

## **Aeromagnetic Interpretation over Maiduguri and Environs of Southern Chad Basin, Nigeria**

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### **Abstract**

Aeromagnetic data over a part of Maiduguri and Environs of the Southern Chad Basin, Nigeria was analyzed. The aeromagnetic anomaly map, its qualitative and quantitative interpretation helped in identifying the nature and depth of the magnetic sources in the study region. Depth to the basement of the basin structure ranges from about 0.5 km in the southern part of the study area and gets deeper toward the northern part up to 3.0 km. Lineament structural map and magnetic depth map values have been utilized to construct the interpretation of the main subsurface structures affecting the studied area, which correlate with the previous studies of the Chad Basin. The study area is characterized by predominant magnetic lineament trend in NE-SW (North East-South West) direction and subordinate E-W (East-West) direction. Results of the Spectral analysis method enabled delineation of the lithology and mapping the depths of subsurface geologic structures. The results also showed the most significant structural (NE-SW) trends affecting the distribution of these magnetic anomalies in the study area. The spectral analysis employed in depth calculations and temperature at depth calculations helped in revealing the possible subsurface structure of the area that assisted in delineation of promising area for hydrocarbon exploration.

**Keywords:** Aeromagnetic, Chad Basin, Lineament, Spectral Analysis and Basement Depth

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## **1 Introduction**

Exploration of the subsurface requires innovative techniques and the magnetic method offers an excellent opportunity to map the structure and lithology of the subsurface. The magnetic fields change when the physical properties like susceptibility and thickness of the subterranean rocks change. The magnetic data finds wide applications and is able to provide very valuable subsurface information. Modern high-resolution magnetometers are able to collect data with an accuracy of 0.001 nT [1]; this coupled with the major strides made in the acquisition, processing and interpretation of aeromagnetic data has made it possible to use the magnetic method for identifying intra-sedimentary units associated with hydrocarbons

Airborne geophysics, form a critical component of geological mapping and mineral resource inventory programmes in many countries. The data they provide, aid better geological knowledge within a country or region and also form part of a larger initiative that helps to attract investments in the mining sector and grow GDP. They also contribute to tectonic reconstruction, groundwater resource management, petroleum and mineral exploration, mining and environmental protection application.

Hence this study deals with an interpretation of the observed aeromagnetic data of some parts of Chad Basin area. This interpretation is based on application of spectral analysis method. The potential advantage of these methods is that it was used because of its ability to filter almost all the noise from the data while making sure information is not lost in the process.

The study area is bounded by latitudes  $11^{\circ} 30'$  -  $12^{\circ} 30'$  N and longitudes  $13^{\circ} 00'$  -  $14^{\circ} 00'$  E in Northeastern Nigeria (Fig.1). It has an area of about 12,100 square kilometers. It covers places such as Mafa –Bama, Maiduguri, Marte and Masu, and can be accessed through main roads such as Maiduguri –Bida road, Bama –Marte road, Maiduguri –Masba road etc with other minor roads and main paths (Fig.1).

## **2 Geological Setting of the Study Area**

Geologic outcrops in the Chad Basin are scarce, being blanketed by Quaternary sediments. The rare exposures of the older series of Early Cretaceous are mostly found in the basin, within the Republic of Niger. The sedimentary fill in most parts of the basin is made of Late Cenozoic – Middle Eocene continental sediments and Cretaceous and Tertiary series accumulating preferentially in tectonic rifts (Fig. 2). Data gathered from the adjacent basins and boreholes indicate that the Bornu Basin is consisted of five stratigraphic units that

include the Bima Sandstone at the bottom, the Gongila Formation, the Fika Shale, the Keri-Keri and Chad Formations. In most cases the Chad Formation lies directly unconformably on the Fika Shale (Fig.3).

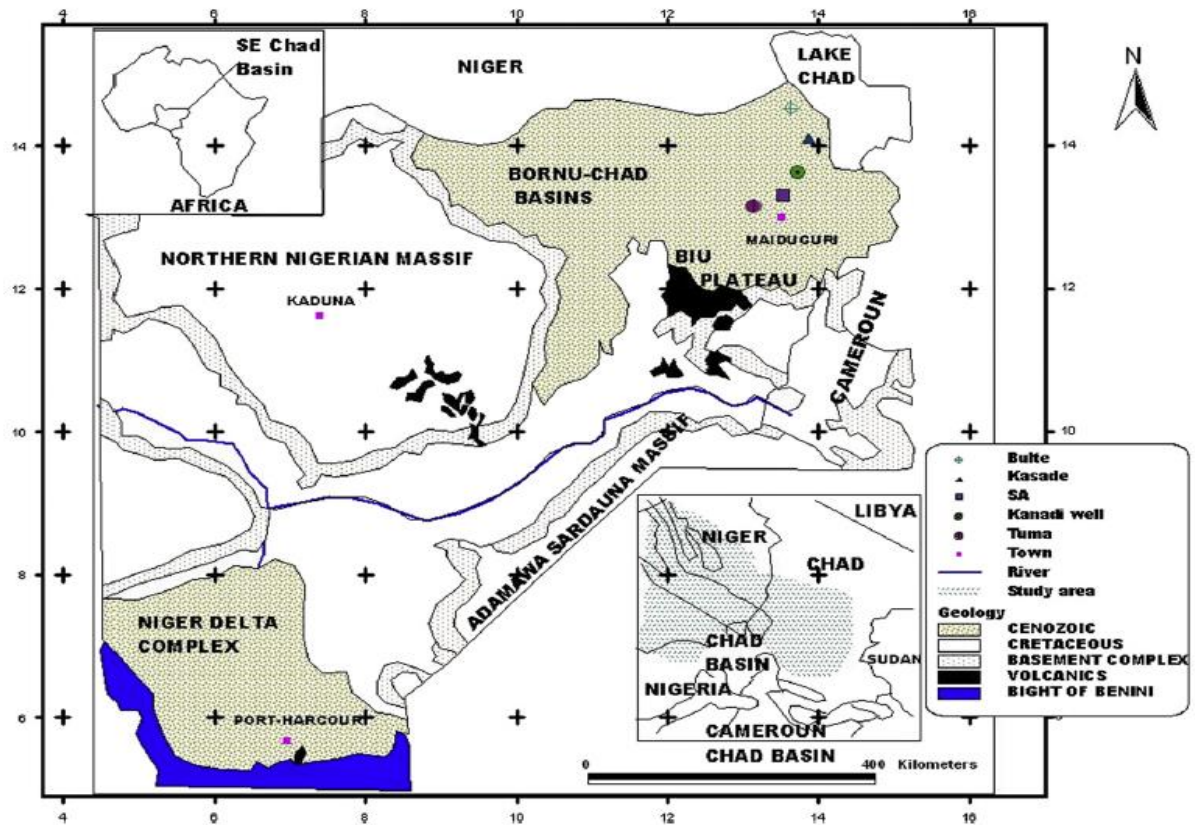


Fig.2: Geological map of the Nigerian sector of the Chad Basin [2].

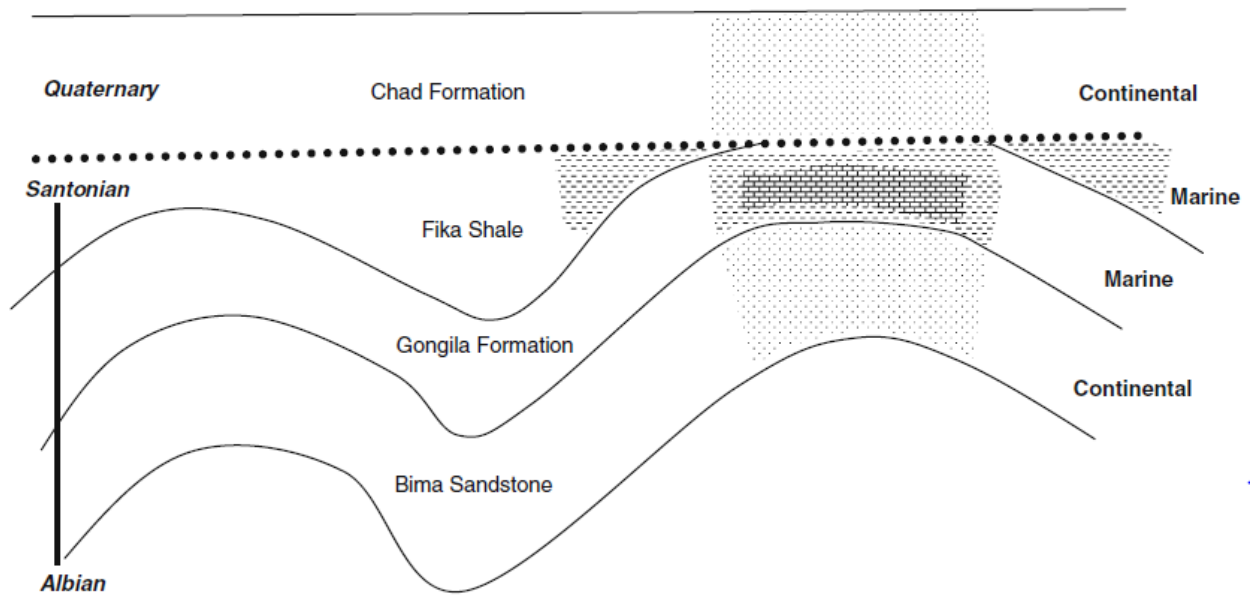


Fig.3: Stratigraphic Successions in Nigerian sector of the Chad Basin [3].

### 3 Methodology

To achieve the purpose of this Project work, four aeromagnetic sheets were procured from National Geological Survey Agency, Abuja. The sheets are 91 (Mafa-Bama), sheet 90 (Maiduguri), sheet 68 (Marte) and sheet 67 (Masu).

These sheets were assembled and analyzed. The aeromagnetic data were obtained as part of the nationwide aeromagnetic survey sponsored by Geological survey of Nigeria. The digital data was windowed from the National Grid Data base delivered in ASCII file in Geosoft format. The data was later converted to Microsoft Excel format for easy use with other applications. The data were acquired along a series of NW – SE flight lines with a spacing of 500 m and an average flight elevation of about 80 m while tie lines occur at about 2 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 total area covered was about 12,100 square kilometres. The aeromagnetic maps were digitized along flight lines with a spacing of 500 m and the intersection points were picked and contoured using software.

The contoured digitized data which is referred to as the total magnetic field intensity of the study area contains both the regional and residual anomaly. To interpret the local field, the regional field was removed from the data. In this case, 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 aeromagnetic anomaly map that would be interpreted.

The Trend Surface equation (regional gradient) becomes:

$$T(x,y) = -3.5393x + 2.4515y + 7909.47 \quad (1)$$

Equation (1) which is the linear trend surface equation was then subtracted from the aeromagnetic (observed) data and the resultant residual anomaly obtained. Both the digitized data and the residual data were contoured and their Digital Terrain Models obtained using Surfer32 software.

Discrete Fourier Transform method is the mathematical tool used in this study. This method has been applied by so many researchers [4, 5, 6, 7, 8, 9, 10, 11 and 12]. The Discrete Fourier Transform is applied to regularly spaced data such as the aeromagnetic data. The Fourier Transform is represented mathematically as shown below:

$$Y_i = f(x) = \sum_{n=1}^N \left[ a_n \cos\left(\frac{2n\pi xi}{L}\right) + b_n \sin\left(\frac{2n\pi xi}{L}\right) \right] \quad (2)$$

where:  $Y_i$  = Reading at  $X_i$  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 Amplitude  
 $b_n$  = imaginary path of the amplitude spectrum

## 4 Results and discussion

### 4.1 Qualitative Interpretation

The aeromagnetic map of Maiduguri and Environs (Fig.4) shows there is a large magnetic anomaly of 8200nT at Dikwa area (Northeastern part of the map). Towards the southern part, there is another anomaly of small size and its maximum amplitude is 7950nT. In addition, the residual aeromagnetic map of Maiduguri and Environs (Fig.5) shows positive and negative magnetic anomalies, which are distributed throughout the area. Maximum magnetic value (400 nT) was recorded at the eastern part and the minimum value (- 520 nT) was recorded at the western part. Figures 4 and 5 also show that the area is composed of three main magnetic regions; north-eastern, south-eastern and central region. These regions can be distinguished on the basis of the variations in density of the contour lines, which reflect the variation of intensity of magnetic response. The north-eastern and south-western regions are characterized

by high magnetic anomalies trending in the NE-SW and W-E directions. The observed magnetic anomalies in the eastern and western regions have a width of 1-3 km with moderately steep gradients, indicating intermediate depth sources. The western part of the area is characterized by low magnetic amplitude.

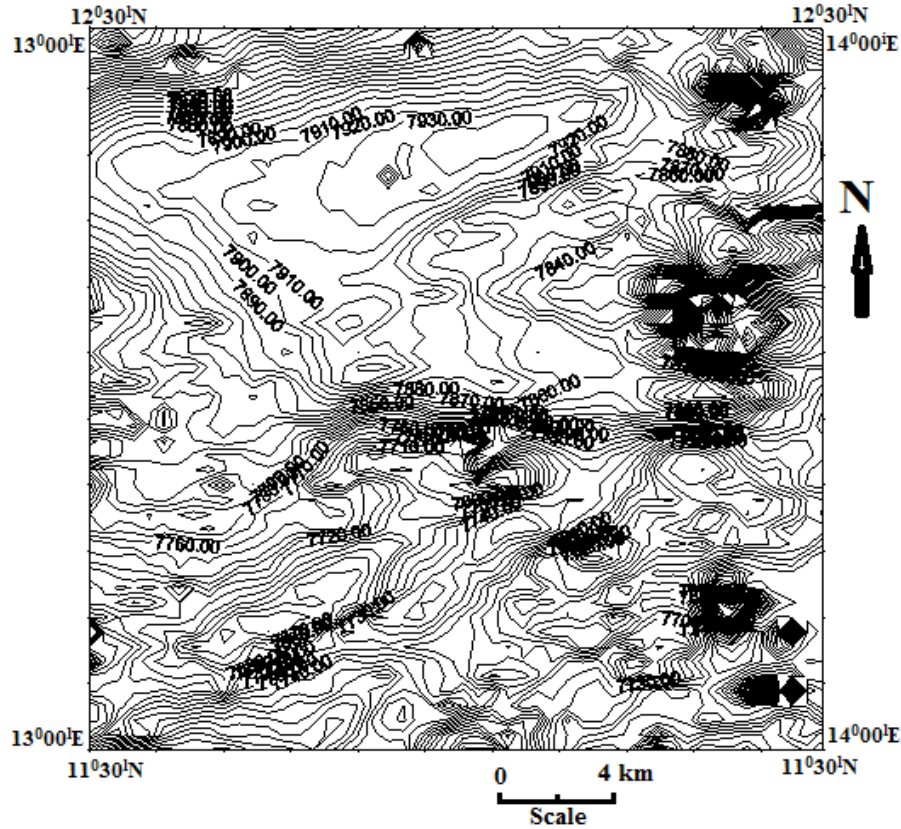


Fig.4: Total Magnetic Field Intensity Map (Contour Interval ~ 10nT)

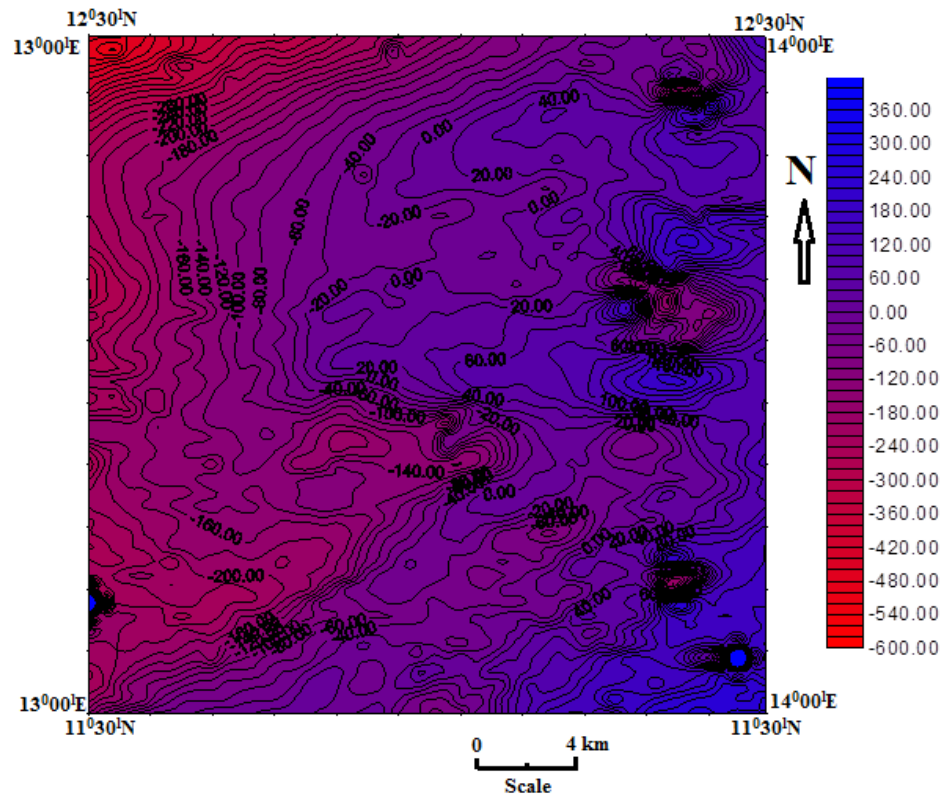


Fig.5: Residual anomaly map of the study area (Contour Interval ~ 20nT)

Visual inspection of the aeromagnetic map (Fig. 4) indicated that the most dominant trend in the study area is the NE-SW direction, which is related to the main trend of the basin itself. The second dominant trend is found to be in the W-E direction, which also conforms to the structural trend of the Chad basin itself. These structural trends are clearly shown in the lineament map of the study area (Fig.6).

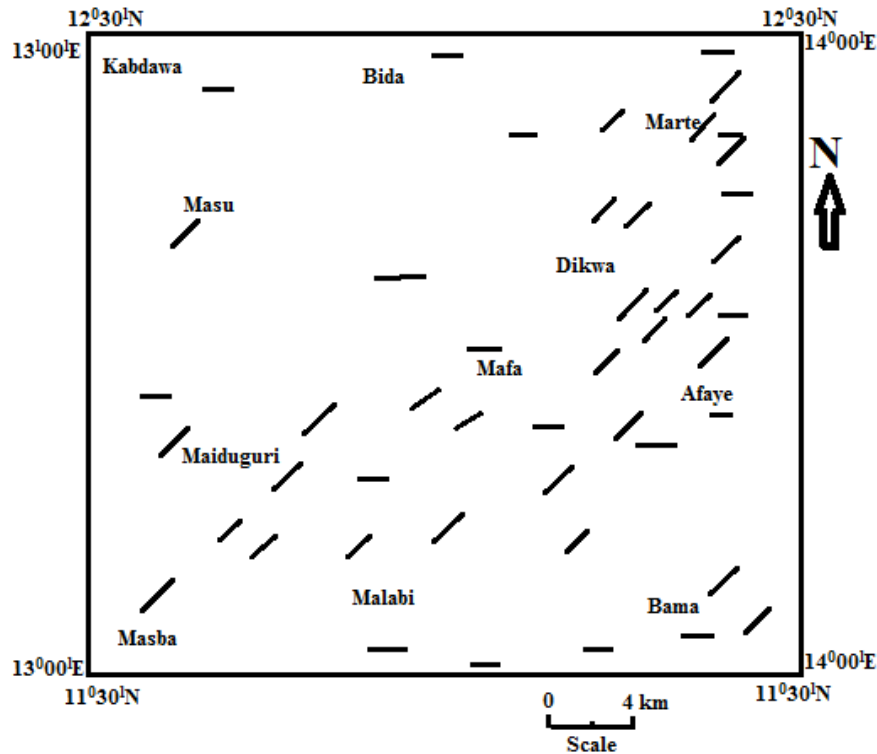


Fig.6: Magnetic lineament map of the study area

#### 4.2 Quantitative interpretation

The quantitative interpretation of aeromagnetic survey data can be so complex. However, rigorous analysis is carried out on a routine basis only when simple geometrically models are utilized to represent the subsurface sources. In this study, dyke is considered as the predominant structural source of magnetic anomaly. In exploring sedimentary basins, the assumption is generally made that intrusive rocks within the basement are truncated by erosion at their surfaces. If this is the case, the depth to the top of the dyke is equal to the thickness of the sedimentary section. The intrusives may not be extended upward as the basement surface, therefore, any computed sedimentary thickness is generally considered to be a minimum [13].

#### 4.3 Depth to basement

The quantitative interpretation of the geophysical anomalies is often based on the assessment of data observed along selected profiles (Fig.7). Some sample profiles (Fig. 8) have been selected for detailed interpretation. These serve as representatives of the others as they behave almost in the same way. Graphs of the logarithms of the amplitude against



frequencies obtained for the various profiles were obtained (Fig. 9). Linear segment from the low frequency portion of the spectral, representing contributions from the deep-seated causative bodies could be drawn from each graph. The gradient of the linear segment was evaluated and the depth to magnetic sources was determined along these selected profiles using a spectral analysis method (Table 1). This method is very useful to locate subsurface magnetic sources, which reflect the structure framework of the area. The depth to the top of the source is a useful tool for finding thickness of sedimentary succession, and sometimes for locating major structures in basement rocks. Some anomalies arise from basement rocks may be due to lithological changes rather than to structural features.

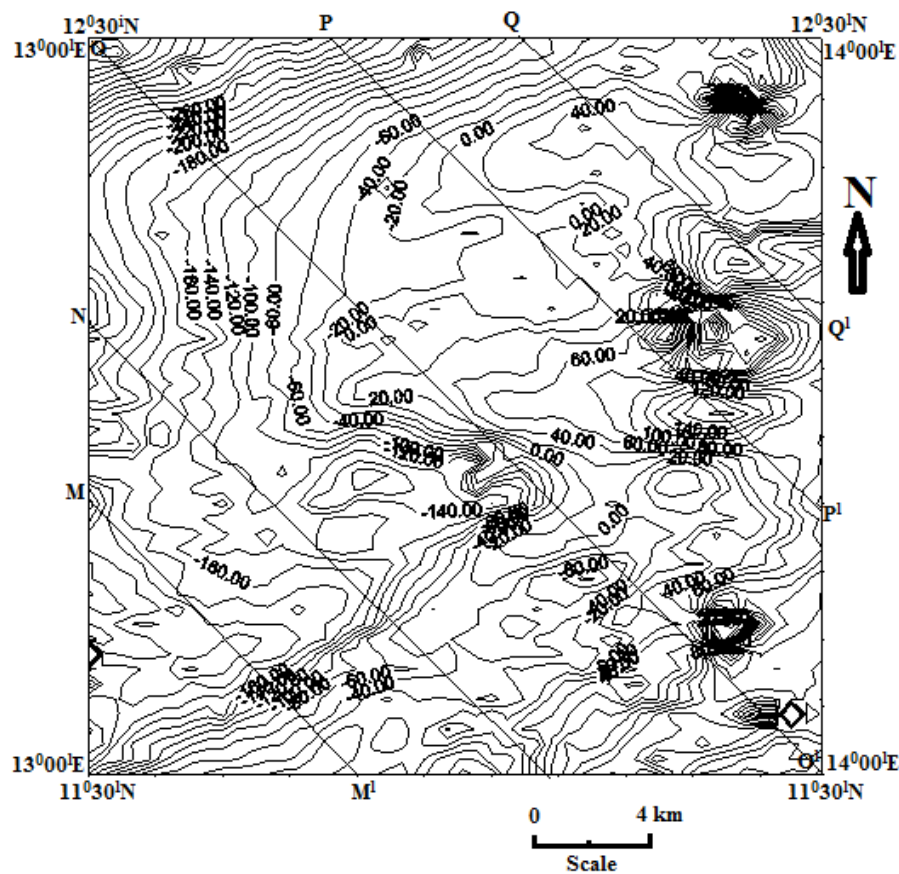


Fig.7: Residual anomaly map of the study area with cross sections (Contour Interval ~ 20nT)

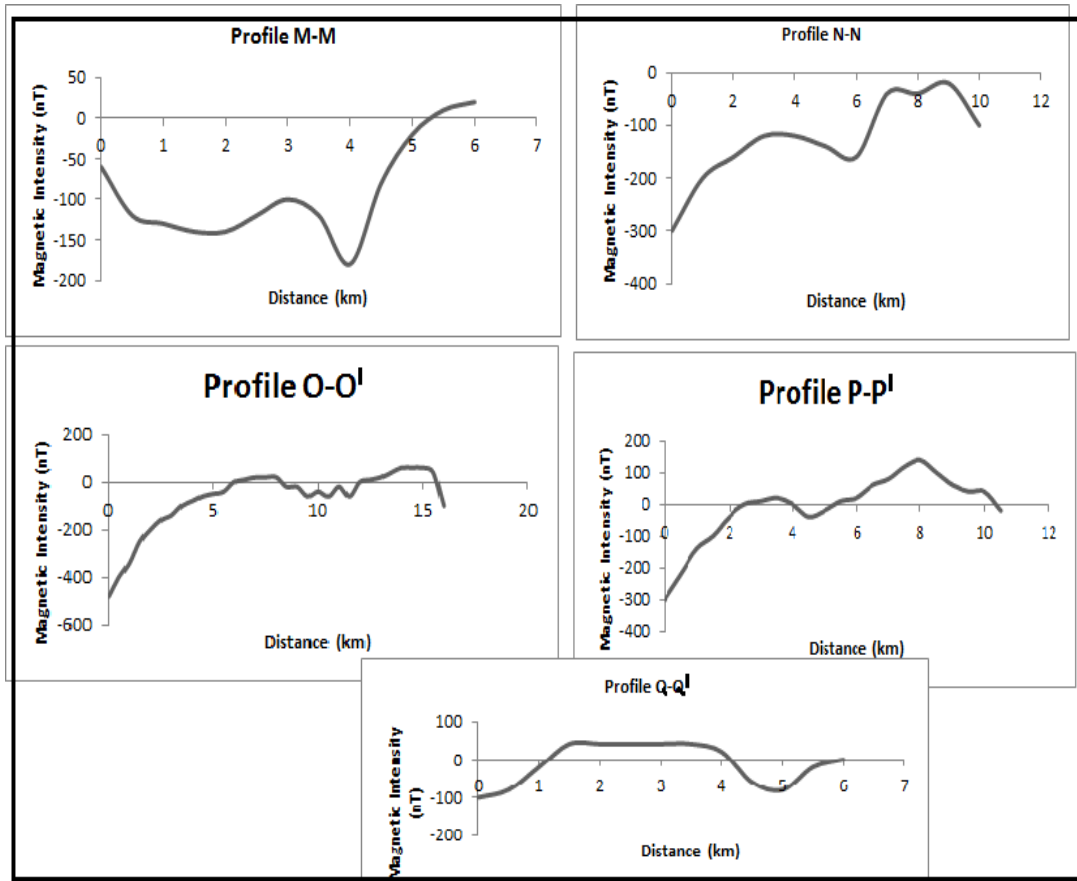


Fig.8: Selected cross sections along NW-SE direction

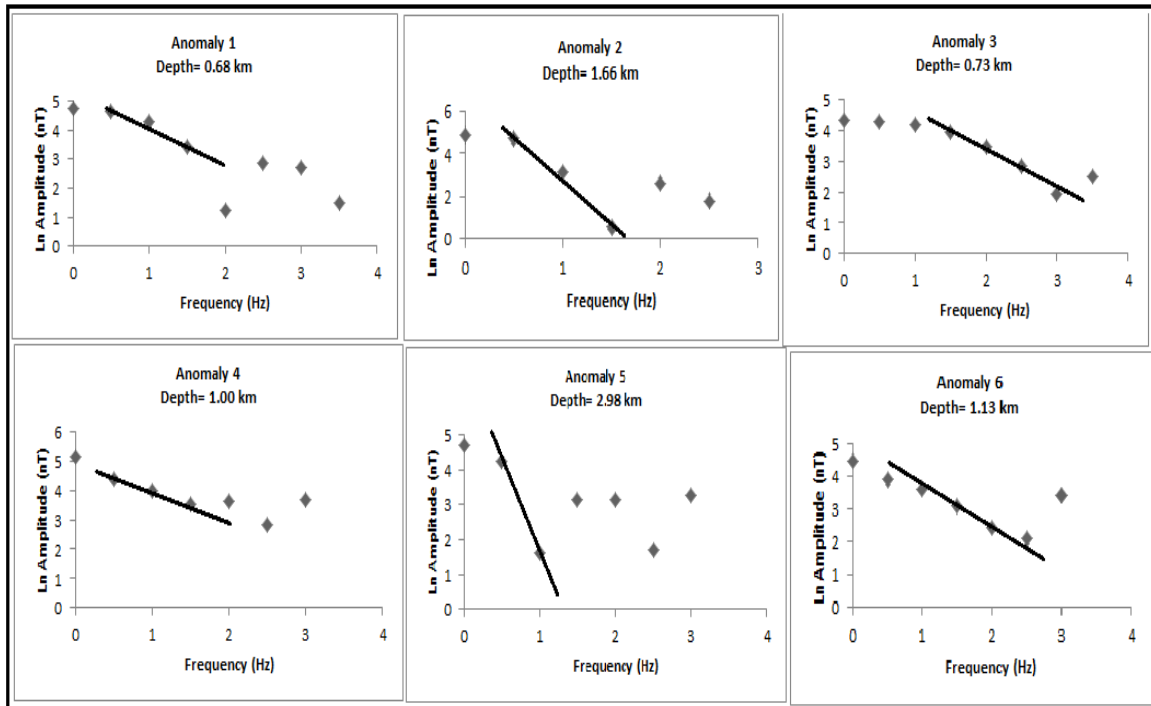


Fig. 9: Representative of spectral analysis graph for various anomalies.

Table 1: Basement depth determined from spectral analysis

Profile name	Profile direction	Anomaly	Depth (km)
M - M <sup>1</sup> Along Maiduguri	NW-SE	1	0.676891
	NW-SE	2	1.663697
	NW-SE	3	0.726535
N - N <sup>1</sup> (Along Masu & Maiduguri)	NW-SE	4	0.996909
	NW-SE	5	2.975231
	NW-SE	6	1.13354
O - O <sup>1</sup> (Along Masu Maiduguri & Mafa -Bama)	NW-SE	7	1.801104
	NW-SE	8	1.962932
	NW-SE	9	1.379476
P - P <sup>1</sup> (Along Masu & Bama)	NW-SE	10	1.581452
	NW-SE	11	1.436129
	NW-SE	12	0.57722
Q - Q <sup>1</sup> (Along Marte)	NW-SE	13	1.018203
	NW-SE	14	0.513131

#### 4.4 Profile M – M<sup>1</sup>

This profile passes through an area of relatively high magnetic anomalies in the South-western part of the map. The geological model section of the profile is shown in Fig.10a. The maximum magnetic value along this profile is 20nT and the minimum is – 180nT. The depth values range along this profile is from 0.68km to 1.67km. The depth obtained along this profile indicates shallower magnetic source.

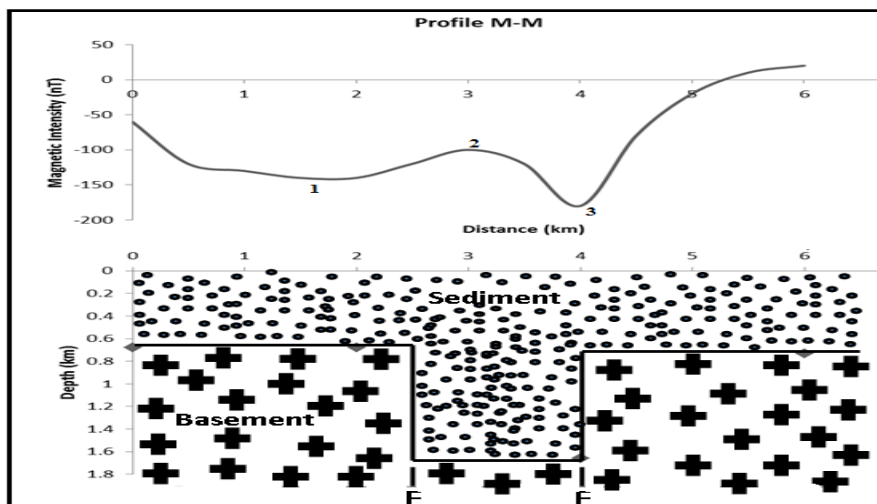


Fig.10a: Geological modelling of anomalies along profile M-M<sup>1</sup>

#### 4.5 Profile O – O<sup>1</sup>

Figure 10b shows the geological model section of Profile O – O<sup>1</sup> which passes along Kabdawa – Birguma areas of the study area. The maximum magnetic intensity value along this profiles is 80nT while the minimum is – 80nT. The depth value range along this profile is 1.3 km to 2.0km. Thus, the broad part of the curve can be found along the entire profile indicating deeper magnetic source.

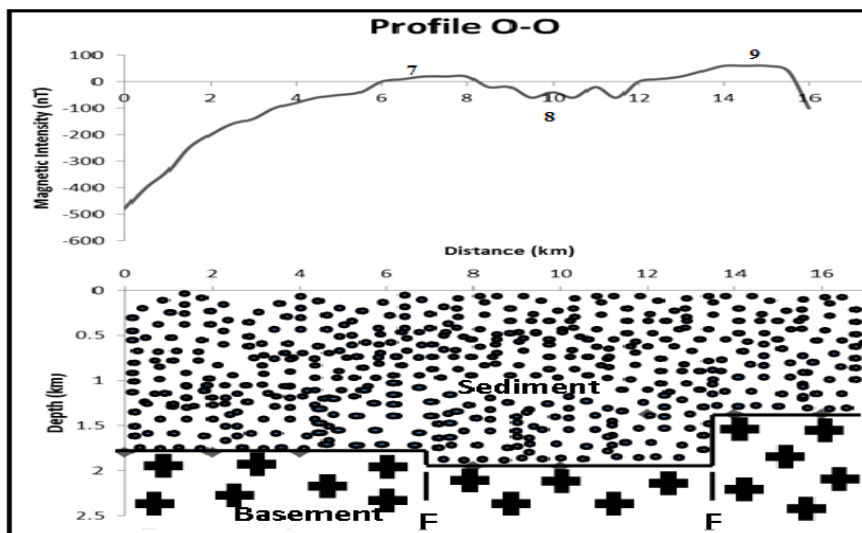


Fig.10b: Geological modelling of anomalies along profile O-O<sup>1</sup>

#### 4.6 Profile Q - Q<sup>1</sup>

This profile passes through an area of relatively high magnetic anomalies in the north-eastern part of the map. The geological model section of the profile is shown in Fig.10c. The maximum magnetic value along this profile is 40nT and the minimum is – 80nT. The depth values range along this profile is from 0.5km to 0.8km. The depth obtained along this profile indicates shallower magnetic source.

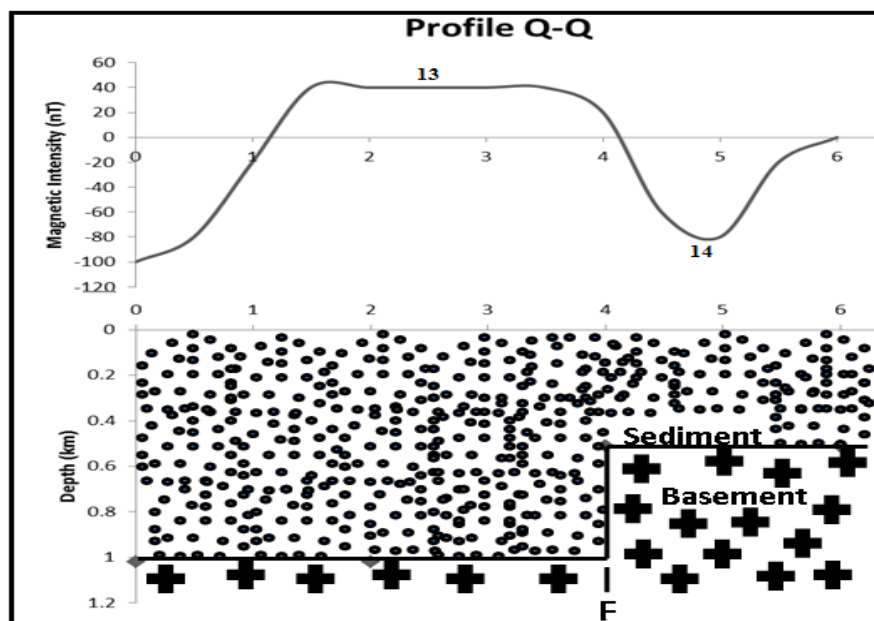


Fig.10c: Geological modelling of anomalies along profile Q-Q<sup>1</sup>

#### 4.7 Magnetic Basement Depth Map

Using the computed depth values from the Discrete Fourier Transform technique, the magnetic basement depth map was plotted and contoured using Surfer 32 Software. The map gives the configuration of the basement within the study area (Fig.11). From the map, red color confirms the presence of basalt and basement complex while the blue part of the map indicates the sedimentary terrain. Hence, the sedimentary thickness is increasing in the northern direction starting from 0.3km to 3.2km within the study area. The highest depth to basement of 3.0km is around the northern area and the lowest depth to basement of 0.5km around southern region. Hence, two magnetic sources can be deduced namely: shallower

sources which have depth range of 0.5 to 1.5km and the deeper sources range from 1.6 to 3.0km.

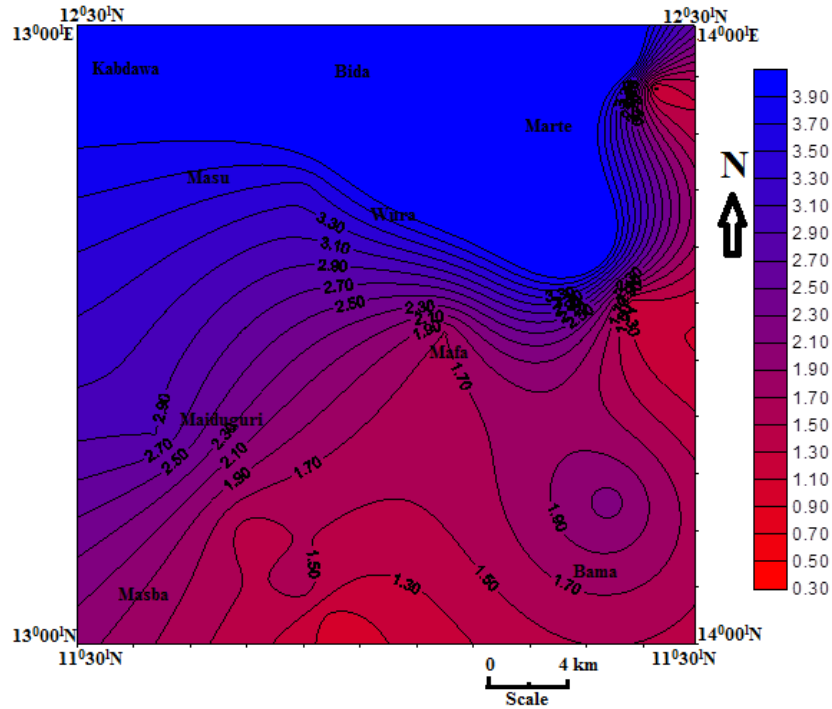


Fig. 11: Depth to basement map of the study area (Contour Interval  $\sim 0.2nT$ )

## 5 Estimation of Temperature at Depth

Geologists often refer to the temperature range in which oil forms as oil window, below the minimum temperature the organic matters remain trapped in the form of Kerogen and above the maximum temperature the oil is converted to natural gas through the process of thermal cracking. Usually, the oil window is often found in the 60-120°C interval with approximate depth of 2-4km [14].

In order to estimate 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 [11]:

$$T_h = mh + T_0 \quad (3)$$

Where,

$T_h$  = temperature in °C at depth( h) ;  $m$  = geothermal gradient

$h$  = depth of interest;  $T_0$  = surface temperature

It was further assumed that the surface temperature was 30°C while the average geothermal gradient in the study area was given by Nwankwo et al (2009) as 3.4°C/100m. From the

values of the sedimentary thicknesses obtained, which vary from 1.6 to 3.0km, the temperatures at depth for each anomaly block were estimated from equation (3) by solving for the unknown  $T_h$  (temperature at depth  $h$ ). The values obtained range between 84.4 and 132<sup>0</sup>C with an average of 108.2<sup>0</sup>C.

Thus, the sedimentary cover within the study area is generally high which increases towards the northern parts and therefore may support hydrocarbon formation. Actually, any prospective sediment must have a good quality source rock, good reservoir and seal lithology, favourable regional pathways and trapping mechanisms. The Fika and Gongila Shale 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 [15]. Thus, more than 90 percent of the study area 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 2.0km as well as other conditions necessary for hydrocarbon formation [14 and 16]. Based on the computed sedimentary thickness (1.6-3.0km) and temperature at depth (84.4-132<sup>0</sup>C), the possibility of hydrocarbon generation in the northern part of the study area is feasible (Fig.12).

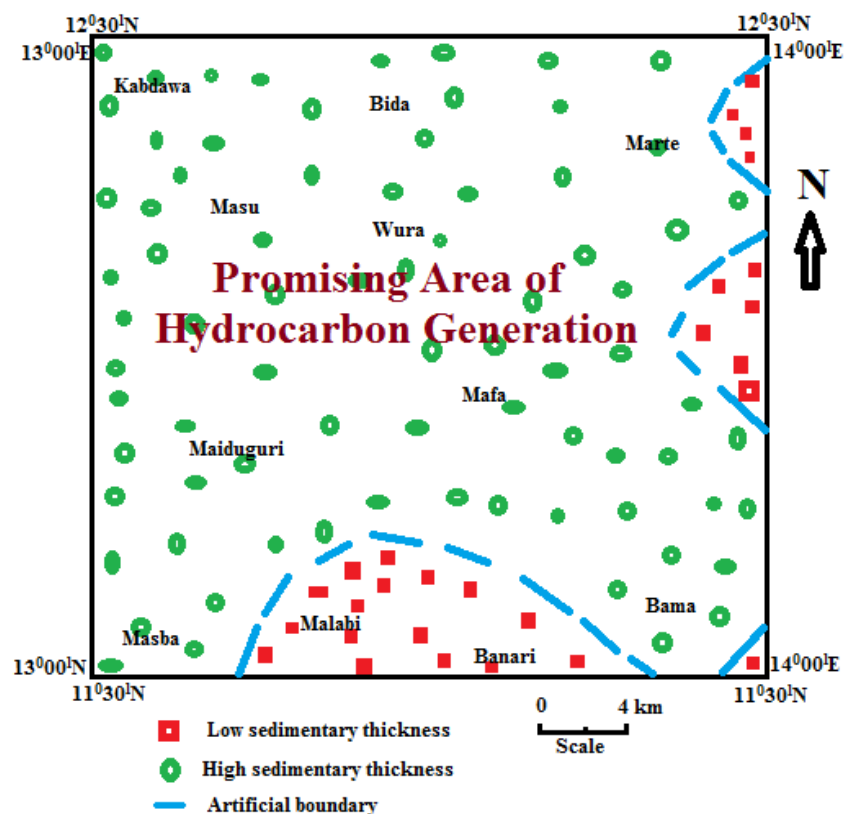


Fig.12: Promising area of hydrocarbon generation

## **6 Conclusions**

Airborne geophysical study is utilized to delineate the subsurface structure which controls the anomalous mineralization zones of the studied area. The depth to the top of the intrusive causative targets was calculated from the aeromagnetic map using spectral analysis method. It was found that the computed depths range between 0.5 and 3.0 km. The relatively deep values are observed mainly towards the eastern region of the study area (for example Marte, Dikwa, Mafa, Bama, Maiduguri) which corresponds to the occurrence of the Quaternary sediments, while the relatively shallow depth values correspond to the mountainous areas. These results agree well with both topographical and geological maps of the studied area. The interpreted depths helped greatly in the interpretation of the basement relief. In addition, the trend system is approximately NE-SW direction and subordinate W-E direction. This trend conforms to the trend of the Basin itself. The magnetic lineament map shows that the distribution of magnetic minerals in the studied area is in the trend of NE - NW, which mainly controls the presence of minerals. The present study delineates the significant magnetic anomalies that lie within the zones which were affected by these two trends.

The depth to basement map of the study area shows clearly that the sedimentary cover is generally shallow towards the western parts and therefore is not likely to favour hydrocarbon formation. But at the eastern parts, the map showed thick sedimentary cover which may favour hydrocarbon when all other conditions necessary for hydrocarbon formation are present. Finally, it could be concluded that, the application of aeromagnetic survey combined with geological studies provide a powerful tool in delineating the lithological and structural setting which may control the mineralization in Chad Basin.

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