

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 7, July 2018

Structural Interpretation of Northern Sokoto Basin, Using Airborne Magnetic Data

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ABSTRACT: Analysis of high resolution aeromagnetic data was carried out to evaluate the structural complexity of Sokoto Basin, Northern Nigeria. The total magnetic intensity data covering the basin were processed and filtered using First vertical derivative (FVD) and Horizontal gradient (HG) filters. The FVD and HG were computed to enhance faults, fractures and folds. Ten major fault systems were defined trending majorly in the NE-SW direction with minor NW-SE trends. The lineament of the area was extracted and plotted to define the major trends of both major and minor structures. The lineament map and corresponding rose plot show a dominate NE-SW trend with minor NW-SE, EW and NS structures within the study area. The structural complexity was computed using the lineament map. The lineament density map shows that the eastern part of Gwadebawa, Jiga Birne, Jega, Wamako, Sokoto, Raka, Gayawa, Manu, Giden Madi, Matona, Talata Mafara, Moriki, Gada, Dakko and Baban Baki are intensely deformed. Kuka, Birnin Kebbi, Kaingwa, Binji, Satuka, Tureta, Rabah, Isa, Sabon Birni and eastern part of Raka are moderately deformed; and Satuka, Arbkwe, Bui, Kuka, Botawa, Binji, Sabon Birni, southern part of Tureta and eastern part of Manu are less deformation. Interpretation of the structural complexity yields that Arbkwe, Bui, Kuka, Botawa, Binji, Sabon Birni, southern part of Tureta, eastern part of Manu, Kuka, Birnin Kebbi, Kaingwa, Binji, Satuka, Tureta, Rabah, Isa and eastern part of Raka have structural deformation suitable for the formation of structural traps.

KEYWORDS: Sokoto, Kebbi, Aeromagnetic, First Vertical Derivative, Horizontal Gradient, Hydrocarbon, Exploration, Structures, Lineament.

I. INTRODUCTION

The Iullemeden Basin is an intracratonic epeirogenesis basin which extends from the crystalline areas of Adrar des Iforas, the Ahaggar and Aïr (Niger Republic) in the north to the Gusau-Kano area (Nigeria) in the south. It covers a total land area of over 700,000 km². The Sokoto Basin is an embayment of the Iullemeden Basin and is located at the southeastern part of the Iullemeden Basin and northeast of Nigeria.[1] Sokoto Basin is one of the young (Mesozoic – Tertiary) inland cratonic sedimentary basin of West Africa.[2], [3] The basin like other intra-continental basins of the region and African continent in general developed by epeirogenic warping of stretching and rifting of technically stabilized crust. These movements commenced around the beginning of the Paleozoic and continued upper cretaceous and more responsible for the south western propagation of sediments deposited within the basin.[4], [5]

Since the pioneering work of [6], there have been three different detailed stratigraphical classifications of sediments in the area. [7], [8], [5] The sediments of the Iullemeden Basin were accumulated during four main phases of deposition. [3] Overlying the Pre-Cambrian Basement unconformably is the Illo and Gundumi Formations which is made up of grits and clays, constitute the PreMaastrichtian “Continental Intercalaire” of West Africa. They are overlain unconformably by the Maastrichtian Rima Group (Taloka and Wurno Formations), consisting of mudstones and friable sandstones, separated by the fossiliferous, shelly Dukamaje Formation. The Dange and Gamba Formations (mainly shales) separated by the calcareous Kalambaina Formation constitute the Paleocene Sokoto Group. The overlying continental Gwandu Formation forms the Post-Paleocene Continental Terminal. These sediments dip gently and thicken gradually towards the northwest.

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The geological map of the Sokoto Basin is shown on Figure 1. The study area is located in the Northwestern part of Nigeria. It is bounded in the north and south by Latitudes 10.00 °N and 12.00 °N and east and west by Longitudes 3.50 °E and 7.00 °E respectively. It covers a total surface area of about 55,963 km². It covers three states within the northeastern part of the country which are Sokoto, Kebbi and Zamfara states.

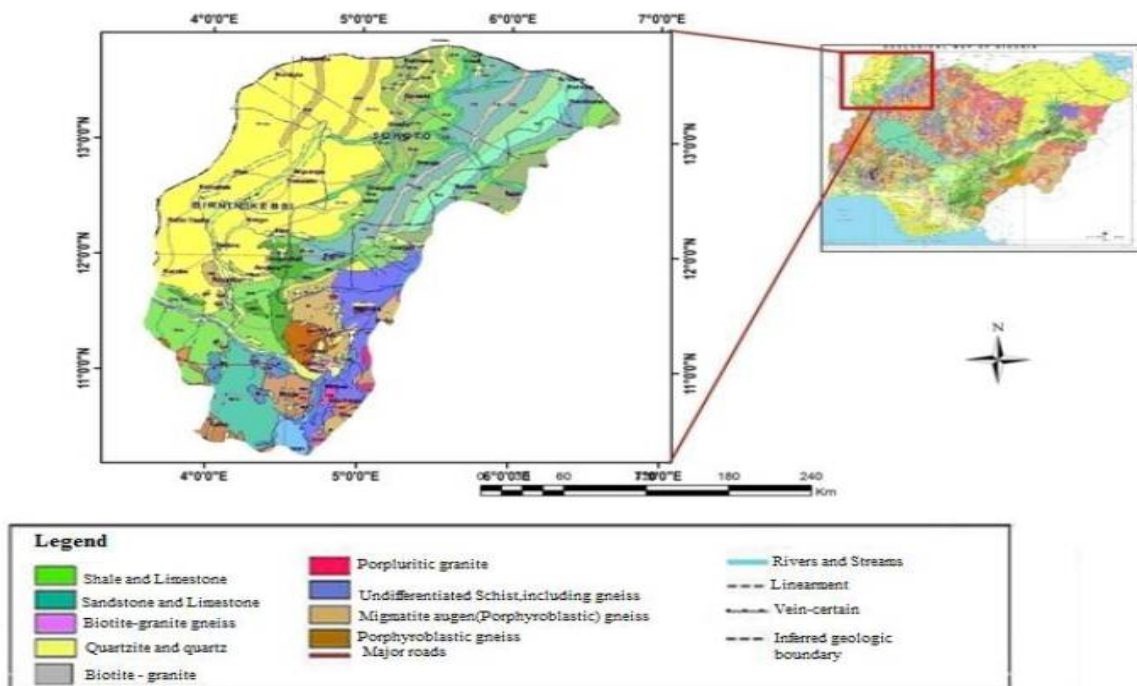


Figure 1: Geologic map of Sokoto Basin (Adapted from Nigerian Geological Survey Agency, 2006).

Previous geophysical work done within the study area [9], [3], [10], [11], [12] dwelt more on the depth to basement and sediment thickness within the basin using source parameter imaging analysis of aeromagnetic method. This work used the recent high resolution aeromagnetic data acquired by Fugro Airborne Survey over Nigeria with the aim to evaluate the structural complexity of sediments within the Northern part of the Sokoto Basin which was defined sediment-thickness suitable for hydrocarbon generating by [11].

II. MATERIALS AND METHOD

Data Acquisition

The aeromagnetic dataset used for this study is from the high-resolution airborne survey coverage in Nigeria carried out by Fugro Airborne Survey at 826,000 km along a series of NW – SE flight lines of magnetic surveys flown at 500 m line spacing and 80 m terrain clearance in 2009 and was obtained from the Nigerian Geological Survey Agency. The parameter measured was the total magnetic field. It consists of seventeen (17) square blocks of map sheets (1, 2, 3, 4, 5, 8, 9, 10, 11, 12, 13, 26, 27, 28, 29, 30, and 31) of square block which represents a map on the scale of 1:400,000.

Data Processing and Enhancement

First Vertical Derivative

Derivatives (vertical) are based on the principle that the rates of change of magnetic field are sensitive to rock susceptibilities near the ground surface than at depth. First vertical derivative is physically equivalent to measuring the magnetic field simultaneously at two points vertically above each other, subtracting the data and dividing the result by

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the vertical spatial separation of the measurement points.[13] The first vertical derivative was obtained from Laplace equation which is used to describe the magnetic potential field (U) thus,

$$\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2} + \frac{\partial^2 U}{\partial z^2} = 0 \tag{1}$$

$$\text{but, } -\text{grad } U = T \tag{2}$$

Hence,

$$-\frac{\partial T}{\partial x} - \frac{\partial T}{\partial y} - \frac{\partial T}{\partial z} = 0 \tag{3}$$

Therefore,

$$\frac{\partial T}{\partial z} = -\left(\frac{\partial T}{\partial x} + \frac{\partial T}{\partial y}\right) \tag{4}$$

Where, U = magnetic potential field

T = total magnetic field vector

Rewriting equation (4) in numerical form we have,

$$-\frac{\partial T}{\partial x} = \left[\frac{T(x+\Delta x) - T(x)}{\Delta x} + O(\Delta x)\right] \tag{5}$$

$$O(\Delta x) = \text{error terms} \tag{6}$$

$$-\frac{\partial T}{\partial x} = \left[\frac{T(x+\Delta x) - T(x)}{\Delta x}\right] \tag{7}$$

Similarly,

$$-\frac{\partial T}{\partial y} = \left[\frac{T(y+\Delta y) - T(y)}{\Delta y}\right] \tag{8}$$

Therefore,

$$\frac{\partial T}{\partial z} = -\left[\frac{T(x+\Delta x) - T(x)}{\Delta x}\right] - \left[\frac{T(y+\Delta y) - T(y)}{\Delta y}\right] \tag{9}$$

Equation (9) was applied on TMI grid to produce the first derivative map.

Δx = grid interval in x – direction

Δy = grid interval in y – direction

Horizontal Gradient

This Calculates the n^{th} horizontal derivatives in the x and y directions. This process involves a phase transformation as well as an enhancement of high frequencies. Horizontal gradient method is least susceptible to noise in the data. The phase transformation generally has the result of producing anomaly peaks approximately located over the edges of wide bodies and the enhancement of the high frequencies sharpens these peaks to increase the definition of the body edges. This quality of horizontal derivatives is used to map body outlines.[14], [15] Horizontal gradient is given as,

$$\text{horizontal gradient } (HG_{x,y}) = \left[\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2\right]^{1/2} \tag{10}$$

where $\frac{\partial T}{\partial x}$ and $\frac{\partial T}{\partial y}$ are the horizontal gradients of the magnetic field in the x and y directions, respectively.

Horizontal gradient of the TMI was carried out in order to identify contact areas (lateral variation), infer faulted areas, and enhance the high frequency, short wavelength anomalies.

III. RESULTS AND DISCUSSION

First Vertical Derivative (FVD) enhances and sharpens up anomalies over causative bodies and tends to reduce complexity, allowing a clearer imaging of the causative structures. The FVD map (Figure 2) shows inferred faults, fractures, folds, contacts and to some extent the shape of some lithologic contacts which indicate structural features.

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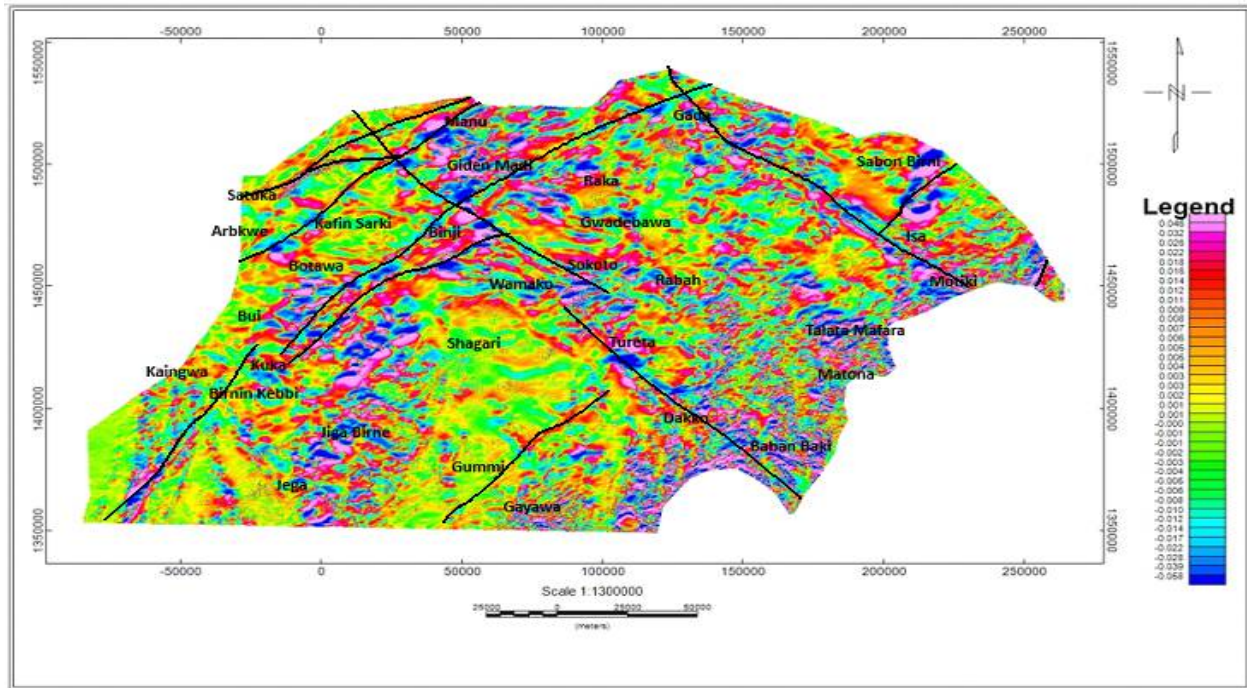


Figure 2: First Vertical Derivative (FVD) Map of the Study Area Showing interpreted Fault

Prominent regional fault and fracture systems were observed Satuka, Botawa, Isa, Moriki, Gummi, south of Kaingwa, Kuka, Dakko and western Shagari (Black polygon in Figure 2). These structures trend majorly NE-SW with Minor NW-SE trend. The two longest faults have lengths 196 km and 141 km, stretching from Kuka to Gada and Moriki to Gada respectively. One of the structures at the western part of the study area stretches for about 87 km from Gaya (Niger) to Kuka and the second stretches for about 81 km. At the NW part of the study area, the two major fault systems that were interpreted stretches from Satuka to Manu and Kafin Sarki to Manu with lengths of about 86 km and 109 km respectively. The fault at the south stretches for about 86 km within the study area from Gayawa to Tureta; this structure looks to be continuous to the southern part of Sokoto Basin. A NW-SE trending fault running from Baban Baki to Wamako cuts across NE-SW structure at the northeastern part of the study area.

The FVD map helped to attenuate broad, more regional anomalies and enhanced local, more subtle magnetic responses because of its sensitivity to shallow magnetic source bodies and contacts [15], [16]. High frequency bodies are observed at Manu, Giden Madi, Binji, Jiga Birne, Jega, Matona, Talata Mafara, Moriki, Gayawa, Dakko, Wamako, and Gada. The bodies are defined as shallow surface intrusives associated with the study area.

The Horizontal Gradient (HG) is a simple method to estimate linear structures such as contacts and faults from the aeromagnetic data. This enhancement is also designed to look at fault and contact features [17]. It is complementary to the first vertical derivative enhancement in that it produces a more exact location for faults than the vertical derivative. The Horizontal Gradient anomaly map for the study area is shown in Figure 3.

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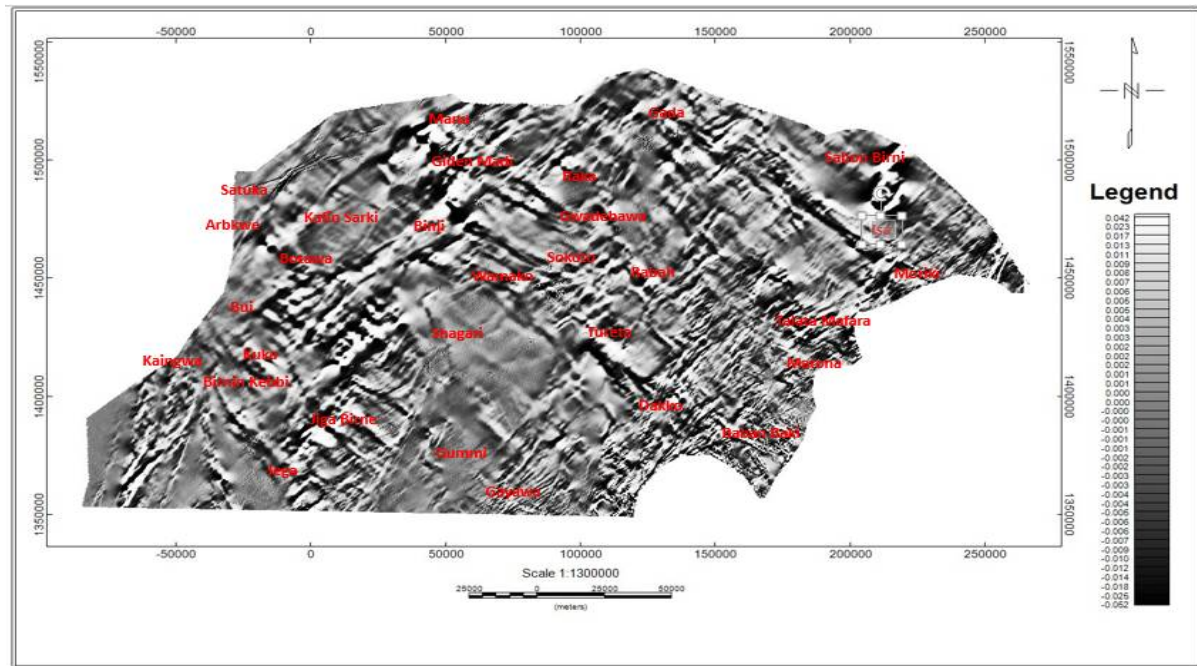


Figure 3: Horizontal Gradient (HG) Map of the Study Area

The Horizontal Gradient anomaly map shows the highest value of magnetic anomalies are found elongated from NE to the SW direction at Manu, Giden Madi, Binji, Jiga Birne, Satuka, Kaingwa, Sokoto, Jega, Matona, Talata Mafara, Moriki, Gayawa, Dakko, Wamako, and Gada. NW-SE bodies are observed at Gwadebawa, Jiga Birne, Jega, Tureta, Wamako, Sokoto, Isa and Gada. These lineaments are well matched with the known trend of the Sokoto basin. The HG map better enhance the faults within the basin, hence making it more visible and interpretable.

Lineaments are linear features on a landscape which express the underlying geological structures such as faults, joints, and arched zones or even geological contacts and could be of regional extent usually in linear or curvilinear, continuous or discontinuous over an entire length [18]. The lineaments are marked in black ticks while dykes and sills are marked in arched curves. The orientation and lengths of the lineaments extracted from the Vectorization lineament map (Figure 4) were displayed in a rose diagram to analyze the spatial distribution of lineaments. The rose diagram (Figure 5) shows that the structures within the study area trend majorly NE-SW and EW with minor NW-SE, N-S directions. The EW trending structures are found majorly at the eastern part of the study area which is associated with the contacted sediments and basement rocks at the boundary between the Sokoto Basin and the Northcentral Basement Complex of Nigeria. The defined trends are in agreement with earlier work by [19] on the Sokoto Basin.

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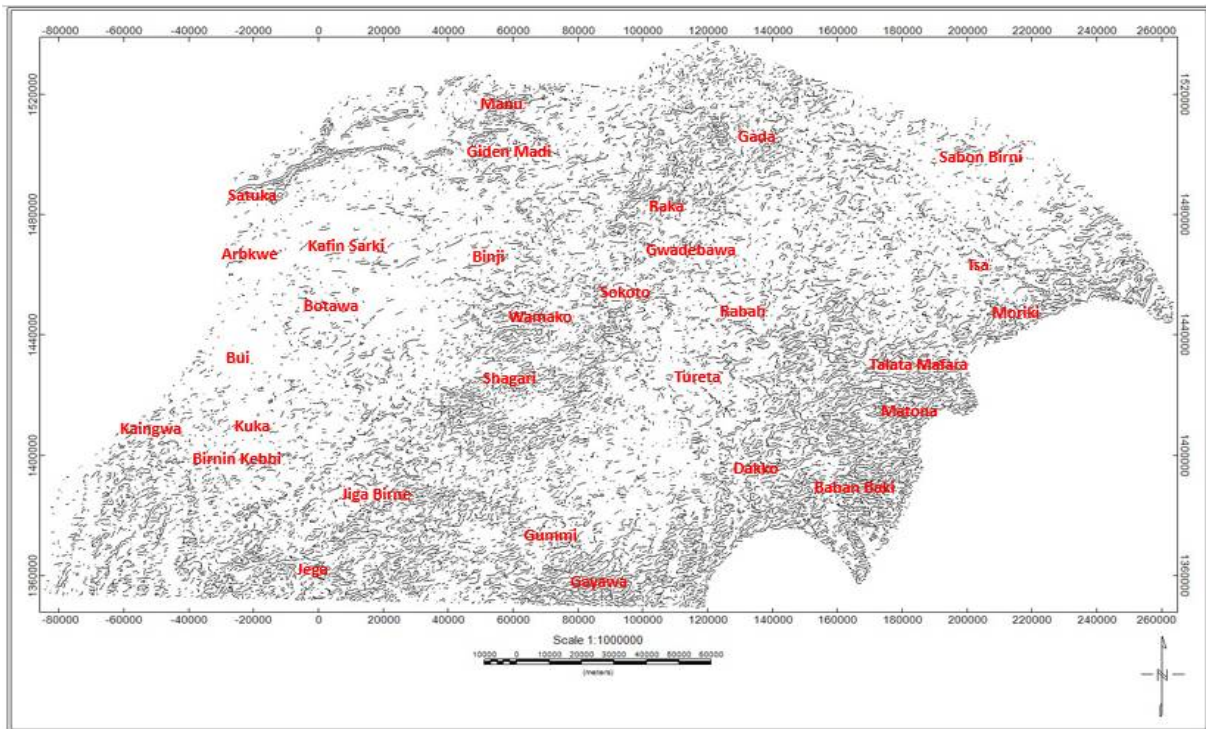


Figure 4: Lineament Map of the Study Area

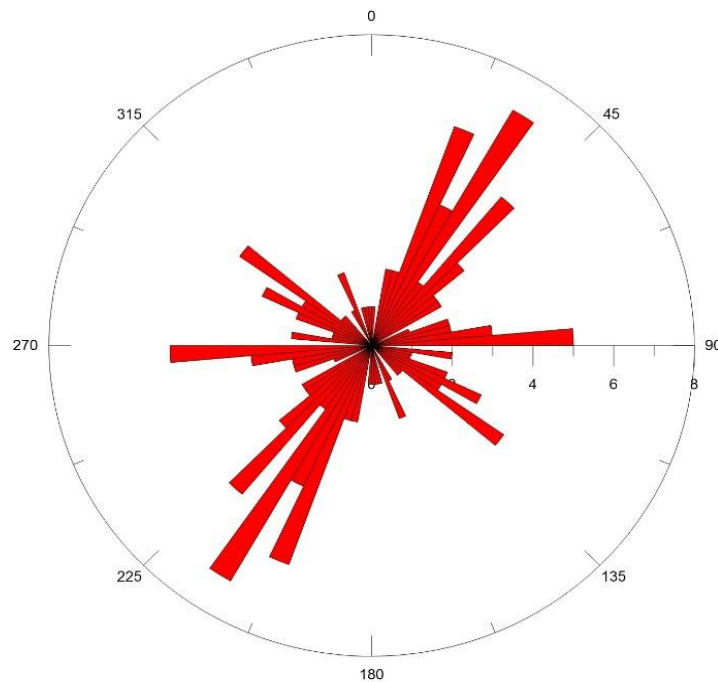


Figure 5: Rose Diagram of the Study Area

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The Intensity of deformation is evaluated using the lineament density map (Figure 6). Areas that have high lineament density indicates high deformation and closure to basement rocks, while areas with less lineament density indicate low deformation with plane grounds mainly composed of sediments [20]. Areas of intense deformation include eastern part of Gwadebawa, Jiga Birne, Jega, Wamako, Sokoto, Raka, Gayawa, Manu, Giden Madi, Matona, Talata Mafara, Moriki, Gada, Dakko and Baban Baki. Moderate deformation is observed at Kuka, Birnin Kebbi, Kaingwa, Binji, Satuka, Tureta, Rabah, Isa, Sabon Birni and eastern part of Raka. Low deformation is observed at Satuka, Arbkwe, Bui, Kuka, Botawa, Binji, Sabon Birni, south of Tureta and eastern part of Manu.

Structural complexity is important to formation of traps for hydrocarbon accumulation. High deformed sediments could lead to the destruction of stratigraphic traps and enhance the occurrence of structural traps but due to its intensity it could yield leakage of traps due to micro faults or total destruction of structural trap. Hence, moderately deformed areas host better structural traps. Arbkwe, Bui, Kuka, Botawa, Binji, Sabon Birni, southern part of Tureta, eastern part of Manu, Kuka, Birnin Kebbi, Kaingwa, Binji, Satuka, Tureta, Rabah, Isa and eastern part of Raka show structural complexity good enough to favour the formation structural traps within the area.

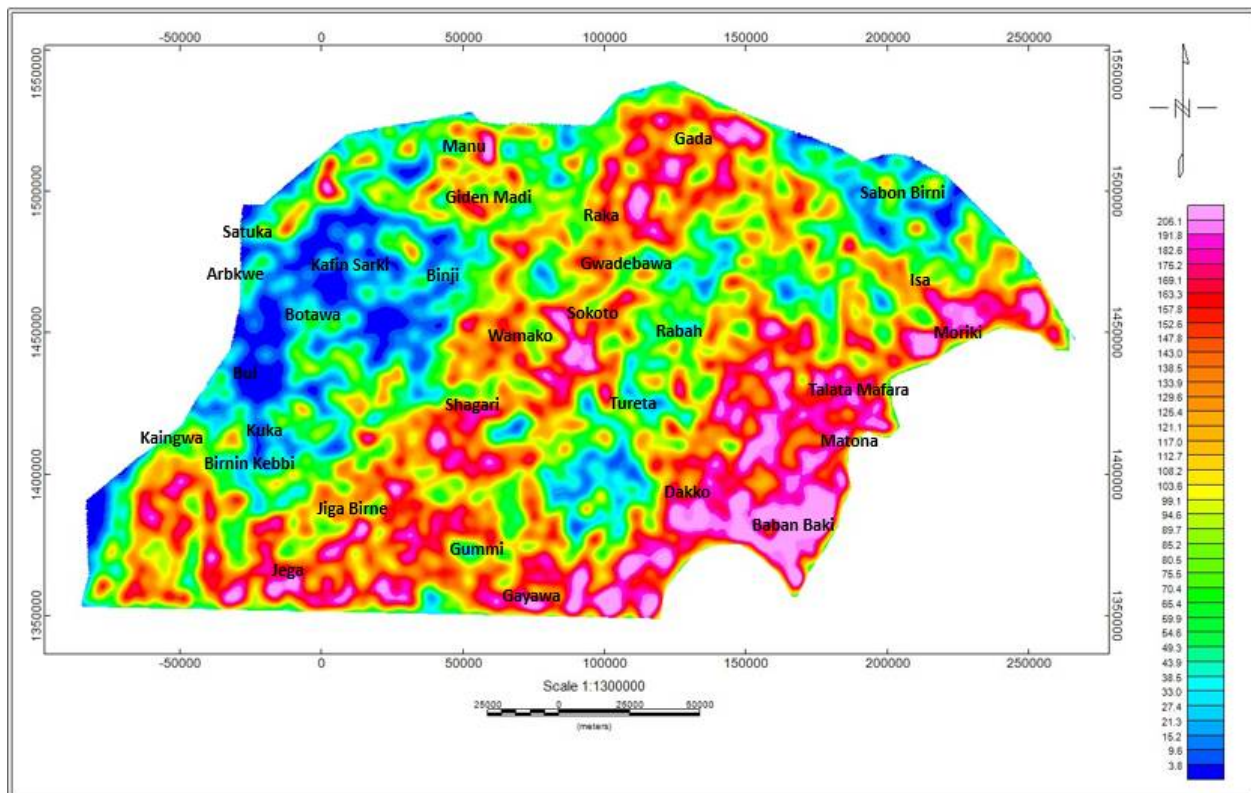


Figure 6: Lineament Density Map of the Study Area

IV. CONCLUSION

The aeromagnetic data covering northern part of Sokoto Basin was processed and filtered using first vertical derivative and horizontal gradient maps. These were done to enhance the structures within the study area. Interpretation of the first vertical derivative maps defined ten major fault systems within the study area, with dominate trend in the NE-SW direction and with minor NW-SE trends. The horizontal gradient map better enhanced the faults and fractures in the study area. It improved the visibility of the structures at Jiga Birne, Jega, Gada, Wamako, Birnin Kebbi, Tureta and Dakko.

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The structural complexity of the study area shows intense deformation at eastern part of Gwadebawa, Jiga Birne, Jega, Wamako, Sokoto, Raka, Gayawa, Manu, Giden Madi, Matona, Talata Mafara, Moriki, Gada, Dakko and Baban Baki. It shows moderate deformation at Kuka, Birnin Kebbi, Kaingwa, Binji, Satuka, Tureta, Rabah, Isa, Sabon Birni and eastern part of Raka. Low deformation is shown at Satuka, Arbkwe, Bui, Kuka, Botawa, Binji, Sabon Birni, southern part of Tureta and eastern part of Manu.

The analysis shows that Arbkwe, Bui, Kuka, Botawa, Binji, Sabon Birni, southern part of Tureta, eastern part of Manu, Kuka, Birnin Kebbi, Kaingwa, Binji, Satuka, Tureta, Rabah, Isa and eastern part of Raka have structural deformation suitable for the formation of structural traps.

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