IJSRM
INTERNATIONAL JOURNAL OF SCIENCE AND RESEARCH METHODOLOGY
An Official Publication of Human Journals

Human Journals
Research Article
June 2019 Vol.:12, Issue:4

2D-Modeling of the Major Structures within the Chad Basin, Nigeria, from Aeromagnetic Data

IJSRM
INTERNATIONAL JOURNAL OF SCIENCE AND RESEARCH METHODOLOGY
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Submission: 26 May 2019
Accepted: 31 May 2019
Published: 30 June 2019

HUMAN JOURNALS

www.ijsrm.humanjournals.com

Keywords: Aeromagnetic Data, 2-D modeling, Structures, lineaments (faults, fractures and discontinuities)

ABSTRACT

2-D modeling of the major Structures within the Chad basin, Nigeria, was carried out using Vertical derivative, Horizontal derivative and 2D-Modeling. The study area is bounded by latitude 12°N to 13.5°Nand longitude 12.5°E to 14°E. It is covered by nine high resolution total magnetic intensity data sheets covering a total area of 27,255 square kilometers. The result from the Vertical derivatives shows that the major magnetic features (like faults and fractures) delineated were oriented in the NE-SW direction. It also shows different rock types which might be granite intrusion or basaltic intrusion. Isolated anomalies with high amplitude, for example at the edge of Zari are a large body with high amplitude and it has been identified as a Basaltic body. It is also observed that the low intensity structure (blue) at the bottom of the TMI map has disappeared from the derivatives is an indication of signatures from deeply seated structures. The northern and southern portion show similar characteristics attributed to surface and near surface intrusion of magnetic rocks (biotite, granite, undifferentiated shale and sandstone). Also from the result of horizontal derivatives, the turning points in the magnetic values are clearly shown which defined the edge of the anomalies. Regions with high susceptibility per meter were noted as deeper depth and regions with low magnetic source rocks as shallow depths, these are around Zari and Karriwa at the upper part and southeastern corner of the area precisely around Marte and below Monguno. Result from the Models shows that the Susceptibility of the sediment is generally zero except in isolated cases such as in profile 1 and 3 where the profile passes through a highly susceptible basaltic body which slightly influences the susceptibility of the sediments. The Susceptibility of basement rock varies from 0.002 to 0.004 emu cm^{-1}.

INTRODUCTION

Over the years, the search for subsurface natural resources especially mineral deposits and hydrocarbon potential has become a major concern to geophysicists, geologists and exploration scientists. The Earth's subsurface contains natural resources, which include hydrocarbon, mineral deposits, rocks, underground water and so on (Dobrin, 1976).

The study area is the Nigerian section of the Chad Basin (also known as Borno Basin), is a sedimentary basin situated in the North-Eastern part of Nigeria (Figure 1). The area is bounded by Latitude 12^0N to 13.5^0N and Longitude 12.5^0E to 14^0E, it is a plain which is devoid of rock outcrops and is covered by superficial deposits of sand and clay.

The climate in the study area is semiarid in the south and arid in the north. The annual rainfall over the entire basin is 320 mm varying from 1,500 mm in the southern part of the region to less than 100 mm in the northern parts. The basin contains an upper aquifer of early Pleistocene alluvial deposits. The area is in the sudano-sahelian ecological zone of the north-eastern part of Nigeria between Borno and Yobe state. The typical vegetation on sandy position is the Brachiaria-type. A part of Brachiaria, Xantholenca species like Borreria Chaetocephala, Leucas Mortinicensis, Eragrostis tremula and Ceratotheca Sesamoides can be found in the herb layer. The presence of species like Zornia glochidiata indicates the influence of cattle grazing. The shrub layer is dominating by Balanites aegyptiaca, Bauhinia rufescens and Calatropis Procera (Schnell, 1976) and (Grouzis, 1988). The Adamawa Plateau, Jos Plateau, Biu Plateau, and Mandara mountains lie to the South. To the west, the basin is separated by a watershed from the Niger River, and to the south, it is separated by a basement dome from the Benue River. Further east, watershed separate it from the Congo Basin and the Nile.

The aim of this survey is to model the major structures within Chad Basin Nigeria, using 2-D Modeling. In addition, some of the works were carried using land survey measurement, which could be restricted in some areas due to differences in topography, thus not giving adequate information of the area. Therefore, there is need to use a high resolution airborne data which will not only provide the capability of traversing regions that were otherwise difficult or impossible to cover by land survey geophysical methods but will produce a much more detailed and better resolved picture of the geologic structures in the area. Hence, the result from the work could be used to suggest portions of hydrocarbon and mineral presence in the area as well as the possible depths of assessment.

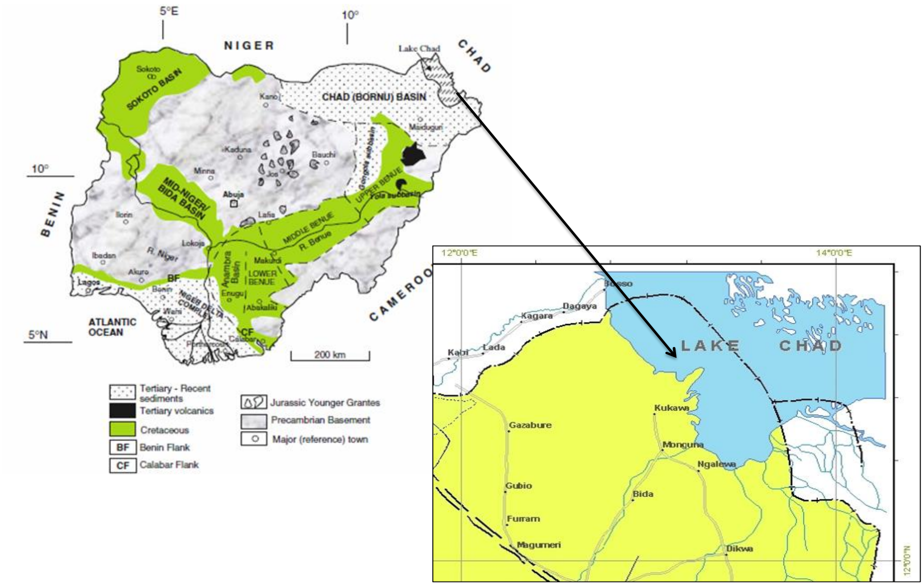

Figure.no. 1 Location of the Study Area on Geological map of Nigeria adopted from (Obaje, 2009).

2. GEOLOGY OF BORNO BASIN

The Nigerian Chad Basin is one of Nigeria's inland basins located in the northern part of the country. It represents about one-tenth of the basin and has a broad sediment-filled depression spanning northeastern Nigeria and adjoining parts of the Republic of Chad (Mohammed, 2015). The basin belongs to Tertiary-Recent sediments (figure 1&2) and later rift basins in Central and West Africa whose origin is related to the opening of the South Atlantic (Obaje et al., 1998; Genik, 1992). The Chad Basin belongs to the African Phanerozoic sedimentary basins whose origin is related to the dynamic process of plate divergence. Notable exceptions, however, are the deformed basinal sequences of the Paleozoic fold belts of Morocco and Mauritania and the Tindouf and Ougarta basins which are Paleozoic successor basins. It is an intracratonic inland basin covering a total area of about 2,335,000km^2 with Niger and Chad Republics sharing more than half of the basin (Burke et al., 1972, Petters, 1978). The area is characterized by a variety of lithological units, which include many types of igneous, metamorphic and sedimentary rocks. According to Avbovbo et al., (1986), the basement - involved faults resulted in the genesis of horst, grabbers and similar structures. Many of the faults within the basin terminate below the Createaceous - Tertiary boundary unconformity. The main factors responsible for the sedimentation within the study area are the progressive sea level rise from Albian-Maastrichtian leading to worldwide transgression, regression and local tectonics (Igwesi and Umego, 2013 and Petters, 1978). A

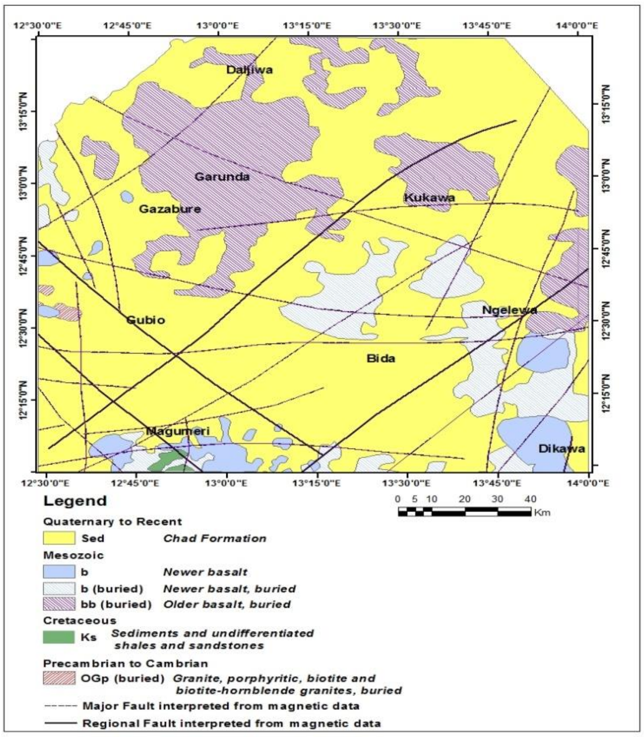

Figure no. 2 Geology Map of the Study area, (Nigerian Geological Survey Agency)

3. MATERIALS AND METHODS

The material employed in this research include Aeromagnetic Magnetic data sheetsZari, Karriwa, Chad Baga, Gazabure, Gudumbau, Monguno,Gubio, Masu, and Marte. Topography Map SRTM (Shuttle Radar Topographic Mission Grid), Detail Geology Map and Computer software's (Oasis Montaj 9.0 and Suffer 11) were used.

3.1 Source of Aeromagnetic Data

Data acquisition: The 2009 IGRF corrected Total Magnetic Intensity data was acquired from the Nigeria Geological Survey Agency while Oasis Montaj 9.0 and Suffer 11 software were used for the analysis. These New data sets has been generated from the largest airborne geophysical survey ever undertaken in Nigeria, which is helping to position the country as an exciting destination for explorers. This survey which was conducted in two phases between 2005 and 2010 was partly financed by the Federal Government of Nigeria and the World

Bank which was part of a major project known as the Sustainable Management for Mineral Resources Project. All of the airborne geophysical work data acquisition, processing and compilation was carried out by Fugro Airborne Surveys. The survey acquired both magnetic and radiometric data. The recent survey has a Tie-line spacing of 500m, flight line spacing of 2km and terrain clearance of 80m using TEMPES system. Compared with the 1970's survey which has a Tie-line spacing of 2km, flight line spacing of 2km and flying altitude of 150m, these levels of survey are intensive and detailed for the objectives of this research. Data covering the Nineaeromagnetic sheets numbered 23 (Zari), 24 (Karriwa), 25 (Chad Baga), 44 (Gazabure), 45 (Gudumbau), 46 (Monguno), 66 (Gubio), 67 (Masu), and 68 (Marte) was acquired from the Nigerian Geological Survey Agency, 31, ShetimaMongono Crescent Utako District, Garki, Abuja. (Figure no. 2).

3.2 METHODOLOGY

3.2.1 Horizontal and vertical Derivatives

The horizontal derivative was applied to sharpen the edge of anomalies and enhance shallow features, the resultant map is much more responsive to local influence than to broad or regional deep seated anomalies.

Derivative in the X direction is given by the algorithm,

$$L\ (\mu) = (\mu ii)^n \qquad (1)$$

Where n is the order of differentiation, μ represents the X component of the wave number,

and ii $=\sqrt{-1}$.

While the derivative in the Y direction is given by

$$L\ (V) = (Vi)^n \qquad (2)$$

where n is the order of differentiation, V represents the Y component of the wave number and

$$i=\sqrt{-1} \qquad (3)$$

The vertical derivative is commonly applied to total magnetic field data to enhance the shallowest geologic sources in the data. As with other filters that enhance the high-wavenumber components of the spectrum, you must often also apply low-pass filters to remove high-wavenumber noise.

$$L(r) = r^n \qquad (4)$$

where n is the order of differentiation. and r is the wave number (radians/ ground- unit) Note: r=2pk where k is cycles ground unit. Ground unit is the survey ground units used in the grid (e.g. meter, feet etc).

3.3 Modeling of Aeromagnetic Anomalies

This involves making numerical estimates of the depth and dimensions of the sources of anomalies and this often takes the form of modeling of sources which could, in theory, replicate the anomalies recorded in the survey. In other words, conceptual models of the subsurface are created and their anomalies calculated in order to see whether the earth-model is consistent with what has been observed, i.e. given a model that is suitable with the physical approximation to the unknown geology, the theoretical anomaly of the model is calculated (forward modeling) and compared with the observed anomaly. The model parameters are then adjusted in order to obtain a better agreement between observed and calculated anomalies (Talwani and Heitzler, 1964). The modelling technique that was used in this work is a two dimensional (2D) modelling. The program, Gravity/Magnetic System (GMSYS), is an extension available in Oasis montaj version 9.0

4. RESULTS AND DISCUSSION

4.1 Application of Vertical and Horizontal Derivatives

Figure 3 is the TMI reduced to equator map produced with major towns (as the area of study is closer to the equator than the pole). The TMI data was subjected to both Vertical and Horizontal Derivatives in x, y and z direction. Both the x and y derivatives were design to detect structural trend and to enhanced the shallow feature. The vertical derivatives also enable us to locate lineaments at the surface. The derivatives in x, y, and z were obtained from TMI-RTP show in (figure no. 4,5, and 6) respectively. Region with high susceptibility per meter are noted for with magnetic source rocks at shallow depth, these are around Zari and Karriwa at the upper part and at the southeastern corner of the study area precisely around Marte and below Monguno.

Figure 5 shows isolated anomalies with high amplitude for example at the edge of Zari is a large body with high amplitude and this body has been identified as Basaltic body on the geology map (figure 2). Also at the southwestern corner of the study area, precisely on Marte sheet (figure 3) these bodies possess high amplitude due to high magnetic susceptibility or are bodies located at shallow depths. The deep seated structures seen in (figure no.4 and 5) have been overshadowed by the predominant surface features in the derivatives, especially at the western and southeastern part of the study area. It is also observed that the large low intensity structures (in blue) at the bottom of the TMI map (figure no.5) have disappeared from the derivatives, an indication of signatures from deeply seated structures. The northern and southern portion from Latitude 12' 45^{o} to 13' 15^{o} and the Eastern portion from Longitude 12' 30^{o} to 12' 45^{o} show similar characteristics attributed to surface and near surface intrusion of magnetic rocks (biotite, granite, undifferentiated shale and sandstone).

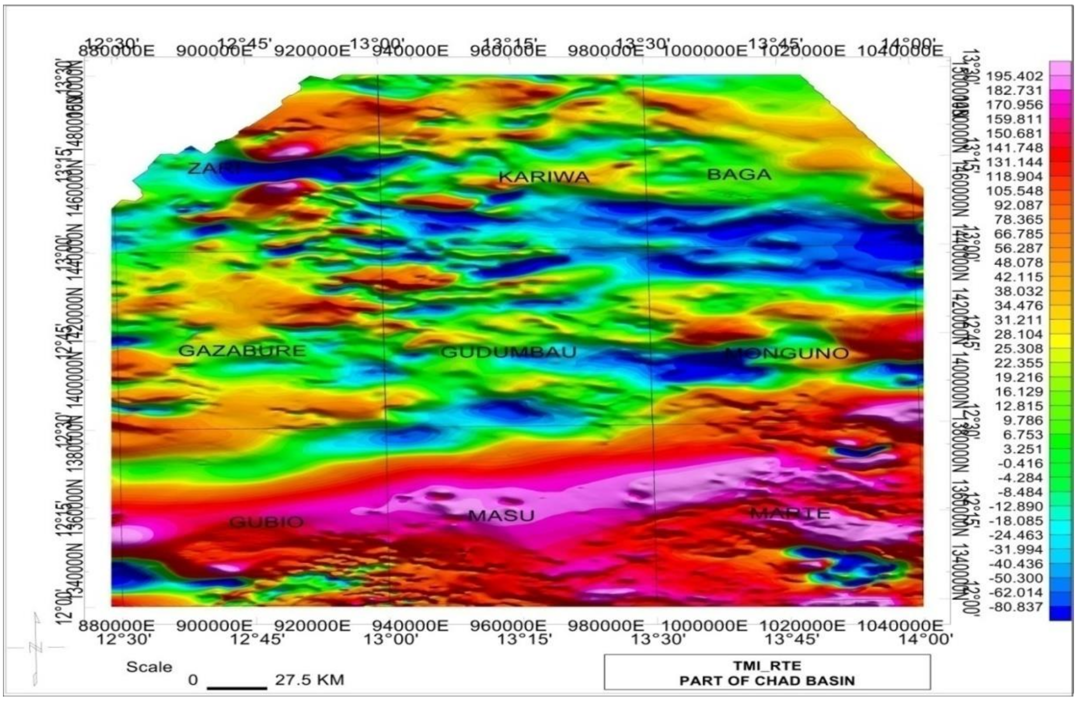

Figure no. 3 Total Magnetic Intensity (TMI) Map of the Study Area with Major Towns.

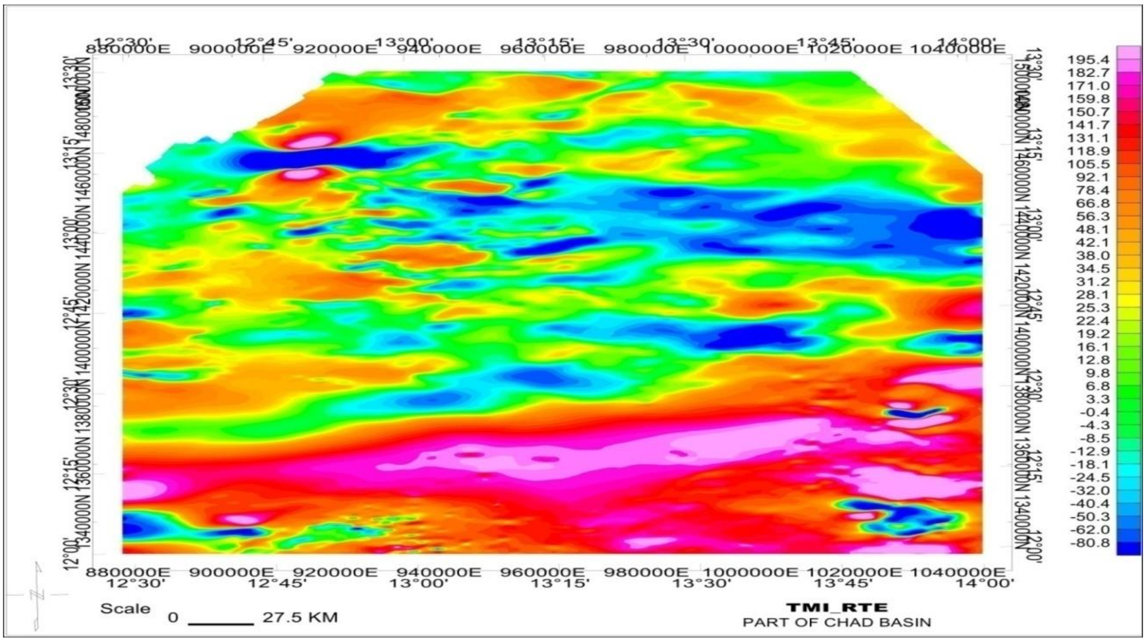

Figure no. 4 Total Magnetic Intensity (TMI) Map of the Study Area Reduced to Equator.

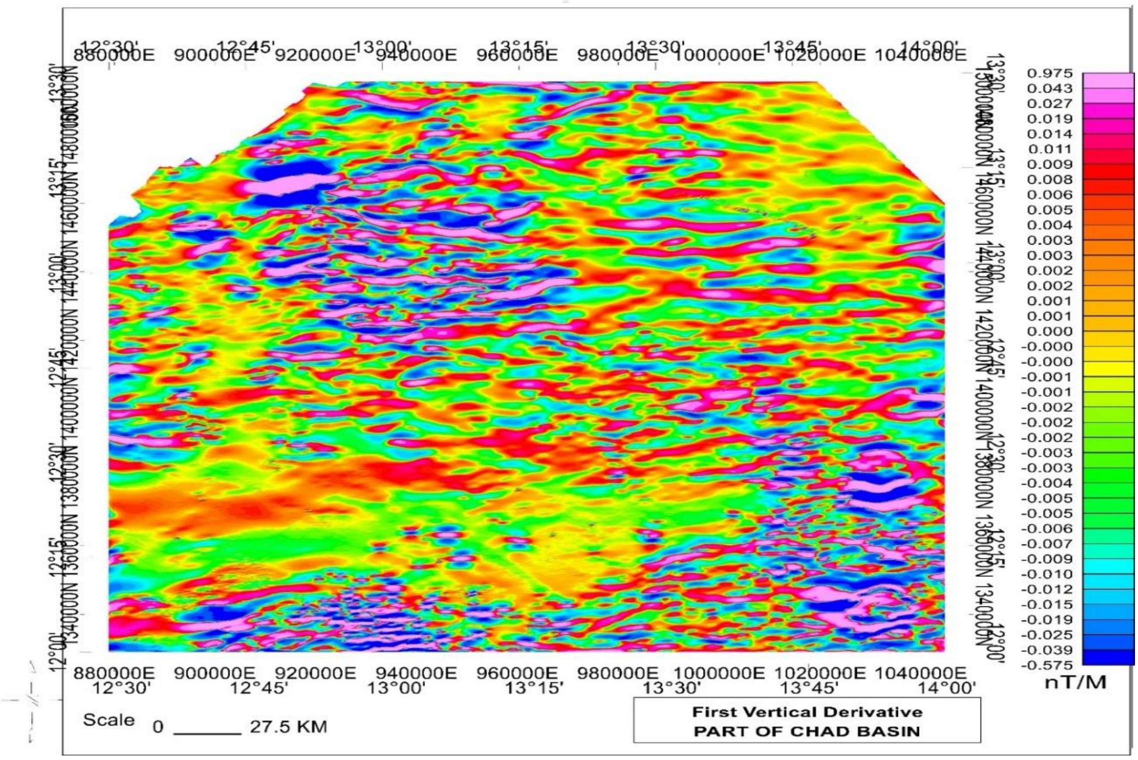

Figure no. 5 First Vertical Derivative Map of the Study Area

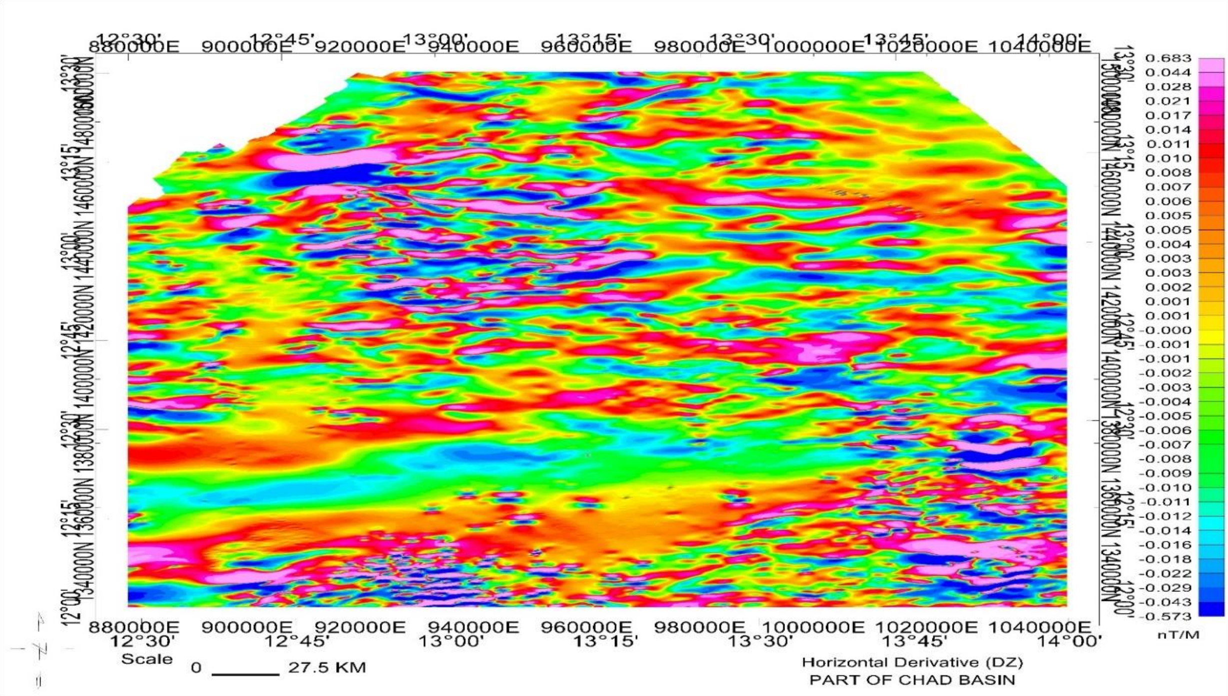

Figure no. 6 Horizontal Derivatives (DZ) Map of the Study Area

4.2 Result of 2-D Modeling

For the purpose of this research four (4) profiles were selected to cut across the major structures identified on the vertical derivative map of the study area. They are labeled profile 1 to profile 4. These four profiles shown on figure 7, were produced from their grids and are stored in a separate database which give the required information on the profile length and the depth of anomalies along the profile.

Four different models are generated using 2D Modeling module from the Oasis montaj package. Moving around between the shape, size of the body, its magnetic susceptibility, magnetization, magnetic inclination and declination, the geologically acceptable model and error margin were obtained.

Each model map consists of two sections:

The first section is the profile section, from which the following information were obtained, The sensor indicates the topography of the area along the profile, it is controlled by the SRTM values, and the distance channel, which gives the total length of the profile, its direction is relative to the direction of the profile on the TMI grid while the depth channel is the vertical distance (Thickness) along the profile. It is controlled by the SPI values and can be adjusted.

The second section is the magnetic response which is obtained from the TMI grid, on this section the black dots represent the observed values in nanotesler (nT) while the thin curved line represents the calculated value in the same unit (nT).

To achieve the required model, the shape, susceptibility, and the strike angle (for basement rocks) are adjusted so that the calculation will match the observed within the region. A good model is achieved when the accuracy level is between 80 to 100 percent.

4.10.1 PROFILE 1

The first profile is line trending Northwest (figure 7). Is a vertical direction of length 1574 km. The total field intensity, declination and inclination used are 33224.9 nT, -9.3^{o} and -2.1^{o} respectively. The azimuth of this profile 1 is 90^{o} (Figure 8). It started from the edge of Zari running through Gazabure down to Gubio, the major anomaly targeted by the profile is the lobe of high and low susceptibility below Zari. The entire profile is covered by sediments, the maximum thickness is 1.9 km. The main targeted anomaly has been reveal as intrusion of Basaltic rock in the basement rock.

4.10.2 PROFILE 2

Profile 2 is a line trending Northeast (figure 7). Is also a vertical direction of length 1493 km (figure 9). The Total Field Intensity, declination and Inclination used are 33224.9 nT, -9.3^{o} and -2.1^{o} respectively. The azimuth of the profile 2 is 90^{o}. It begins from Baga, enters Monguno and end in Marte town. The entire profile is covered by sediments with the maximum thickness of 1.5 km. The major anomaly in the profile has been reveal as an intrusive body below Monguno that is before Marte.

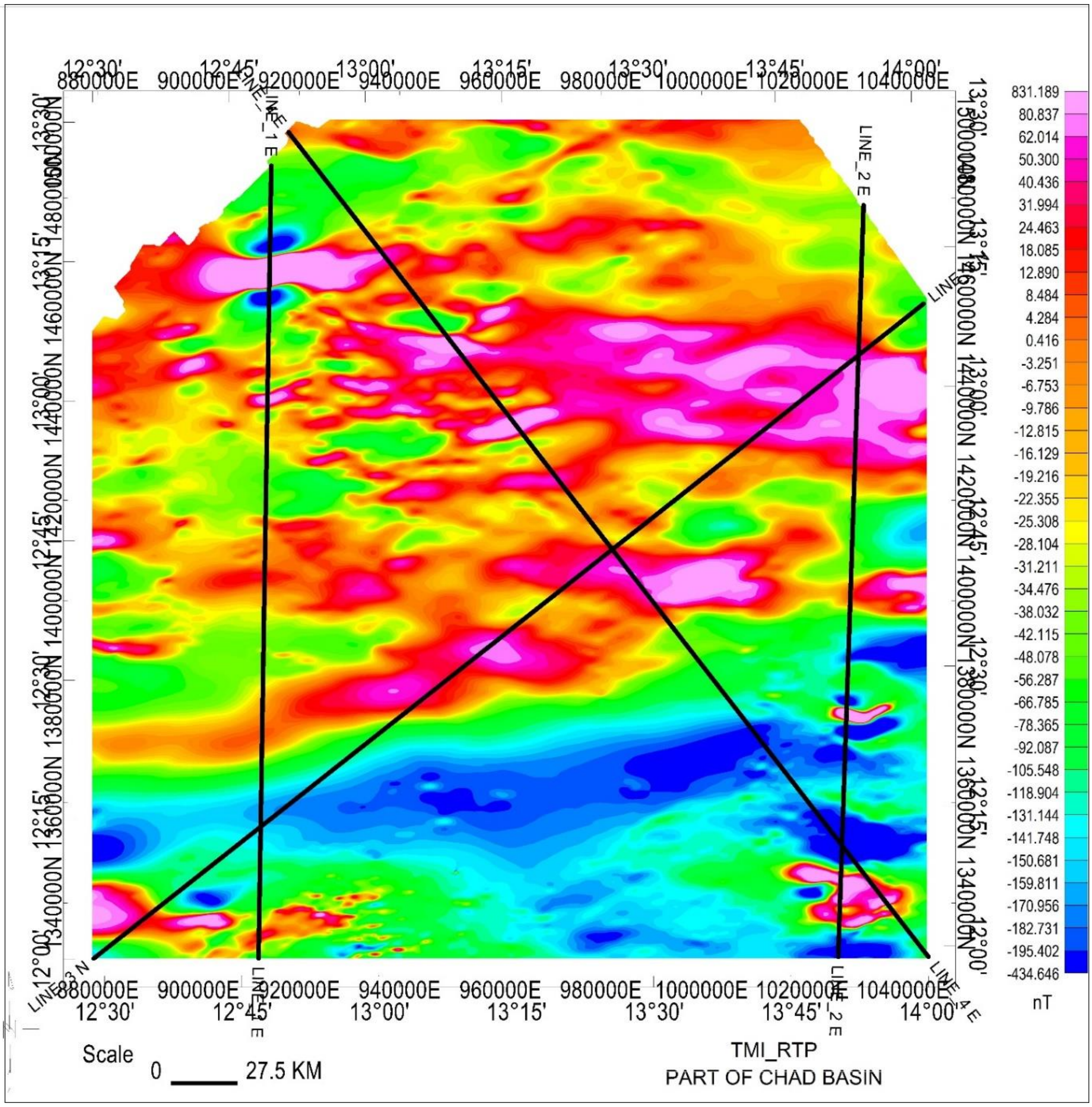

Figure no. 7: Total Magnetic Intensity Map (RTP) showing Profiles Modeled.

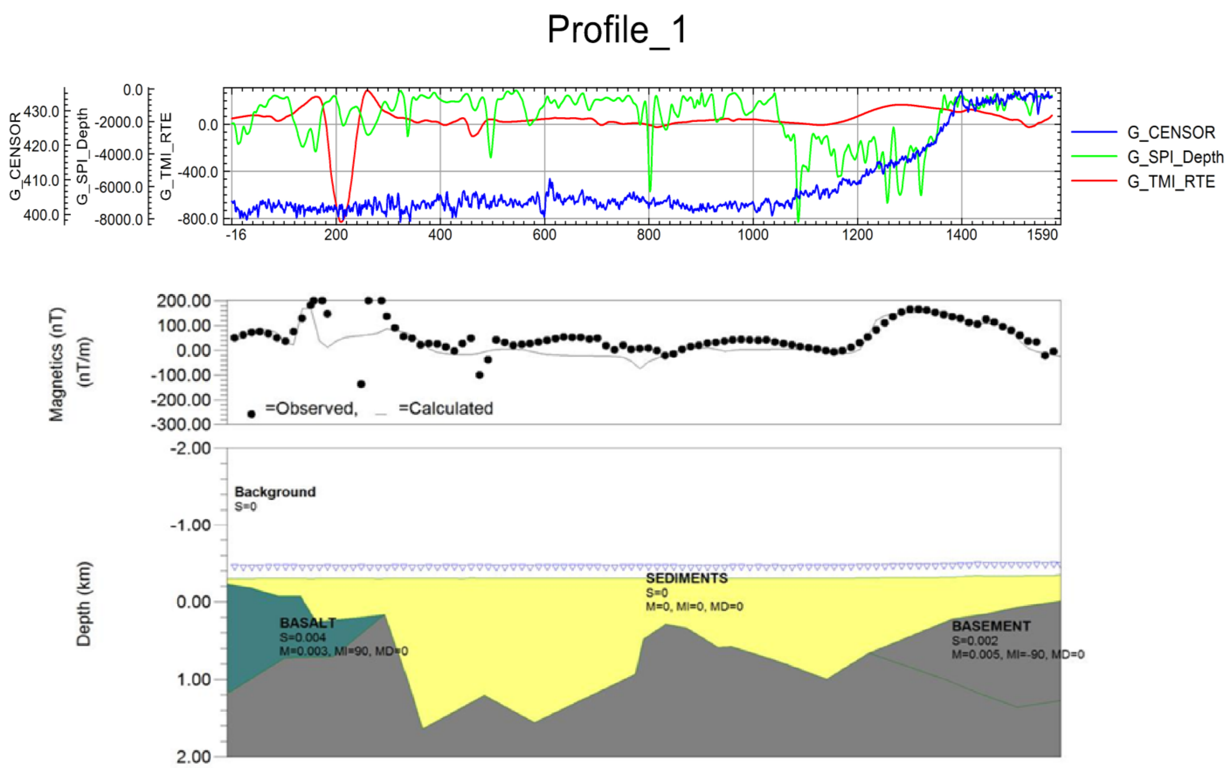

Figure no. 8: Profile and Model Map for profile 1.

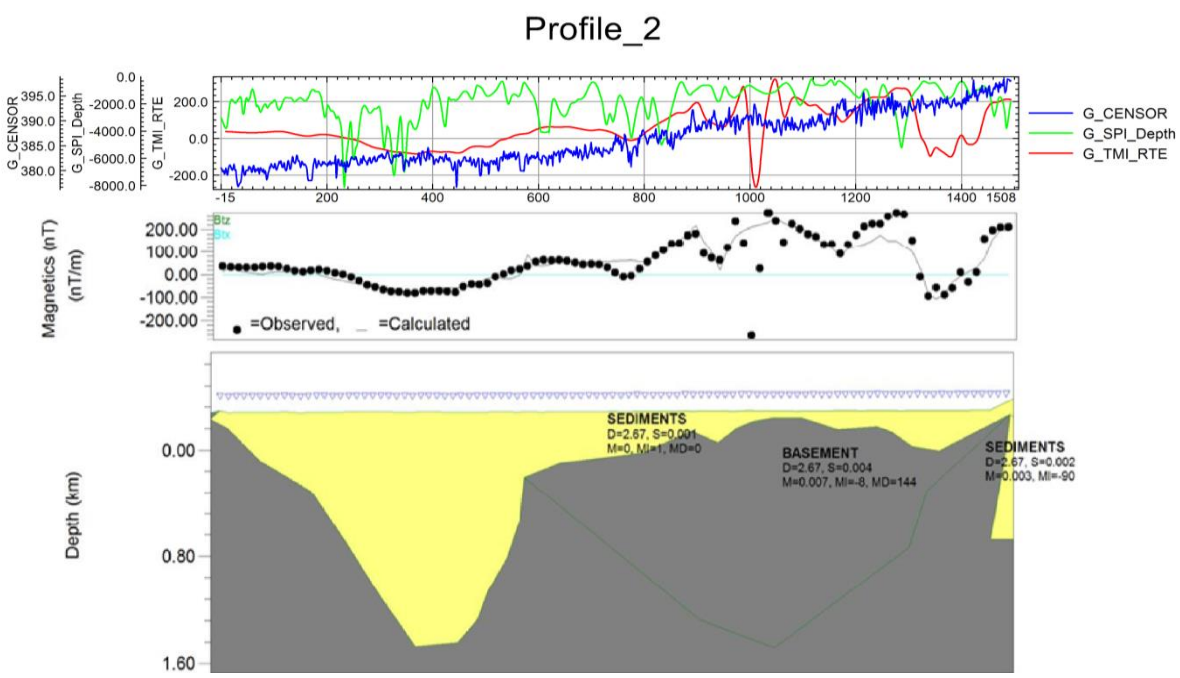

Figure no. 9: Profile and Model Map for profile 2.

4.10.3 PROFILE 3

Profile 3 is the Northeast - Southwest trending line (figure 7). The declination, Inclination and total field Intensity used are -9.3^{o}, -2.1^{o} and 33224.9 nT respectively. The total length of this profile is 2100 km. The profile begins from southern part of Baga and passing through northern part of Monguno, Gudumbau and Gubio towns. It cut across the major anomalies along its path perpendicularly. The maximum sediments thickness obtained is 3 km (fig 10). The profile also started from the sediment which is the Chad formation and cut across some underlying basement rocks and terminate with sediments.

4.10.4 PROFILE 4

Profile 4 is the Northwest - Southeast trending line (figure 7). The total length of this profile is 2073 km. The total field Intensity, Declination and Inclination used are 33224.9 nT, -9.3^{o} and -2.1^{o} respectively. The profile started from northeastern part of Zari and running through western path of Karriwa, eastern part of Gudumbau, southwestern part of Monguno and terminate at eastern part of Marte. The maximum depth of sediment along the profile is 1.6 km (fig 11). It started from sediments and end with basement. It also cut across an intrusive body along it path (down Marte).

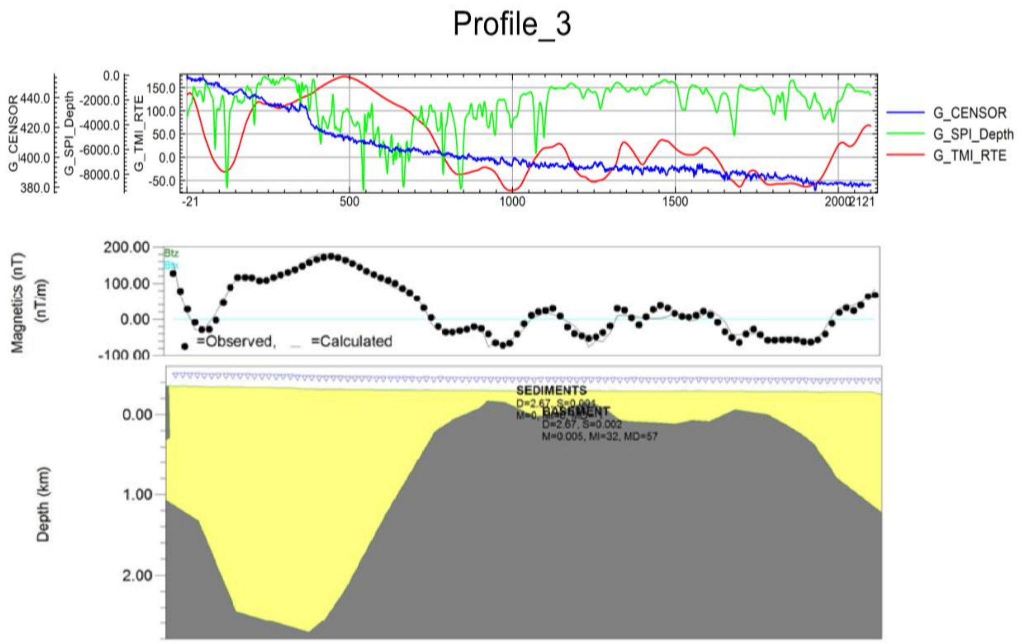

Figure no. 10: Profile and Model Map for profile 3.

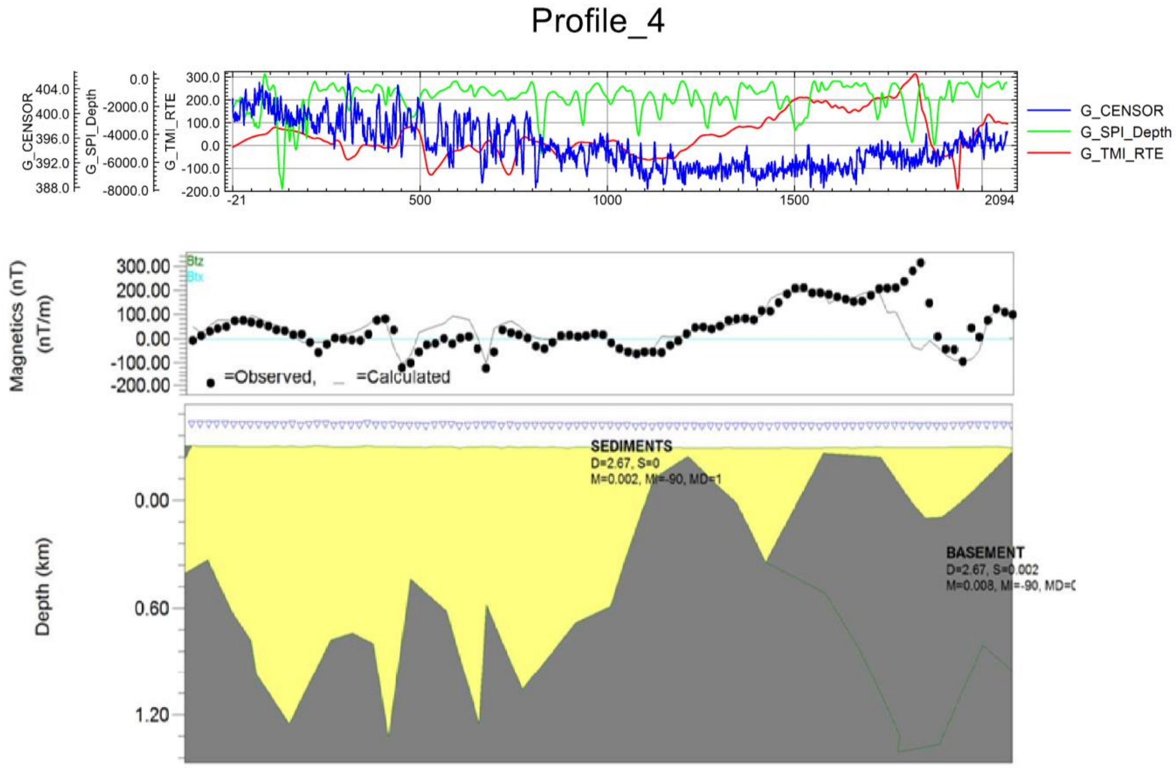

Figure no. 11: Profile and Model Map for profile 4.

CONCLUSION

From the result of the Vertical derivatives, the major magnetic features (like faults, fractures) delineated were oriented in the NE-SW direction. It also shows different rock types which might be granite intrusion or basaltic intrusion. Isolated anomalies with high amplitude, for example at the edge of Zari is a large body with high amplitude and this body has been identified as a Basaltic body on the Geology map. It is also observed that the large low intensity structure (in blue) at the bottom of the TMI map have disappeared from the derivative an indication of signatures from deeply seated structures. The northern and southern portion from latitude 12' 45^o to 13' 15^o and the Eastern portion from longitude 12.0^o to 12' 45^o show similar characteristics attributed to surface and near surface intrusion of magnetic rocks (biotite, granite, undifferentiated shale and sandstone). The major difference observed between the Dx and the Dy derivatives was that the Dx intensifies more structures trending in x direction, while the Dy derivative intensifies more structures trending along Y directions. The result of horizontal derivatives, the turning points in the magnetic values are clearly shown which defined the edge of the anomalies. Regions with high susceptibility per meter were noted as deeper depth and regions with low magnetic source rocks as shallow depths, these are around Zari and Karriwa at the upper part and southeastern corner of the area precisely around Marte and below Monguno (figure no.3).

Result from 2D modeling package, shows that the Susceptibility of the sediment is generally zero except in isolated cases such as in profile 1 and 3 where the profile passes through a highly susceptible basaltic body which slightly influence the susceptibility of the sediments. The Susceptibility of basement rock varies from 0.002 to 0.004 emu cm^{-1}. Which is in agreement with the findings of Emmanuel K. Anakwuba et al., (2011). These result could be used to suggest portions of hydrocarbon and mineral presence in the area as well as the possible depths of assessment.

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