Re-Evaluation of Hydrocarbon Potentials of Eastern Part of the Chad Basin, Nigeria: An Aeromagnetic Approach*

Emmanuel Anakwuba[1] and Augustine Chinwuko[1]

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[1]Geological Sciences, Nnamdi Azikiwe University Awka,Nigeria (emmaanakwuba@yahoo.com)

Abstract

The hydrocarbon potentials of parts of the Nigerian sector of the Chad Basin have been re-evaluated from the interpretation of aeromagnetic anomalies. Nine aeromagnetic maps located between latitudes 11^o 00 min - 12^o 30 min N and longitudes 12^o 30 min - 14^o 00 min E were assembled and analyzed to determine the structural pattern and the sedimentary thickness variations within the basin. The qualitative interpretation indicates that the area is intensely fractured with major faults trending in a NE-SW direction. The aeromagnetic data were subjected to Fourier analysis and results show two depth sources in the study area; the shallower sources have a average value of 1.8 km while the deeper ones have an average value of 4.3 km. The sedimentary thickness of the area ranges from 1.0 to 5.8 km. Based on the computed sedimentary thicknesses and the temperature at depth (125-228^o C), some parts of the study area have been demarcated for detail hydrocarbon exploration.

Introduction

The study area is located within the eastern part of the Nigerian sector of the Chad Basin (Figure 1). The Chad Basin, with an area of about 230,000 km^2, is the largest area of inland drainage in Africa (Barber, 1965; Matheis, 1975; Avbovbo et al., 1986). It extends into parts of the Republics of Niger, Chad, Cameroon, Nigeria and Central Africa. The Nigerian sector of the Chad Basin is about one-tenth of the basin and is the most explored in Nigeria with the exception of the Niger Delta. Active exploration work started in the Chad Basin in 1977 (Nwazeapu, 1992).

Despite these long periods of exploration by the Federal Government through NAPIMS-NNPC, not much success has been recorded. Three major sediment packages, the Bima Formation, Gongila-Fika Shale and the Chad Formation, were identified in the Nigerian sector of the basin (Nwankwo et al., 2009). These sediment packages, according to Nwankwo (2009), contain formations that have both source rock and reservoir potential. However, one major challenge in the discovery of hydrocarbon in the Nigerian sector of the basin has been the presence of intrusive igneous bodies in most of the wells drilled (Nwazeapu, 1992). Furthermore, the presence of Tertiary intrusives prevalent in the southern Chad Basin may be connected with the variation in the geothermal gradient (Nwankwo and Ekine, 2009). There is therefore great need to re-evaluate the geology and hydrocarbon potential of the basin since the same basin outside Nigeria is productive.

The 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, hence a magnetic survey is the first geophysical tool to start with. This study focuses on the interpretation of aeromagnetic anomalies over the basin. This will help to delineate the basin's configuration by determining the depth to magnetic basement. It will also establish the structural features and the possibility of hydrocarbon generation within the basin.

Data and Methodology

The total magnetic field of the study area was obtained by digitizing aeromagnetic maps of the Geological Survey of Nigeria (GSN) airborne geophysical series. 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 effects in sampled data (Bath, 1974). A grid interval of 1 km was used to obtain a 165 x 165 data-point grid. The gridded data were then integrated and used to plot the total magnetic intensity map of the study area (Figure 2). From the total magnetic field obtained, the regional gradient was removed from the composite map by fitting a linear surface to the digitized data, thus leaving the residual gradient, which is then plotted for interpretation (Figure 3).

The residual anomalies obtained along five profiles were subjected to spectral analysis. Spectral analysis has been widely used by several authors (Spector and Grant, 1970; Gerard and Debeglia, 1975; Bhattacharyya, 1978; Ofoegbu, 1988; Onwuemesi, 1997; Abubakar et al., 2010; Anakwuba et al., 2011; etc.) to determine the depths of magnetic anomalies. Energy spectral analysis provides a technique for quantitative studies of large and complex aeromagnetic data sets. The logarithm of the radial average of the energy spectrum is plotted against the radial frequency. The slope of each segment provides information about the depth to the top of an ensemble of magnetic or gravity bodies (Kivior and Boyd, 1998).

Results and Discussion

Aeromagnetic Anomaly Map

The maps of the total magnetic field intensity and residual magnetic anomalies of the study area are shown in Figure 2 and Figure 3. The figures show that the total magnetic field and residual anomalies range from 6900 to 8050 nT, and -30 to 390 nT, respectively. Thus, the maps show areas with both widely-spaced and closely-spaced contours lines (i.e. areas with low and high intensity of magnetization, respectively). The total magnetic field intensity maps show that the contour lines of the northeastern parts are widely spaced, indicating that the depth to magnetic basement in this area is relatively deep. But, in the Gwoza (southeastern part) area, the contour lines are closely spaced, signifying that the depth to basement is shallow in this area.

Depth to Basement

Fourier analysis was used to calculate the depth to basement along five profiles (Figure 3). The sedimentary thicknesses obtained ranges from 1.0 to 5.5 km within the study area. As a result, two depth sources were delineated, namely the shallower and the deeper sources. The shallower sources range from 1.0 to 2.0 km, which represent the igneous intrusive bodies within the study area, while the deeper sources range from 2.1 to 5.8 km which represent the sedimentary cover within the study area. More so, the basement topography was generated from the various depth values determined (Figure 5). The map indicates a northeastern increase in sedimentary cover across the study area. The depth range of 1.0-2.0 km in the southeastern part indicates a shallow depth of basement complex area.

Geological Model and Structural Pattern

Geological model sections were generated for the anomalies as shown in Figure 6. The geological models clearly illustrate the sedimentary cover and the igneous intrusive. It also shows area where there is a discontinuity as indicated by **F.** The models show the magnetic anomalies ranging from -50 to 350 nT with sedimentary thickness ranging from 1.0 to 5.8 km respectively. The structural patterns were also mapped out from the data obtained as shown in Figure 7 and Figure 8.

The closely spaced linear sub-parallel orientation of contours from the total magnetic map (Figure 2) suggests the possibility of faults or local fractured zones passing through these areas. According to Nsikak et al. (2000), there is always 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. Such geological features may appear as thin elliptical closures or nosings on an aeromagnetic map (Figure 7); these features represent geologic lineaments. The prominent trend of the lineaments is

NE-SW with a subordinate E-W trend. Also, three major regional faults trending in the NE-SW direction were delineated (Figure 8) and they conform to the trend of the Benue Trough. This possibly suggests that the two basins are of similar origin.

Temperature at Depth

The temperature at depth was calculated using equation (3) below (Onwuemesi, 1997):

$$T_h = mh + T_o \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where,

T_h = temperature in ^oC at depth (h)
m = geothermal gradient
h = depth of interest
T_o = surface temperature

It was assumed that the surface temperature was 30^o C while the average geothermal gradient in the study area was given by Nwankwo et al. (2009) as 3.4^o C/100 m. From the values of the sedimentary thicknesses obtained, which vary from 2.1 to 5.8 km, the temperatures at depth for each anomaly block (anomalies 1-15) were estimated from equation (3) by solving for the unknown T_h (temperature at depth). The values obtained range from 125 to 228^o C with a mean value of 176.5^o.

Hydrocarbon Potential

The shallower sources may be a result of activities in the basement complex of northeastern Nigeria. These tectonic activities account for the complex fracturing in the area with some fractures extending towards the northern part. The magnetic lineament map shows the major fault trend in the NE-SW direction with a minor fault trend SE-NW. These trends are in conformity with the structures of the basement complex of northeastern Nigeria and could have served as a migratory pathway for hydrocarbon or hydrothermal fluid.

Thus, the sedimentary cover at the southeastern part (Figure 5) is generally low and may not support hydrocarbon formation. This area is therefore designated as an area to be avoided during detail hydrocarbon exploration. Apart from the southeastern part, all the other parts of the study area have a sedimentary thickness that is moderately high. In line with this, for any area to be viable for hydrocarbon formation, the thickness of the sediment must be at least 2.0 km as well as other conditions necessary for hydrocarbon formation (Wright et al., 1985). Also, Nwankwo (2009) said that in the Chad Basin the Fika and Gongila shales are the source rocks, while the reservoir is the Bima Sandstone. Based on the computed sedimentary thicknesses (2.1-5.8 km), the temperature at depth (125 and 228^o

C), and the fractures which serve as migratory pathways for hydrocarbon or hydrothermal fluid, then the possibility of hydrocarbon generation in the northern and southwestern parts of the study area is feasible (Figure 9). These areas have been marked for detail hydrocarbon exploration.

Conclusions

The hydrocarbon potentials of the eastern part of the Nigerian Chad Basin have been re-evaluated using an aeromagnetic approach. This approach involves the use of Spectral analysis in delineating the depth to the basement and structural features that can act as hydrocarbon traps. Information on the geothermal gradient of the area was also determined. The conclusions of the study are as follows:

1) Two depth sources were obtained in the study area: the shallower sources have an average depth of 1.5 km, while the deeper ones have an average depth of 3.8 km.

2) The sedimentary thickness obtained ranges from 1.0 and 5.8 km and are increasing in the northern direction.

3) The area is intensely fractured with three major regional faults trending in a NE-SW direction.

4) The study has demarcated the areas where detail hydrocarbon exploration will be concentrated in the future.

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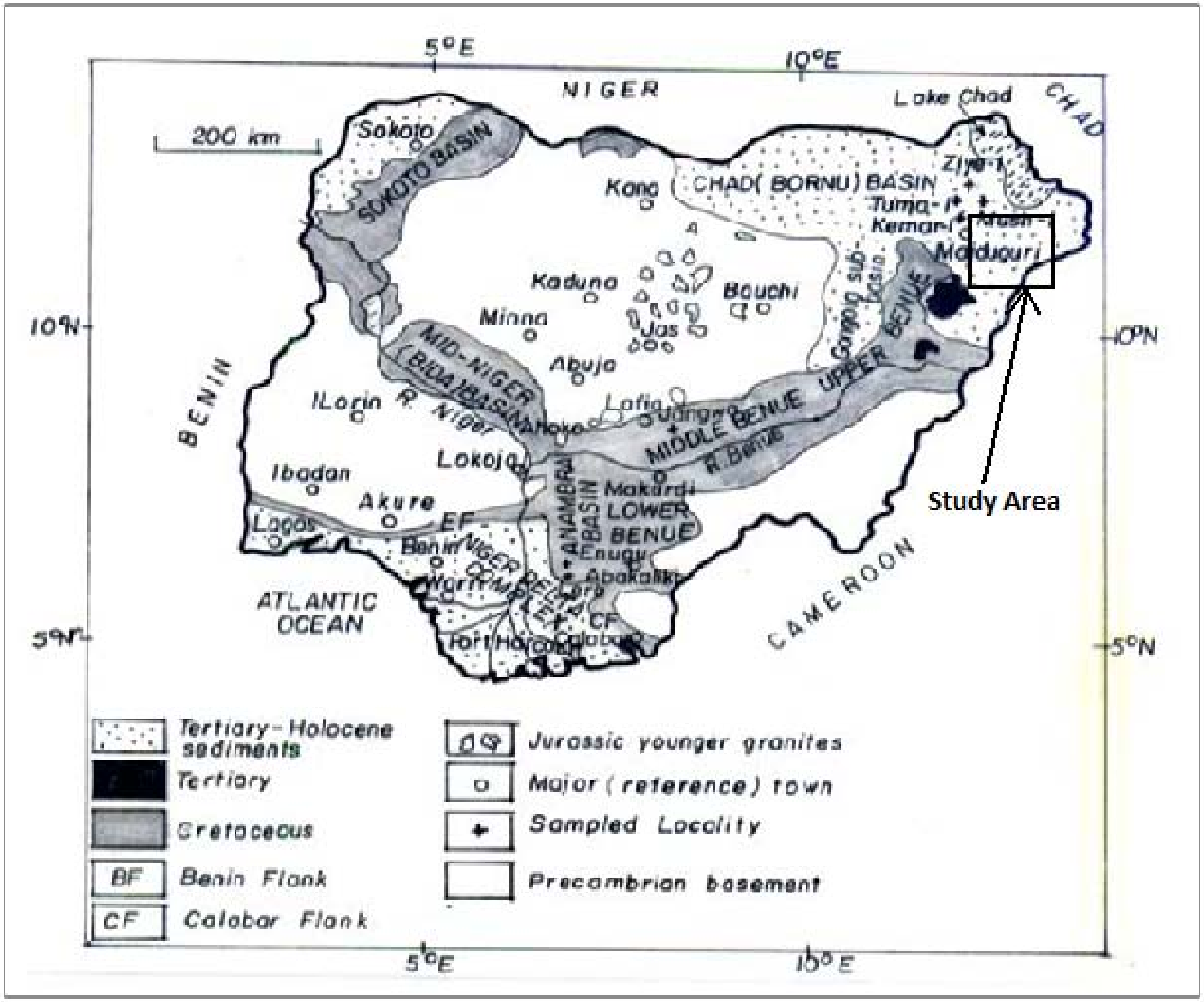

Figure 1. Geologic map of Nigeria showing the study area (adapted from Obaje et al., 2004).

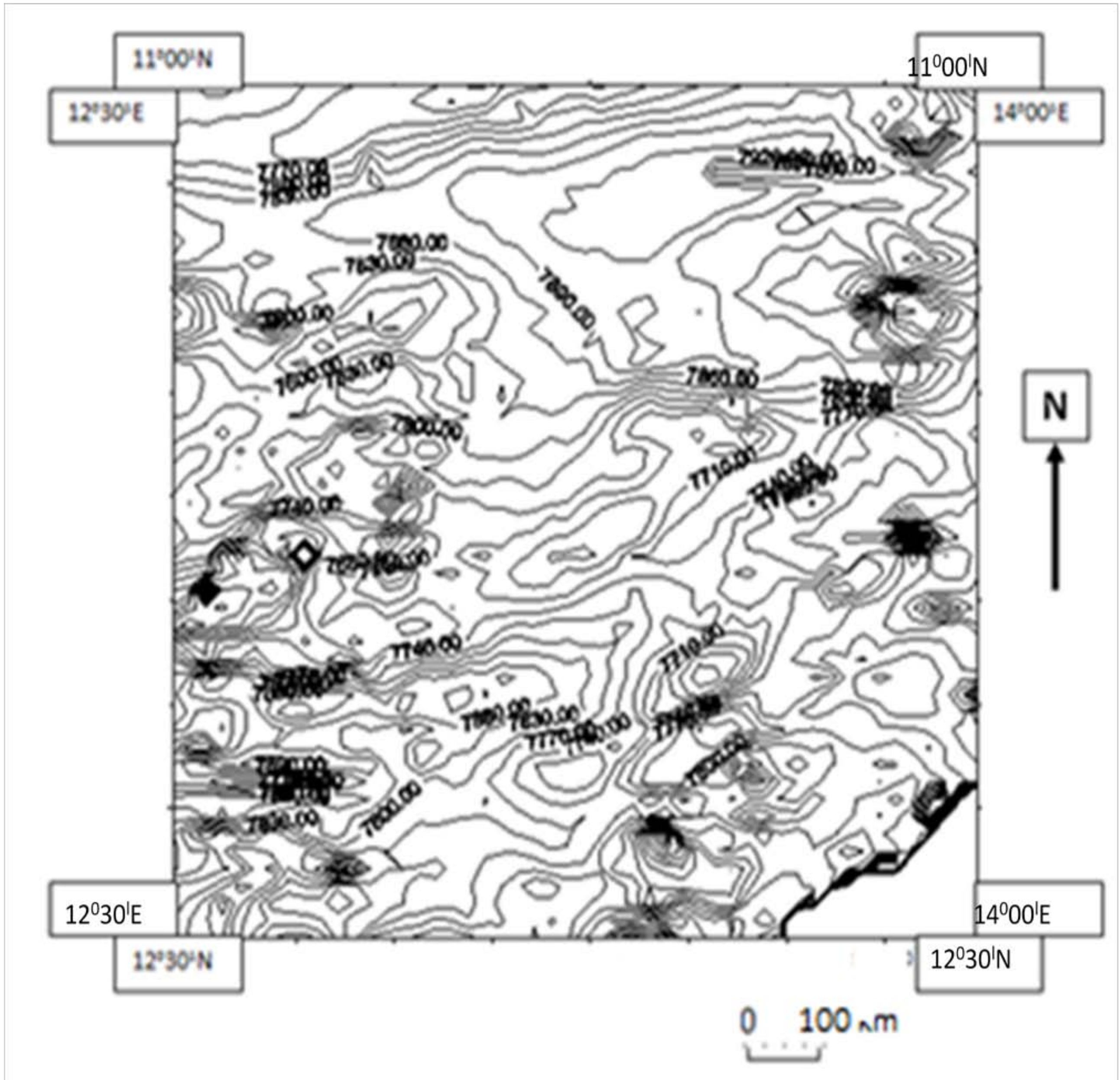

Figure 2. Total magnetic field intensity map (contour interval ~30 nT).

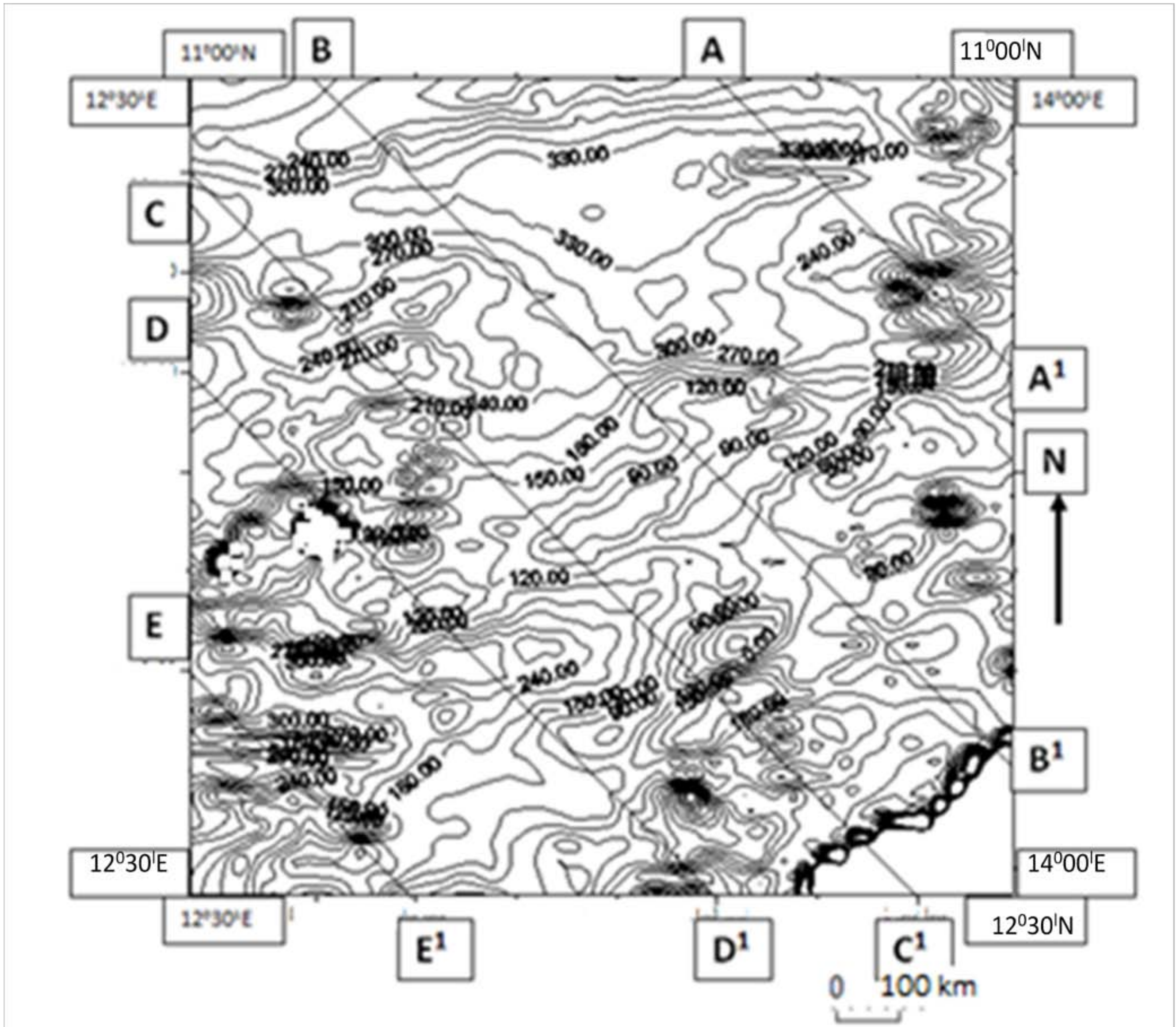

Figure 3. Residual anomaly map (contour interval ~30 nT).

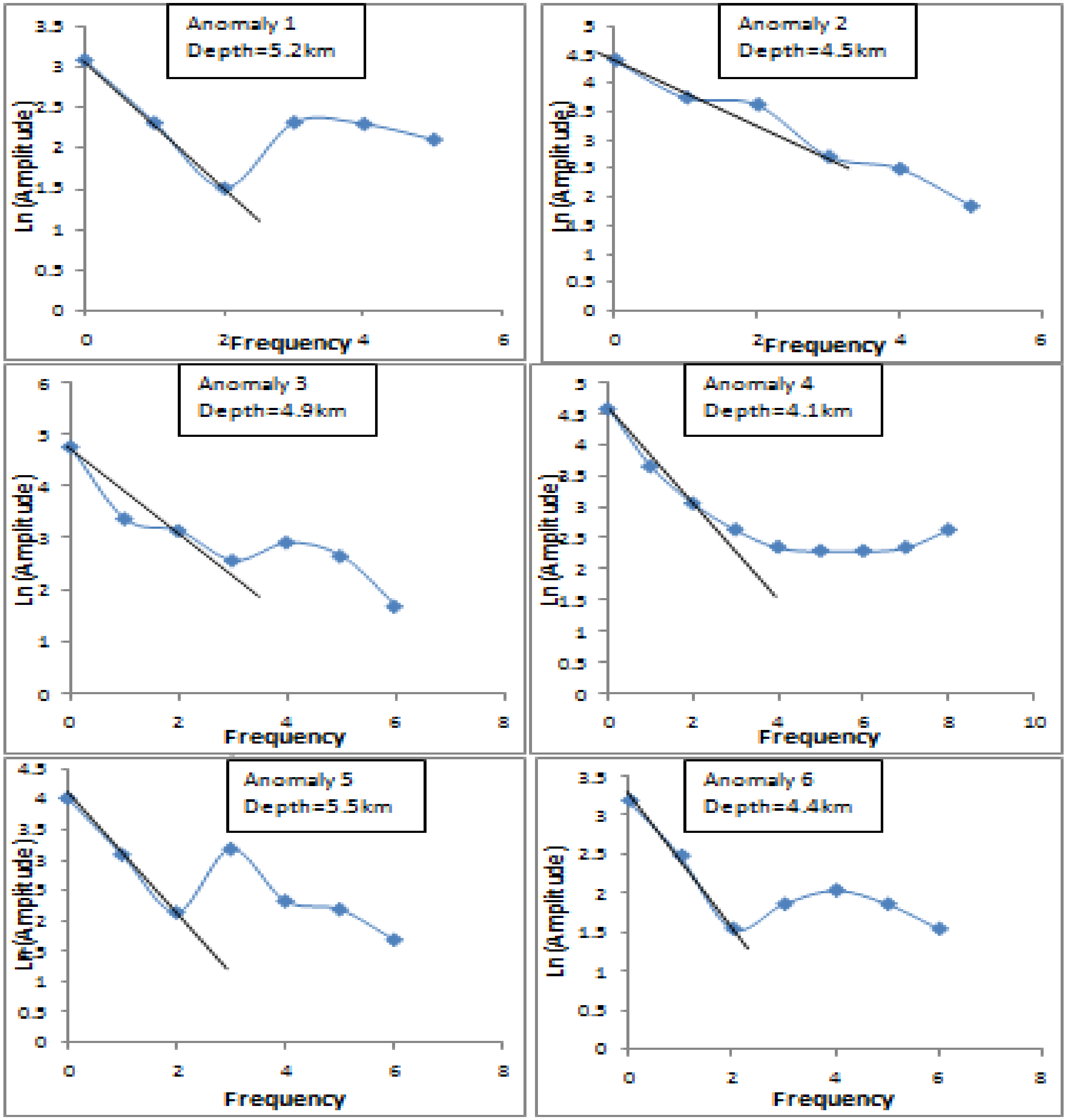

Figure 4. Representation of amplitude spectrum.

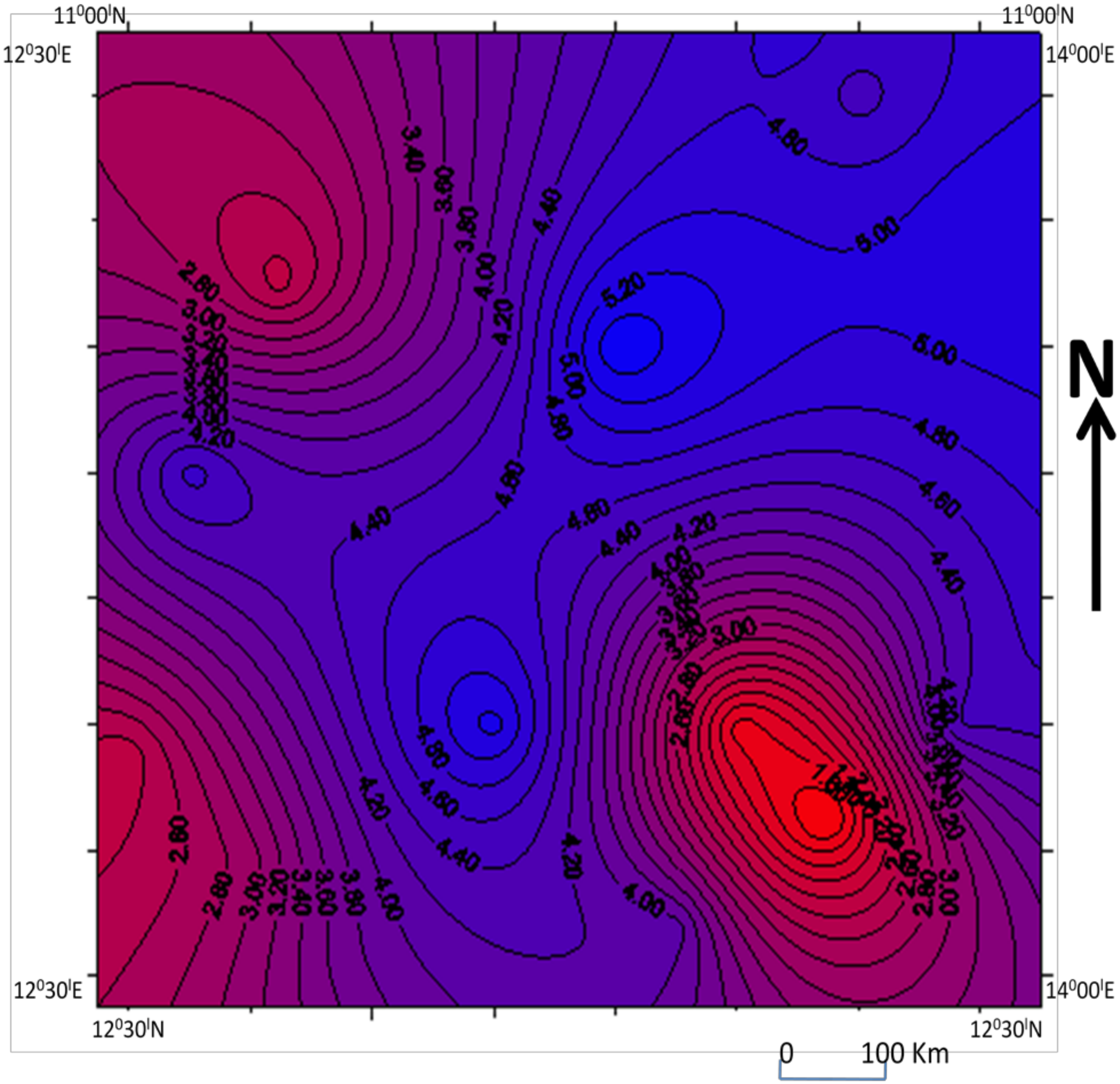

Figure 5. Basement topographic map of the study area (contour interval~0.2km).

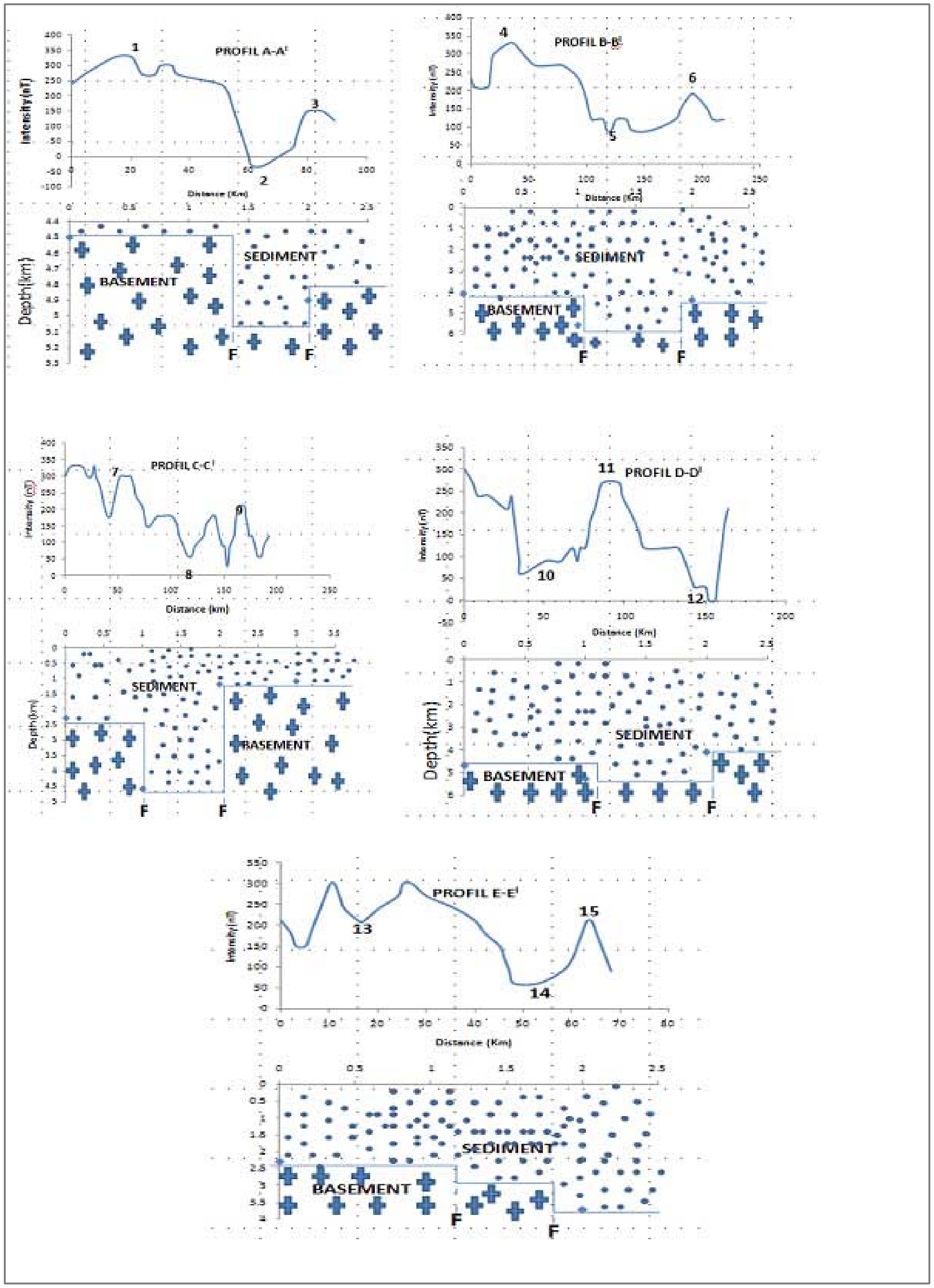

Figure 6. Geological model sections for some anomalies.

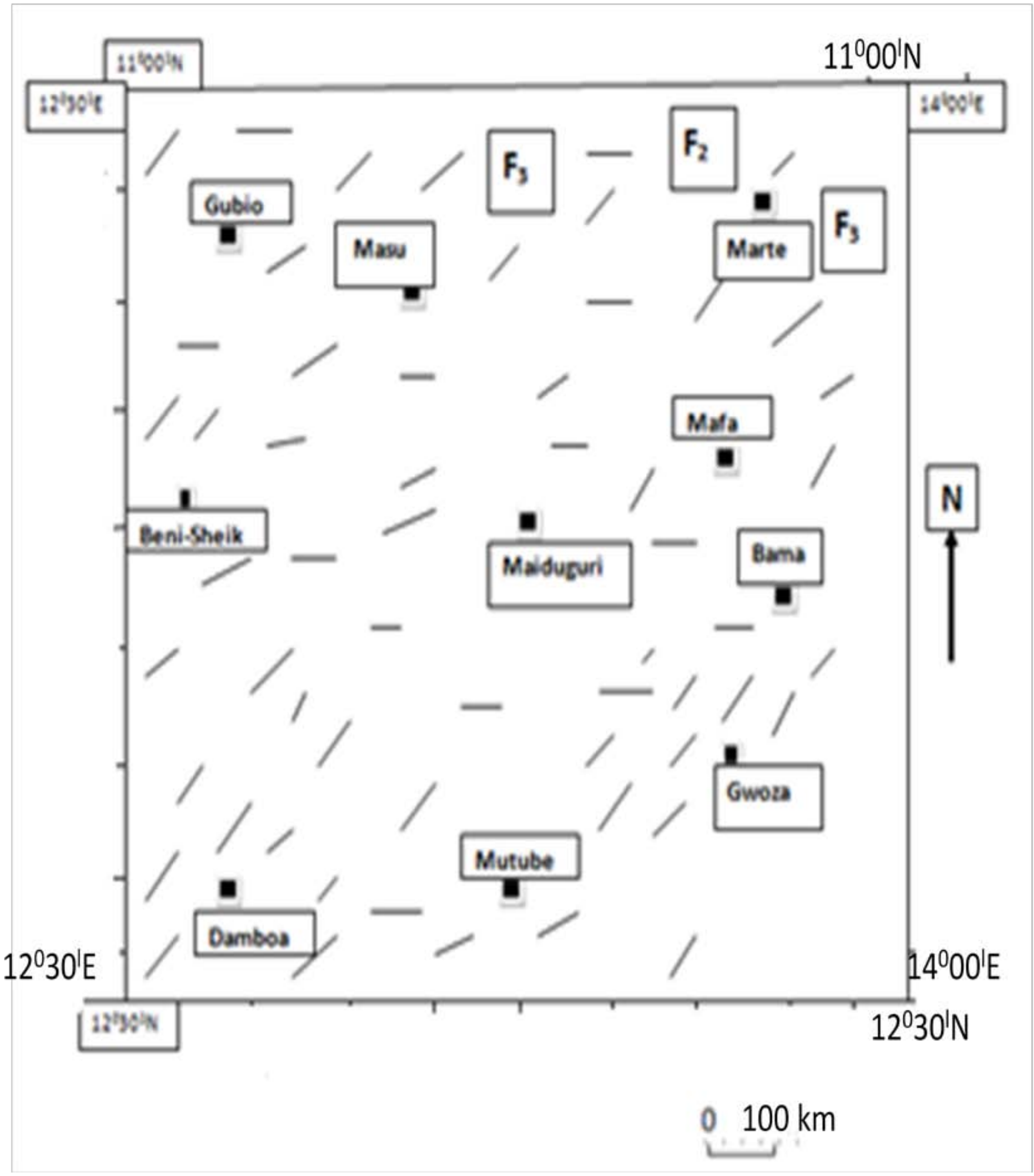

Figure 7. Magnetic lineament map of the study area.

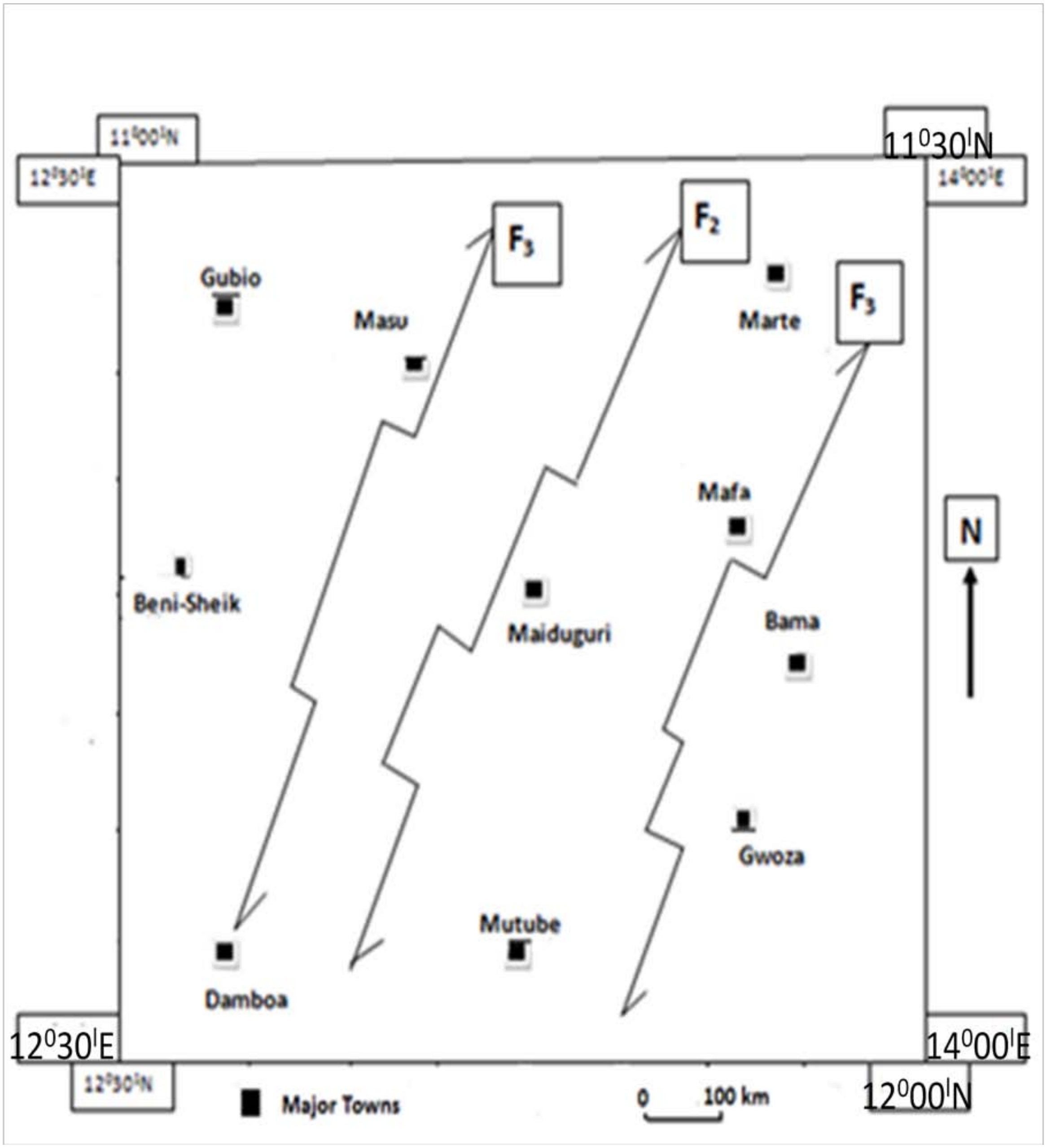

Figure 8. Fault pattern within the study area.

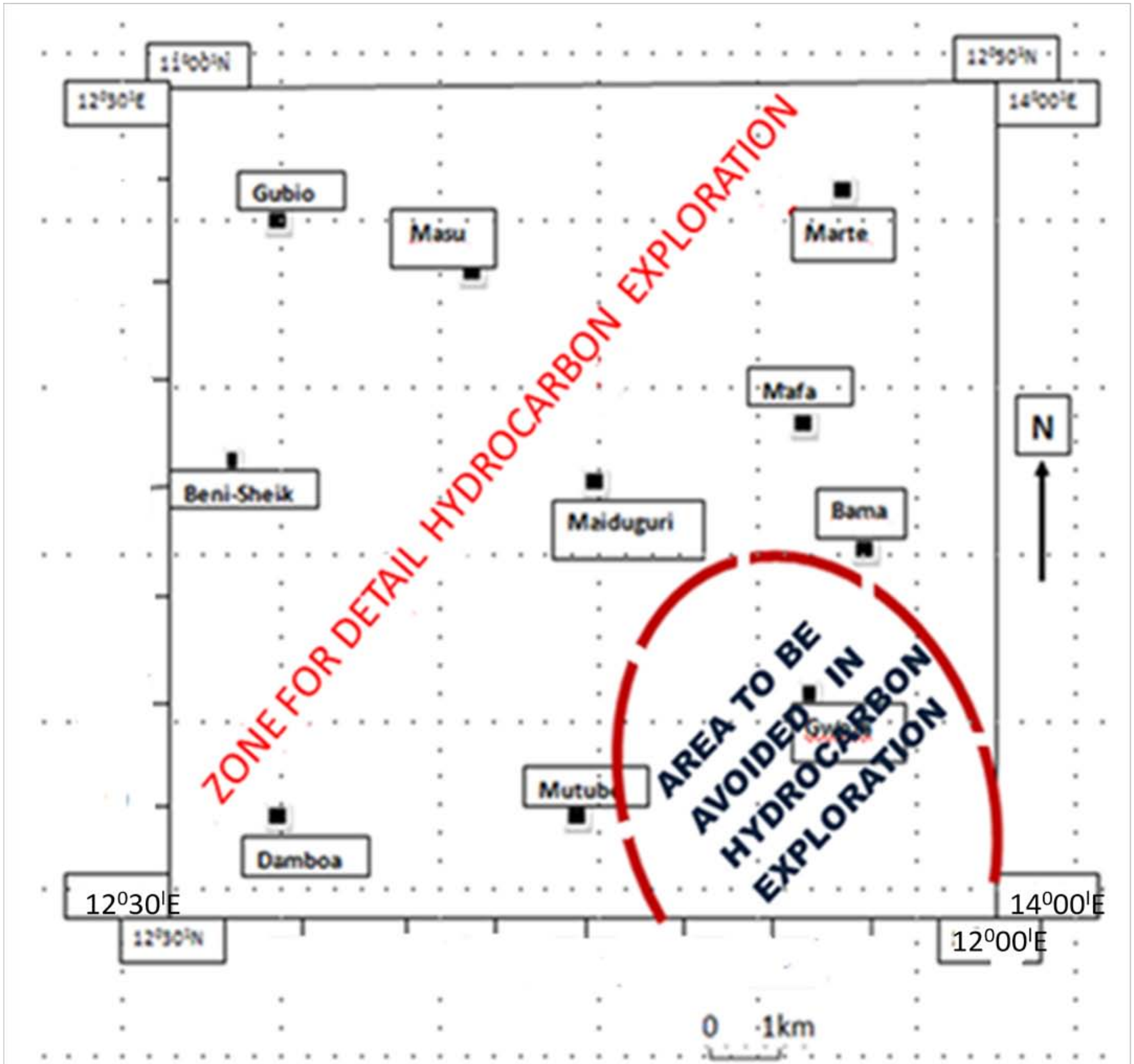

Figure 9. Area isolated for future hydrocarbon exploration.