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The interpretation of aeromagnetic anomalies over Maiduguri – Dikwa depression, Chad Basin Nigeria: A structural view

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ABSTRACT

An aeromagnetic study of the Maiduguri – Dikwa depression in northeastern Nigeria has been carried out to establish its main shallow crustal structural features. The area is intensely fractured with major fractures trending in NE-SW direction. *Spectral analysis and 2.0 D modeling of four profiles selected from the residual anomaly map provide depths to basement of 2.82, 3.41, 2.41 and 2.56 km. These depths constrain the magnetic models along the profiles, which indicate that the sedimentary infill is of variable thickness. Thus, we have three sub–basins along the Maiduguri – Dikwa depression: Maiduguri, Mafa-Bama, and Dikwa sub-basins. These sub–basins are associated with the extensional tectonics that affected the region from the Benue Trough to the Chad Basin. The Mafa-Bama sub–basin is the deepest one. The sedimentary infill is probably dominated with sandy clayey alluvial deposits, sandstones and shales. Depths to basement were constrained with by spectral analysis results.*

Keywords: Aeromagnetic anomalies, spectral analysis, modeling, fractures and Chad Basin.

INTRODUCTION

The study area is bounded by latitudes $11^0\ 30^1$ -$12^0\ 30^1$ N and longitudes $13^0\ 00^1$ -$14^0\ 00^1$ E in Northeastern Nigeria (Fig. 1). It has an area of about 12,100 square kilometers with some major towns like Mafa, Bama, Maiduguri, Marte and Masu; all in Borno state of Nigeria. The study area is found within Chad basin which is an intra-continental basin that owes its immediate origin to the existence of a number of peripheral uplifts. Its location over an old intra-continental rift system may also be significant. It appears to have developed after Africa came to rest with respect to its hot-spots as reflected by Burke and Wilson [6] and the spin axis by Burke and Dewey [7]. In this respect it may resemble the Michigan and other Lower Paleozoic basins of North America that apparently formed when that continent was at rest with respect to the underlying mantle as said by Burke and Wilson [6].

The present study will focus on the interpretation of aeromagnetic anomalies over parts of the eastern portion of the Nigerian Chad Basin using spectral analysis. This will help in establishing the sedimentary thickness variations and the structural patterns of the study area.

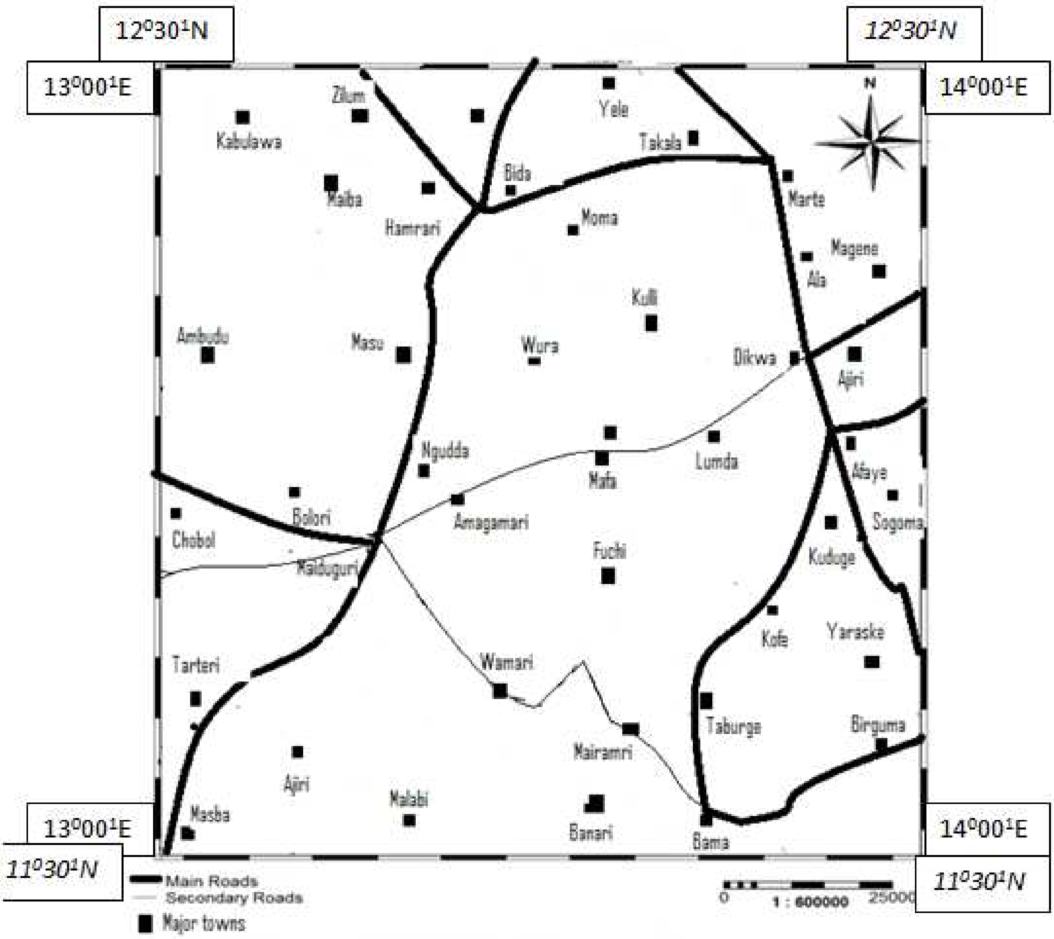

Fig.1: Location and accessibility map of the study area

Geology of the area

The Chad Basin with the area of 230,000 km^2 is the largest area of inland drainage in Africa according to Barber [3]; Matheis [12] and Avbovbo *et al* [2]. It extends into parts of the Republics of Niger, Chad, Cameroon, Nigeria and Central Africa. The Nigerian Chad Basin is about one-tenth of the basin and it is the most explored in Nigeria with the exception of the Niger Delta; active exploration work started in the Chad Basin in 1977 as presented by Nwazeapu [16]. Information on the geology of the Nigerian sector of the basin is scarce. However, the recent advancement in the exploration campaign by the Nigerian National Petroleum Corporation (NNPC-NAPIMS) has revealed more data which formed the basis of the recent studies on the geology of the area. Nwankwo *et al.* [15] identified three major sediment packages – the Bima

Formations, Gongila-Fika Shale and the Chad Formations in the Nigerian sector of the Chad basin.

Nwazeapu [16] attributed the major challenge in the discovery of hydrocarbon in the Nigerian sector of the basin to the presence of intrusive igneous bodies in most of the wells drilled. Nwankwo and Ekine [15] also postulated that the presence of Tertiary intrusive that is prevalent in the southern Chad Basin may be connected with the variation in the geothermal gradient.

Data and methodology

Total magnetic intensity

The total magnetic field over the study area was obtained by digitizing four aeromagnetic maps of the Geological Survey of Nigeria (GSN) airborne geophysical series sheets: 67 (Masu), 68 (Marte), 90 (Maiduguri) and 91 (Mafa-Bama). The maps were digitized along flight lines. The data obtained by the digitization of the various maps are equally spaced, which is good in minimizing aliasing effecting in sampled data according to Bath [4]. A grid interval of 1km was used to obtain a 110 x 110 data points. The gridded data were then integrated and used to plot the total magnetic intensity map of the study area (Fig. 2).

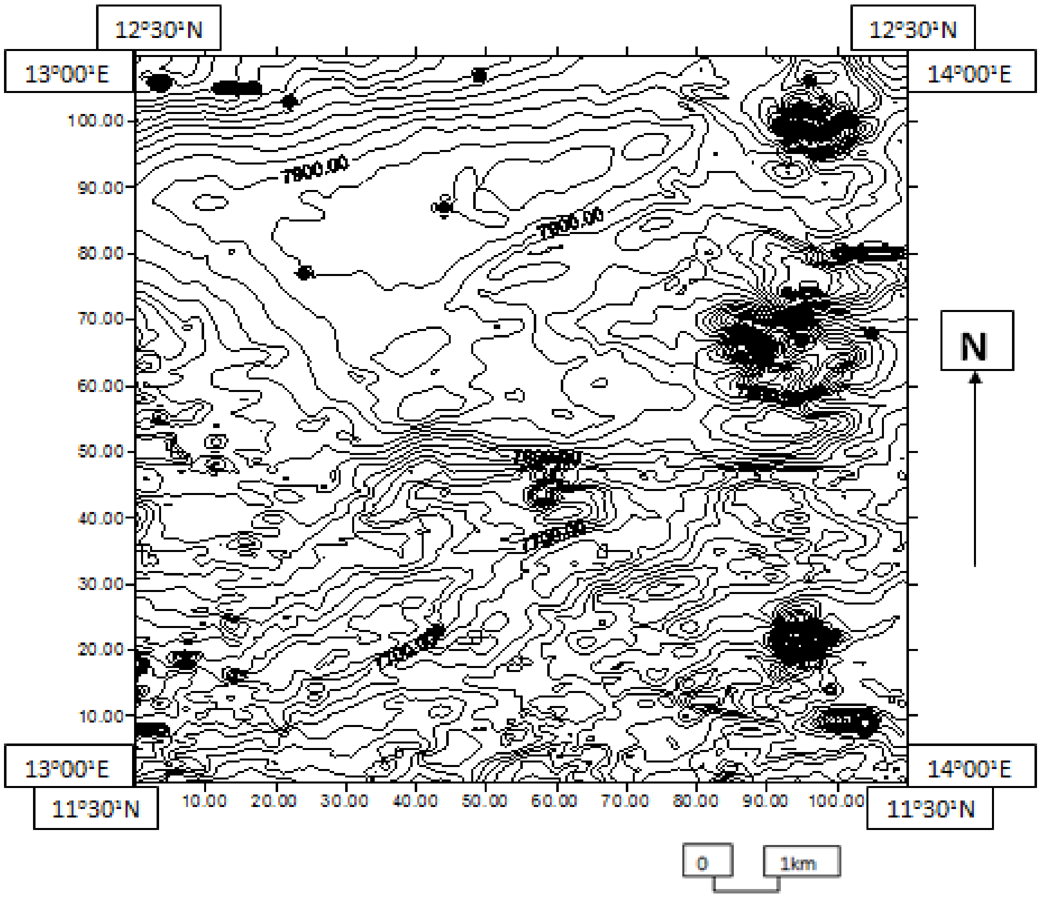

Fig. 2: Total magnetic field intensity map of the study area (Contour interval~ 30nT)

Separation of aeromagnetic data

The regional gradient was removed from the total magnetic field by fitting a linear surface to the digitized data, thus leaving the residual gradient, which is then plotted for interpretation (Fig. 3). The surface linear equation on the data can be given by:

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

Where,

a, b and c are constants

x and y are distances in x and y – directions

T(x, y) is the magnetic value at x and y co-ordinates.

Hence, the values of the constants a, b & c were obtained using the Least Square method of statistical analysis. Then the model equation becomes:

$$T(x, y) = 7770 - 0.5702x + 1.3666y \tag{2}$$

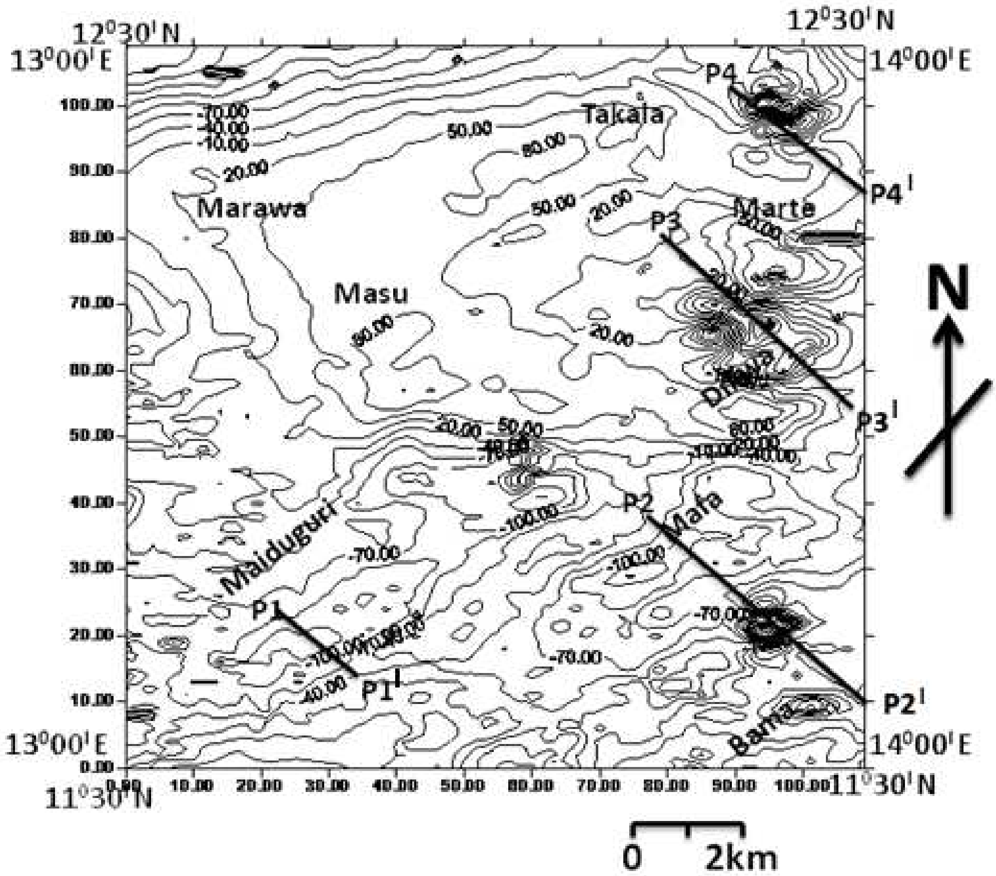

Fig.3: Residual anomaly map showing some cross sections (Contour interval~ 30nT)

RESULTS AND DISCUSSION

Residual magnetic anomaly

The residual anomalies delineate a belt of four conspicuous magnetic lows in the southern – northeastern portions of the study area (Fig. 3). These anomalies are approximately centered at Dikwa (–220nT), Marte (-190nT), Mafa-Bama (-340nT) and Maiduguri (–130nT). Conversely, the most conspicuous magnetic high anomaly centered at Marte-Takala (140nT). Minor magnetic highs are also observed at Bellam, Masu and to the north of Maiduguri. On the basis of the available geological information, Cratchley *et al.* [8]; Avbovbo *et al.*,[2] ; Schuster *et al.*[21] interpreted the sources of the magnetic low anomalies at Dikwa, Mafa-Bama and Maiduguri as corresponding to the sedimentary sub–basins while the areas with high magnetic anomalies are possibly due to uplift of the Precambrian bedrock or to intrusions of volcanic rocks (rhyolites). Initial structural analysis of the magnetic data indicated two sets of faulting and structural trends in the study area with NE–SW and E–W directions.

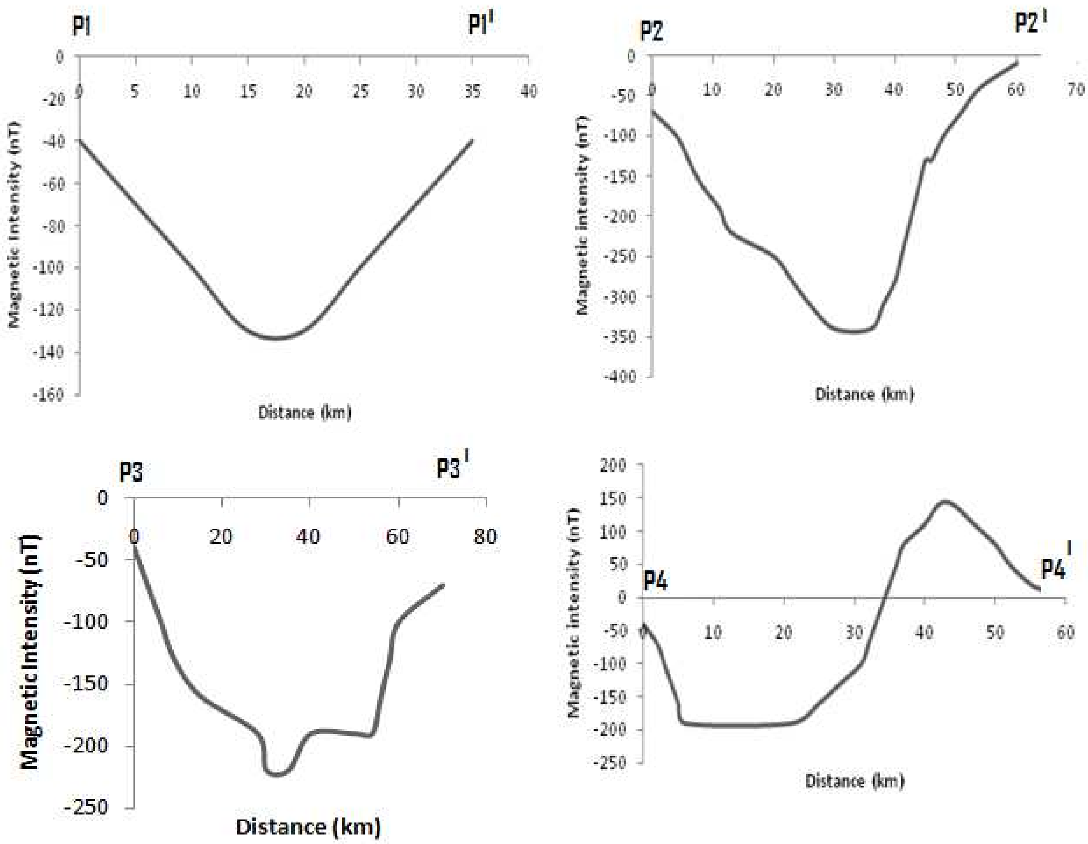

Fig. 4: Plot of profiles across the magnetic low anomalies

The plots of four lines of cross sections namely P1, P2, P3 and P4 (Fig. 3), taken across the areas of magnetic low anomalies reveal variability in the source of the anomaly (Fig. 4). Profile PI with a length of about 35 km, crosses along Maiduguri. The observed anomaly curve presents a magnetic low of –340nT, suggesting the presence of low magnetic sediments. Profile P2 taken across Mafa-Bama, has a length of about 60 km. The residual anomaly curve associated with this profile is characterized by a low magnetic anomaly of approximately –340nT which was interpreted as due to a sedimentary basin that corresponds to the sedimentary infill with a variable thickness reaching maximum at the centre of the profile. Profile P3 passes along Dikwa and it has a length of approximately 70km. The observed anomaly curve presents a magnetic low of –230nT suggesting the presence of low magnetic sediments. Profile P4 crosses along Marte-

Takala and it has a length of about 58km. The observed profile curve presents two magnetic sources namely a low magnetic anomaly of –200nT suggesting the presence of sedimentary cover and a high magnetic anomaly of 150nT, indicating the presence of igneous intrusions.

Depth to the basement

The application of spectral analysis to the interpretation of aeromagnetic anomalies has been discussed extensively by so many authors like Spector and Grant [19]; Ofoegbu and Onuoha [17]; Onwuemesi [18]; Abubakar *et al* [1]. Aeromagnetic data can be represented accurately by an analytic function using Fourier series. The method used in this study involves Fourier transformation of digitized aeromagnetic data to compute the amplitude spectrum. The respective spectrum of the profiles P1, P2, P3 and P4 are shown in Fig. 5. However, the gradients of the low frequency linear segment were evaluated and equation 3 was used to compute the depth to basement (sedimentary thickness).

$$Z = mL/2\pi \qquad (3)$$

Where, Z = depth to basement
m = gradient of the graph
L = width of the anomaly.

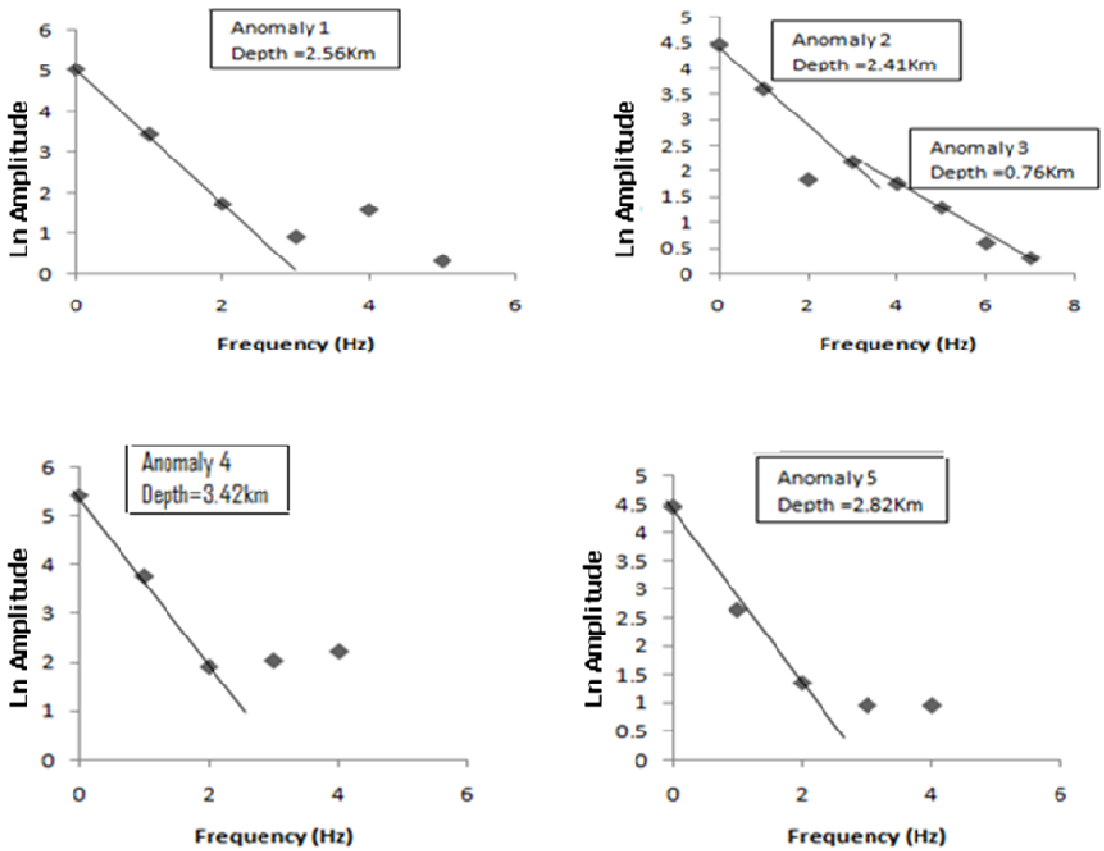

Fig. 5: Amplitude spectra of some anomalies

The depths of 2.82 km, 3.42km, 2.41(0.76) km and 2.56 km obtained from profiles P1, P2, P3 and P4 are related to sediment–bedrock (basement) contact.

The obtained depths to the interface between the shallow unconsolidated and deep consolidated sediments found in the region are in agreement with values of approximately 0.33–8.09 km documented in several zones near the study area by Durand [9], Isiorho *et al.* [11], Fairhead and Okereke [10], Abubakar *et al* [1] and certainly by Schuster *et al.*[20], who combined Landsat satellite images and electrical resistivity soundings in a study of the sedimentary system around Megachad palaeolake. This Megachad basin includes many sedimentary basins for example the Bornu, Termit, Chad Lake, Masenya and Faya Largeau basins.

Geologic modeling and structure

The geological model (Fig. 6) clearly illustrates the sedimentary cover and the igneous intrusive bodies. The sedimentary infillings have a variable thickness ranging from 2.56 km to 3.41 km. Depths to the basement in the models were set around the values obtained from the spectral analysis. As a result, spectral analysis suggests that the Mafa-Bama sub–basin is the deepest while Dikwa sub-basin is the shallowest in the Maiduguri-Dikwa depression (Fig. 6).

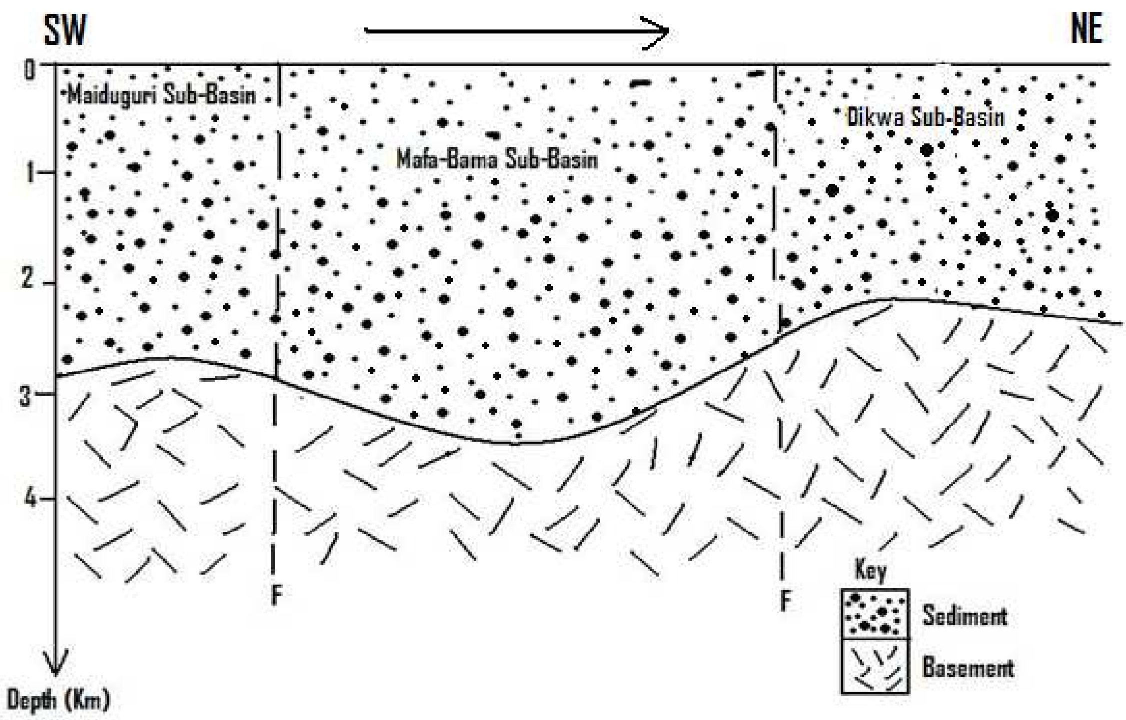

Fig. 6: Geologic model of the Maiduguri -Dikwa depression

Furthermore, the residual anomaly map and model obtained here reveal that the approximately NE–SW elongated composite magnetic low anomaly of short wavelength along Maiduguri–Dikwa depression may be attributed to the presence of structural depressions filled with low density sedimentary rocks. According to the models, the Maiduguri–Dikwa depression comprises three sub–basins (Maiduguri, Mafa-Bama and Dikwa); the Mafa-Bama sub–basin being the deepest one. The sedimentary infill is probably constituted by sandy clayey alluvial deposits, sandstones or shales. The basement comprises granite and gneiss, also basaltic intrusions.

In addition, the prominent trend of the lineaments is NE – SW with subordinate E – W trend. Two major fault patterns were identified within the study area (Fig. 7). They are trending in NE-SW direction which conforms to the structural trend of the basin itself.

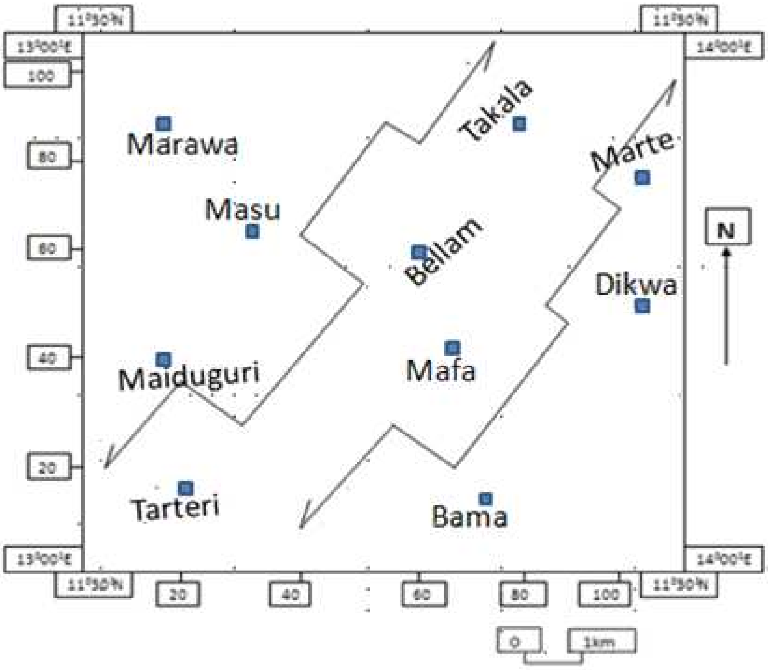

Fig. 7: Fault pattern in the study area

According to the model, the Mafa-Bama basin is a composite depression of tectonic origin associated with the tectonic extension in Chad basin. Originally, this interpretation is justified because the Chad Basin was associated with extensive tectonics as stated by Burke [6]; Cratchley *et al.* [8]; Avbovbo *et al.* [1]. The depths to the basement in the study area are similar to those obtained from an aeromagnetic depth computation in the Borno - Benue Trough was said by Benkheih *et al* [5]. The results indicate source depth ranging from 2 km to 8km. Also, Nur *et al* [13] carried out analysis of aeromagnetic data over parts of Upper Benue Trough. Their result indicated two magnetic depth sources. The deeper magnetic source depth of up to 3328 m (3.328 km) was obtained representing the sedimentary cover, while the depth to the shallower magnetic source model is about 830m which is representing intrusive bodies.

More so, Abubakar *et al* [1] carried out a spectral analysis of aeromagnetic data in Gongola Basin, Upper Benue Trough and suggested that the depth to the causative body is between 2.4 and 8.09 km. The causative bodies were interpreted to be basic to ultrabasic rocks. They also said that the evolution of Gongola Basin is a rift origin. This reinforces the idea of a similar geodynamic evolution for the region from the Benue Trough up to the Chad basin.

CONCLUSION

Spectral analysis has been applied in the interpretation of aeromagnetic anomalies over parts of the Eastern Chad Basin, Nigeria. The conclusions are as follow:

(1) Two depth sources were obtained in the study area; the shallower sources have a mean value of 0.76 km while the deeper ones have an average value of 2.75 km.
(2) The study area constitutes of three sub-basins namely Maiduguri, Mafa-Bama and Dikwa sub-Basins.
(3) The area is intensely fractured with major regional faults trending in NE-SW direction. This conforms to the trend of the Benue Trough.
(4) The study area is of rift origin.

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