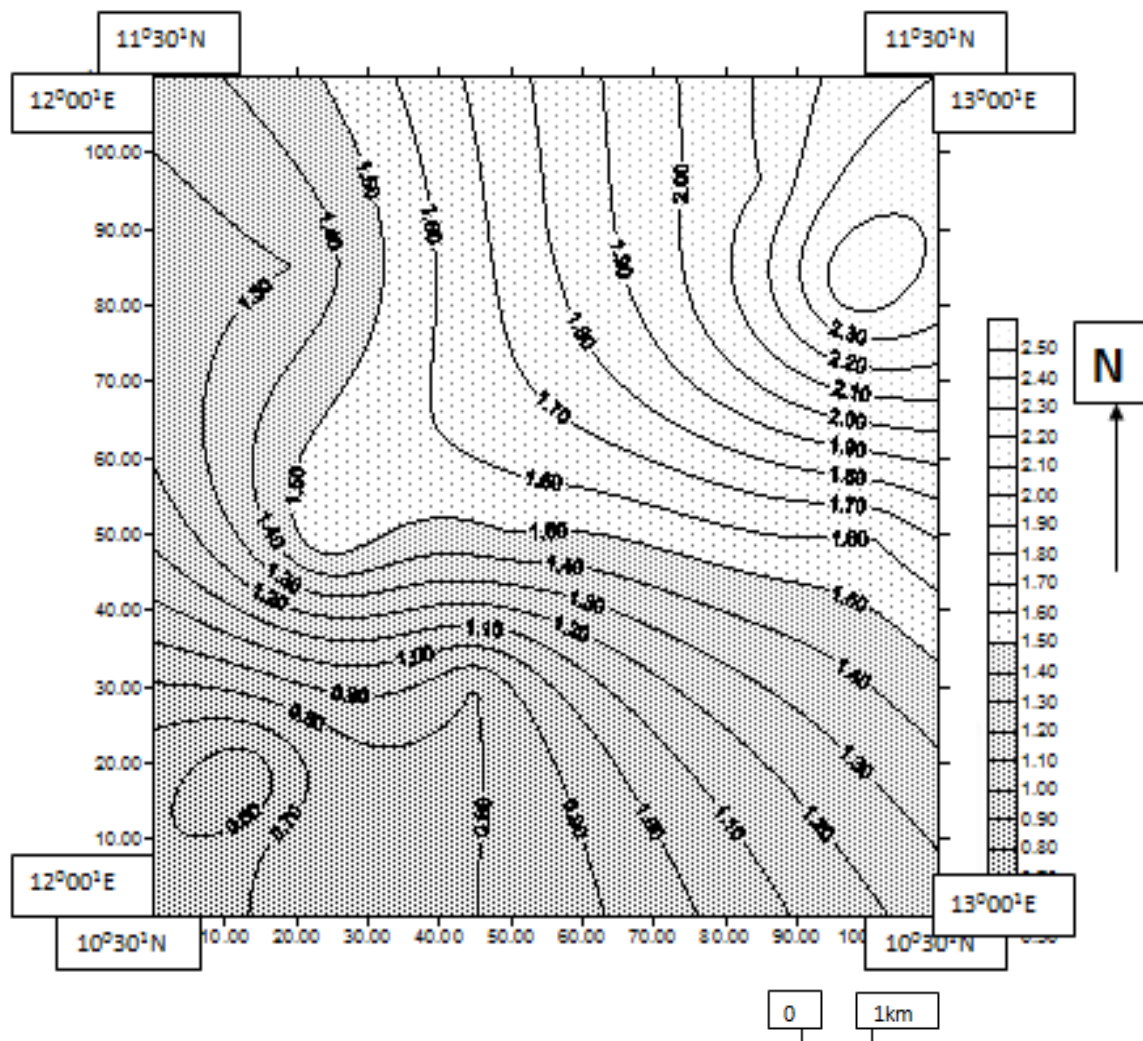


Fig. 5: Map showing the basement topography of the study area

Structural Patterns in the Study Area

The closely spaced linear sub-parallel orientation of contours from the southern parts of the map towards the northwestern parts suggests the possibility of faults or local fractured zones passing through these areas (Fig.6(a)). There would always be a magnetic susceptibility contrast across a fracture zone due to oxidation of magnetite to hematite, and/or infilling of fracture planes by dyke-like bodies whose magnetic susceptibilities are different from those of their host rocks [18]. Such geological features may appear as thin elliptical closures or nosings on an aeromagnetic map (Fig. 6(a)). These features represent geologic lineaments. Also, four major fault patterns were identified within the study area (Fig. 6(b)). Both the prominent lineament and faults are trending in NE-SW direction which conforms to the structural trend of the basins (Anakwuba *et al.*, 2011).

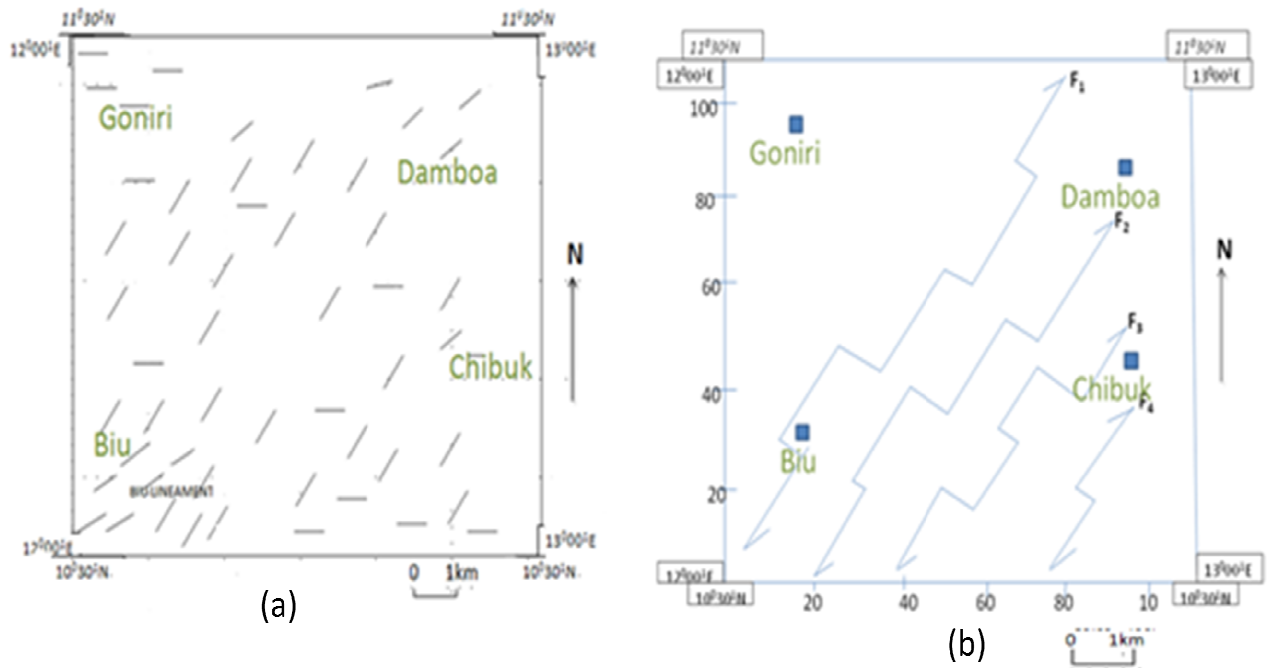


Fig.6: Structural styles of the study area: (a) Magnetic lineament (b) Fault pattern

Temperature at Depth

In order to compute the various temperature at depth within the study area, it was assumed that the temperature changes within the earth are linear and of the form [14]:

$$T_h = mh + T_0 \tag{5}$$

Where,

- T_h = temperature in $^{\circ}C$ at depth
- m = geothermal gradient
- h = depth of interest
- T_0 = surface temperature

The mean surface temperature was assumed to be $30^{\circ}C$ while the average geothermal gradient in the study area was given as $3.4^{\circ}C/100m$ [8]. From the values of the sedimentary thicknesses obtained, which vary from 1.5 to 2.5 km, the temperatures at depth for each anomaly block were estimated by solving for the unknown T_h (temperature at depth). The values obtained range between 81 to $115^{\circ}C$ with an average of $104.8^{\circ}C$.

Hydrocarbon Potential

Generally, basement depths have been determined along five selected profiles within the study area through Discrete Fourier Transform of aeromagnetic data. The results obtained indicate two depth sources; the deeper sources range from 1.5 km to 2.5 km representing the sedimentary cover within the study area while the shallower sources, which range from 0.5 km to 1.4 km, represent the intrusive bodies within the study area. The sedimentary cover around Goniri, Chibuk and Biu areas are generally low and therefore may not support hydrocarbon generation. Although, any prospective sediment must have a good quality source rock, good reservoir and seal lithologies, favourable regional pathways and trapping mechanisms. The Fika and Gongila Shales are the main source rocks in Chad Basin, while the reservoirs may be provided by sandstone facies in the same formations and in the Bima Sandstone [9]. Thus, around Damboa part which is within the Chad Basin, the sedimentary thickness is moderately-high. In line with this, for any area to be viable for hydrocarbon formation, the thickness of sediment must be up to 2.3 km as well as other conditions necessary for hydrocarbon formations [19]. Based on the computed sedimentary thicknesses (1.5 - 2.5 km) and temperature at depth ($81-115^{\circ}C$), the possibility of hydrocarbon generation in the northeastern

part of the study area is feasible (Fig. 7).

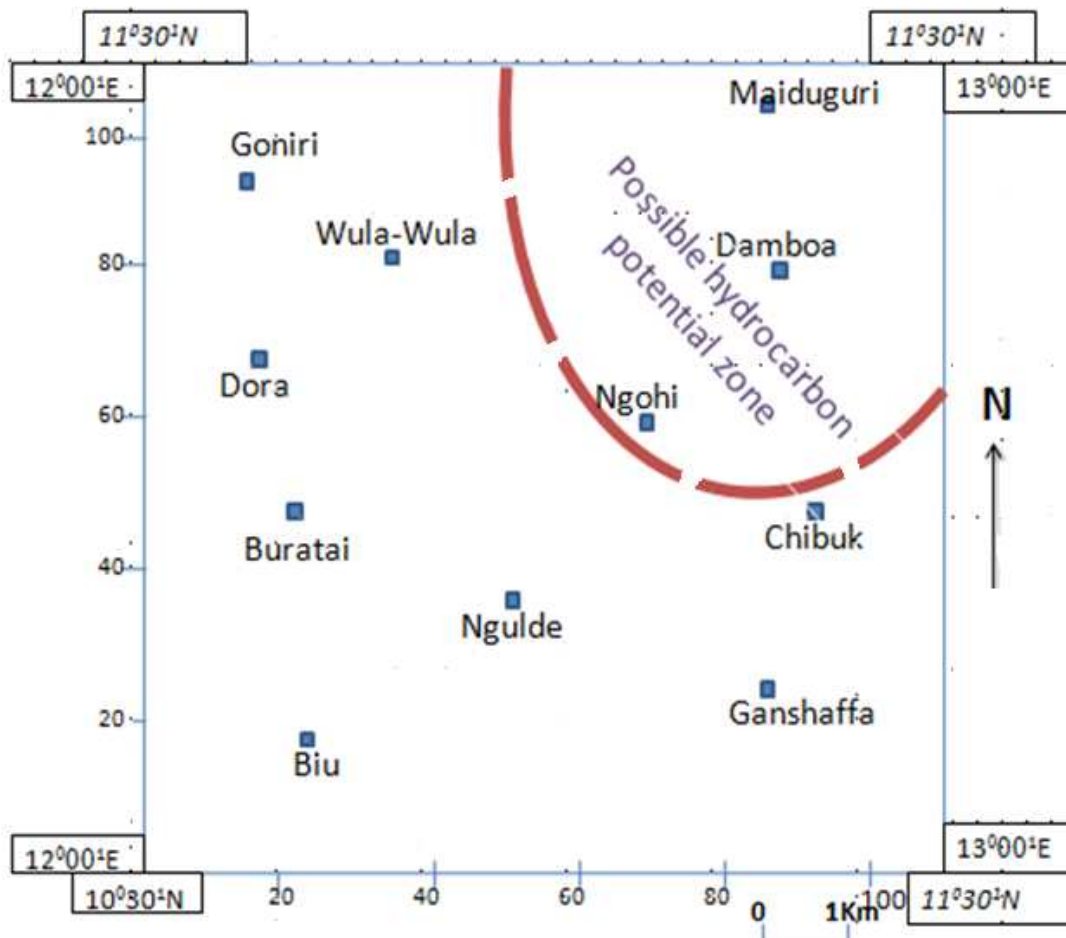


Fig.7: Isolated zone of possible hydrocarbon potential in the study area

CONCLUSION

Discrete Fourier Transform analysis has been applied to a set of aeromagnetic data over parts of Upper Benue Trough and Southern Chad Basin, Nigeria. The results show that two depth sources were obtained in the study area; the deeper sources range from 1.5 - 2.5 km while the shallower sources range from 0.5 - 1.4 km. The depths to magnetic basement are increasing in the northeastern direction and they range from 0.5 to 2.5 km. Four major regional faults trending in NE-SW direction were delineated. These faults conform to the trend of the Benue Trough and possibly suggest that the two basins are of similar origin. However, based on the computed sedimentary thickness (0.5-2.5km) and temperature at depth (81-115°C), the possibility of hydrocarbon generation in the northeastern part of the study area is feasible.

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