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Investigation of Magnetic Structures within the Chad Basin, Nigeria, Using High Resolution Aeromagnetic Data.

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Abstract*: Investigation of the structures within the Chad basin, Nigeria, was carried out using high resolution aeromagnetic data. The study area is bounded by latitude 12^{o}N to 13.5^{o}Nand longitude 12.5^{o}E to 14^{o}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 is a large body with high amplitude and it has been identified as a Basaltic body. It is observed that the low intensity structure (blue) at the bottom of the TMI map have disappeared from the derivatives which 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 of General derivatives revealed some distortions which were organized where a trend was established within the map. A region of linear highs and lows on these regions place the major lineaments which was interpreted as either fractures or fault lines. The analytical Signal shows both high and low amplitude anomaly. The high amplitude anomaly might be as a result of wide variation in susceptibility of rock-units in areas of fracturing/faulting, while the low amplitude anomaly is associated with sedimentary region. From the result of CET Grid analysis, the basement floor signifies a lot of tectonic activities. Intrusive bodies are noted at the northwestern corner, the eastern edge and the lower edge of southern part of the study area. The remaining part of the basin is plain devoid of volcanic activities.*

Keywords*: Aeromagnetic Data, lineaments (faults, fractures and discontinuities), Structures,lithological boundaries.*

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I. Introduction

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 120N to 13.50N and Longitude 12.50E to 140E, it 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 investigate the structures within Chad Basin Nigeria,using high resolution aeromagnetic datathrough Vertical, Horizontal, General derivative, Analytical signal and Centre for exploration Targeting (CET) grid plug-in method. For mineralization that could be of economic and scientific importance.

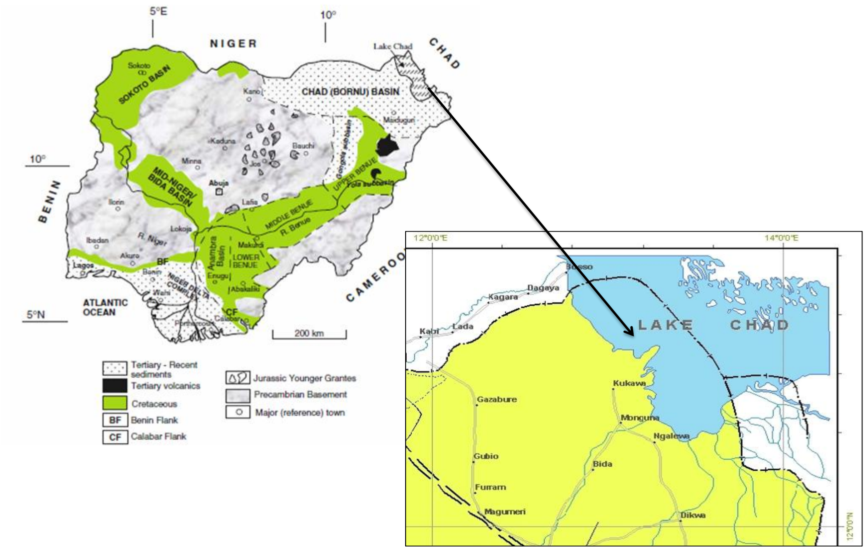

Fig. 1 Location of the Study Area on Geological map of Nigeria adopted from (Obaje, 2009).

II. Geology of Borno Basin

The Borno Basin, which represents the Nigeria section of the Chad Basin, is one of Nigeria's inland basins located in the northern part of the country. It represents about one-tenth of the total areal extent of the Chad Basin, which extends to Cameroon, Niger Republic and Chad basin (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) and (Petters, 1978). The area is characterized by a variety of lithological units, which include many types of igneous, metamorphic and sedimentary rocks. 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).

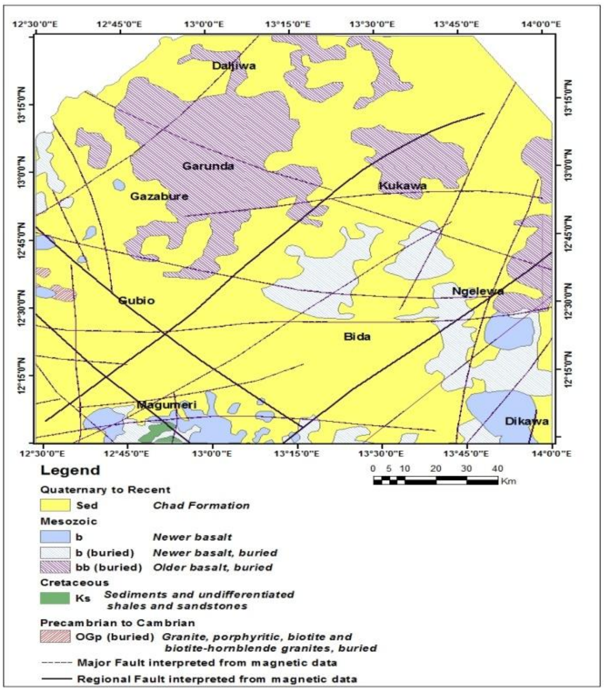

Fig. 2: Geology Map of the Study area, (Nigerian Geological Survey Agency, 2009)

III. Materials and Method

The material employed in this research includeAeromagnetic Magnetic data sheets Zari, Karriwa, Chad Baga, Gazabure, Gudumbau, Monguno, Gubio, Masu, and Marte . Topography Map SRTM (Shuttle Radar Topographic Mission Grid), Detail Geology Mapand Computer software's (Oasis Montaj 9.0) 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 software was used for the analysis. These New datasets 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, Shetima Mongono Crescent Utako District, Garki, Abuja. (Fig: 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 $L\ (V) = (Vi)^n$ (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, the low-pass filters was apply 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).The General derivative used the curvature of magnetic field to reveal details observed by large amplitude anomalies, is much more responsive to local influence than broad or regional effect and therefore tends to give specific information compared to the TMI map. It also provides avenue for visual location of lineaments (faults, fractures and discontinuities) and Location of lithological boundaries.

3.3Analytical Signal

Analytical Signal is an automatic technique used for locating the source of potential field based on both their amplitudes and gradients. The method was developed by Thompson (1982) to interpret 2D magnetic anomalies and extended by Reid et al. (1990) to be used on grid-based data. Magnetic field *M*and its spatial derivatives satisfy Euler's equation of homogeneity.

$$(x - x_o)\frac{\partial M}{\partial x} + (y - y_o)\frac{\partial M}{\partial y} + (Z - Z_O)\frac{\partial M}{\partial Z} = -NM, \qquad 5$$

Where $\frac{\partial M}{\partial x}$, $\frac{\partial M}{\partial y}$ and $\frac{\partial M}{\partial Z}$ represent first-order derivative of the magnetic field along theX_{-}, y- and z- directions, respectively, N is known a structural index and related to the geometry of the magnetic source. For example, N=3 for sphere, N=2 for pipe, N=1 for thin dike and N=0 for magnetic contact (Reid et al., 1990). Talking into account a base level for the regional magnetic field (B) equation (5) can be rearranged and written as

$$x_{\circ}\frac{\partial M}{\partial x} + Y_{\circ}\frac{\partial M}{\partial y} + z_{\circ}\frac{\partial M}{\partial z} + NB = x\frac{\partial M}{\partial x} + y\frac{\partial M}{\partial y} + z\frac{\partial M}{\partial z} + NM., \qquad 6$$

Assigning the structural index (N), a system of linear equations can be obtained and solved for estimating the location and depth of the magnetic body. Using a moving window, multiple solutions from the same source can be obtained. Good solutions are considered to be those that cluster well and have small standard deviations (Thompson 1982: Reid 1990). Selection of the appropriate structural index is very important to obtain the correct depth solutions. However, the estimated horizontal location is independent of the structural index (Barbosa et al, 1999),which means that there is no ambiguity with regard to the structural location.

3.4 Centre for Exploration Targeting (CET) Grid Analysis Plug-in

Locating and mapping of structures using CET starts with the standard deviation, which provides an estimate of the local variation in the data. At each location in the grid, it calculates the standard deviation of the data values within the local neighborhood. Forawindow containing N cells, whose mean value is μ, the standard deviation σofthe cell values x_i is given by:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_{i-\mu})^2} \quad 7$$

When interpreting the output, value which approach zero indicate very little variation, whereas large values indicate high variation. Kovesi (1997). Phase symmetry: this property is useful in detecting line-like features through identifying axes of symmetry. It is also known that the symmetry of a signal is closely related to the periodicity of its spatial frequency. Consequently, it is natural to utilize a frequency-based approach to detect axes of symmetry. This pug-in implements the phase symmetry algorithm developed Kovesi (1997).

In the one-dimensional case (ID), a point of symmetry in the spatial domain corresponds with a point where local frequency components are at either a minimum or a maximum. To identify points of symmetry in two-dimensional (2D) data, we break the data into ID profile and analyze these over multiple orientations at varying scales.

IV. Result and Discussions

4.1 Application of Vertical, Horizontal and General 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 horizontal derivatives in x, y and z direction and vertical Derivative. 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 4,5, and 6) respectively. Region with high susceptibility per meter are noted for with magnetic source rocks at shallow depth, these areasare around Zari and Karriwa at the upper part and southeastern corner of the study area precisely around Marte and below Monguno.

Figure 5 shows isolated anomalies with high amplitude 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 4 and 5) have been over shadowed by the predominant surface features in the derivatives, especially at the western and south eastern 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 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).

The result of General derivatives (Figure 10) revealed some distortions which were organized where a trend was established within the map. A region of linear highs and lows on these regions place the major lineaments which was interpreted as either fractures or fault lines. Major linear features labeled F_1 - F_7, It Is also observed that most of these structures trend in the East-West direction which can be attributed to the stress generated due to the tectonic effect resulting from the American plate separating from the African plate.

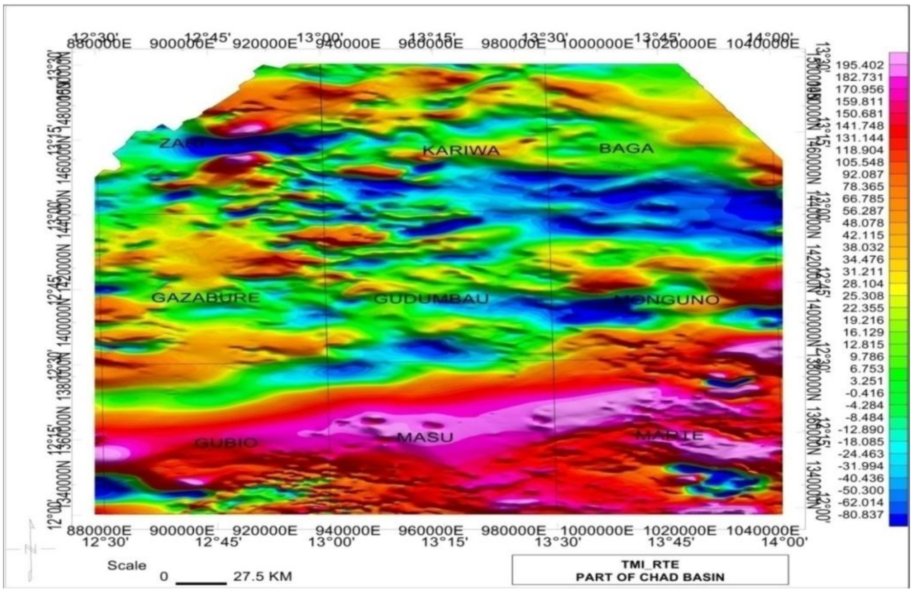

Fig. 3: Total Magnetic Intensity (TMI) Map of the Study Area with Major Towns.

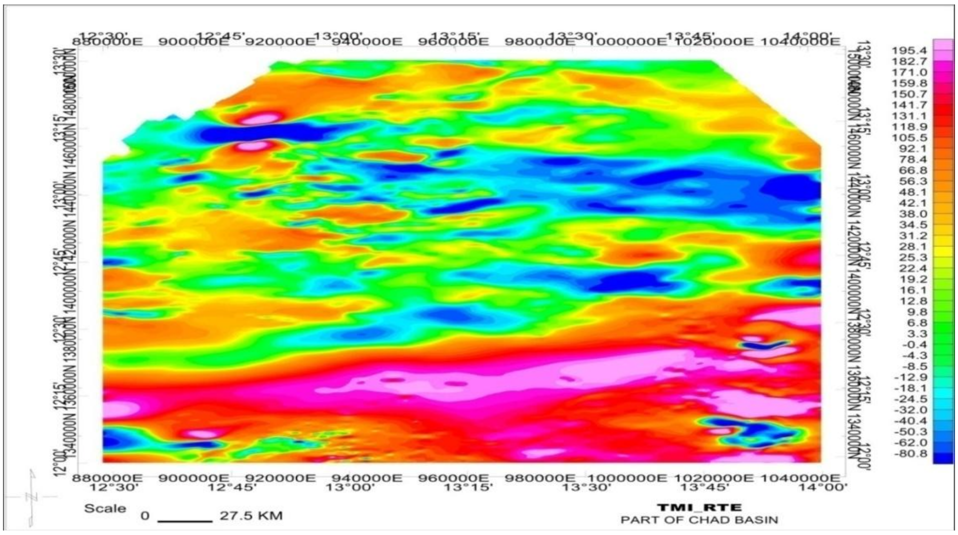

Fig. 4: Total Magnetic Intensity (TMI) Map of the Study Area Reduced to Equator.

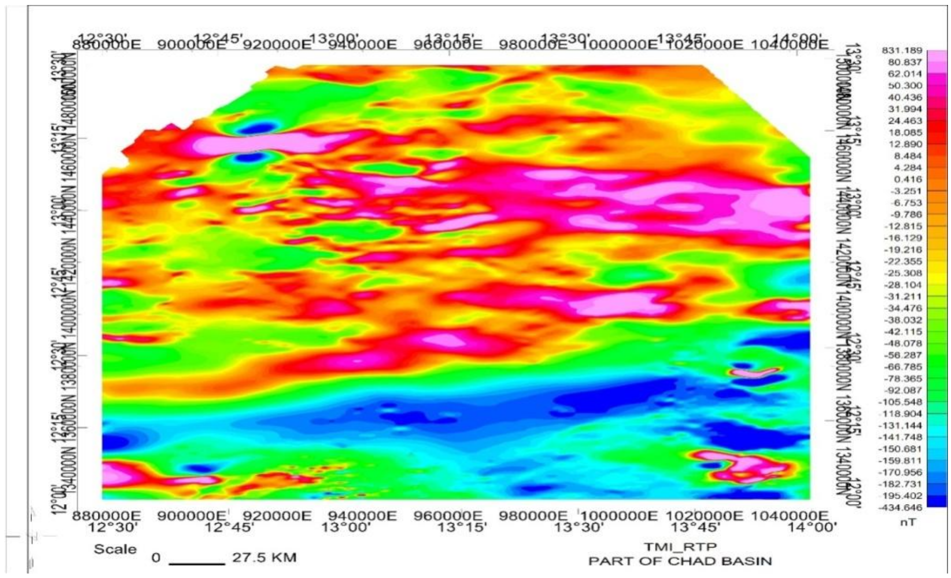

Fig.5: Total Magnetic Intensity (TMI) Map of the Study Area Reduced to Pole.

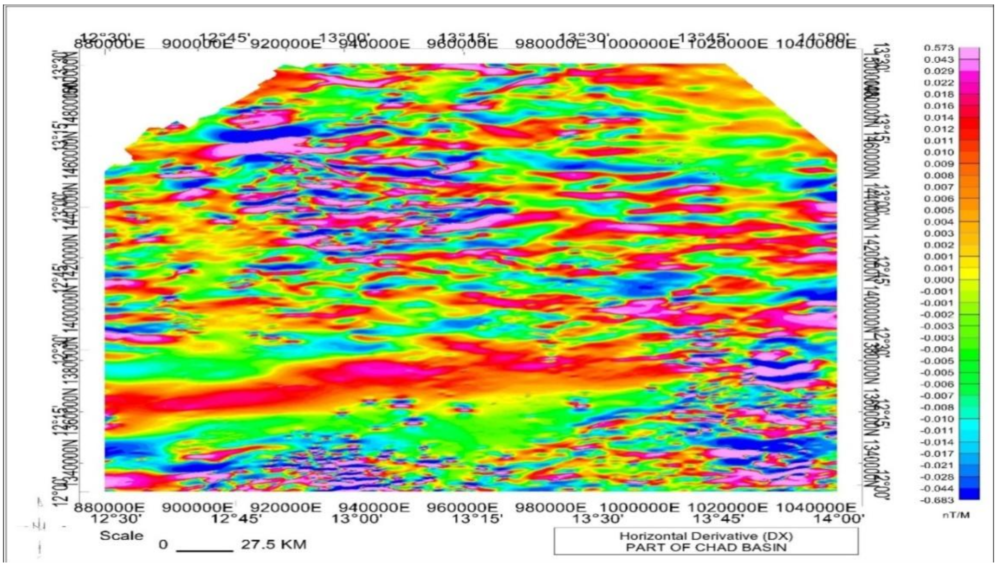

Fig. 6: Horizontal Derivatives (DX) Map of the Study Area

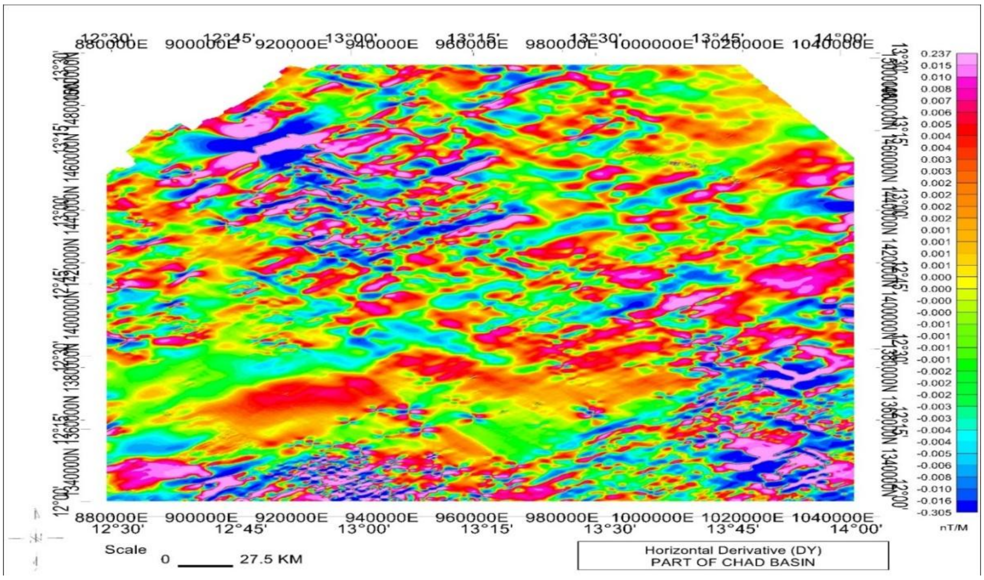

Fig.7: Horizontal Derivatives (DY) Map of the Study Area

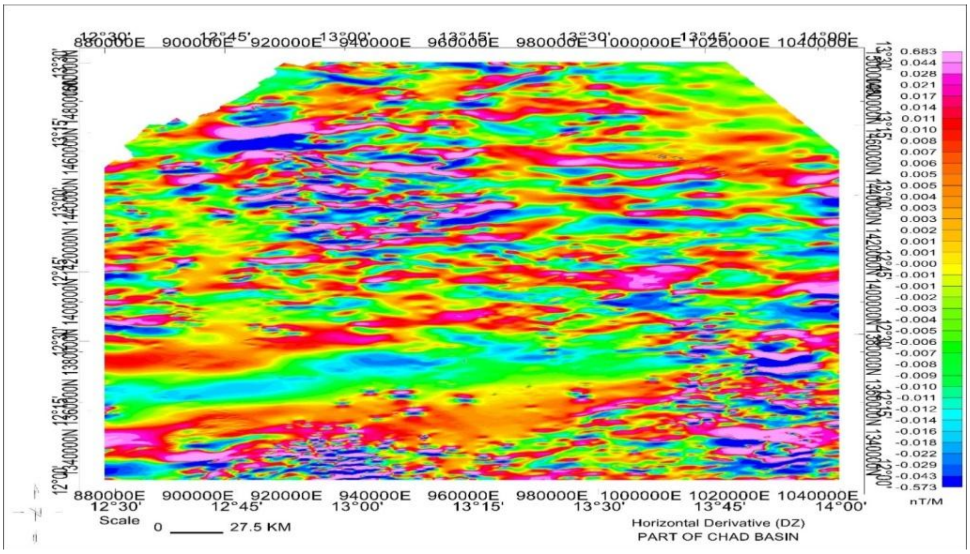

Fig. 8: Horizontal Derivatives (DZ) Map of the Study Area

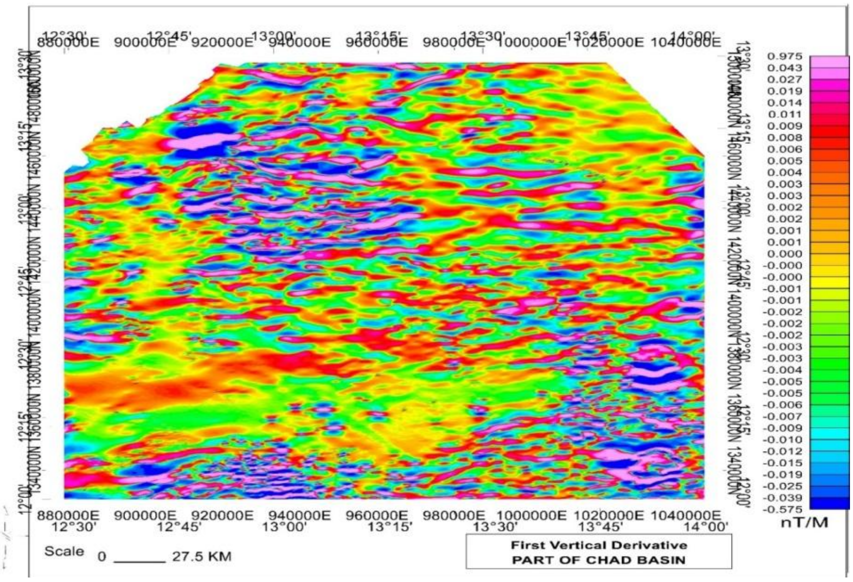

Fig. 9: First Vertical Derivative Map of the Study Area

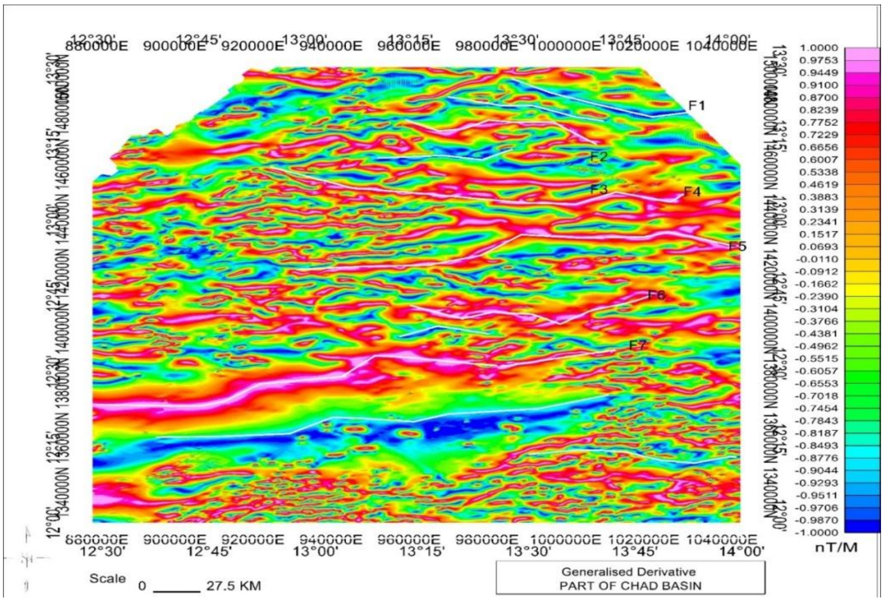

Fig. 10: General Derivative Map of the Study Area

4.2 Result of Analytical Signal

The three derivatives x, y and z were used in Oasis Montaj as input grids to evaluate the 3-dimensional analytical signal map shown in Figure 11, whose amplitude is independent of the direction of magnetization. The result of analytical signal was in amplitude domain and regions with outcrops have high amplitude from 0.080 to 0.092 (shown as pink color). Regions with magnetic rock intruding into shallow depth sedimentary formations has the amplitude between 0.043 and 0.073 (shown as red color), while regions with magnetic rock intruding into deeper depths sedimentary formations have very low amplitudes range from 0.008 to 0.031 (shown in yellow to green color).

4.3 Centre for Exploration Targeting (CET) Grid Analysis Plug-in

Application of the standard deviation and the phase symmetry plug-in produces the map (figure 12) in colored while application of the amplitude threshold and the skeleton to vectors plug-in yield the lineament map of figure 13. The basement floor signifies a lot of tectonic activities. Intrusive bodies are noted at the northwestern corner, the eastern edge and the lower part of southern part of the study area. The remaining part of the basin is plain devoid of volcanic activities. Geological boundaries could be infer from figure 13 some linear structures that signify fault lines are also shown. Though other lineaments are closely located to the geological boundaries which could be classify as mineral vains.

4.4 Comparing Lineament Map superimposed on 1VD map of the Study Area

Figure 14 is the Lineament Map superimposed on 1VD map of the Study Area which can be map out the contact between the basement and the sedimentary basin within the study area. It also shows some similarities between the surface structure as delineated by geologists and the subsurface magnetic features, its indicates that depth to basement is shallow in basement complex region (Northwestern region), South and southeastern region of the area, from the result obtained after comparing Lineament Map superimposed on 1VD map (figure 14) and the Analytical Signal map of the study area (figure 11), the entire area can be identified as two lithologies based on the signatures on the map (figure 14), namely the Sedimentary region and Basement region.

The northern part, southern part and lower eastern part of the map (figure: 14) is mostly engaged by shallow based high frequency, short wave anomalies which are associated with basement signatures. The majority of the structures identified are trending NW - SE, this is in agreement with (Avbovbo *et al.*, 1986) and (Odia, 1989).

The remaining part of the figure 14, North - eastern edge of the map to the South western part is associated with low frequency, long wavelength anomalies running E-W direction. The features (Lineaments)are mostly of sedimentary source. The CET structural mapping clearly identified the contact between these two geological unit.

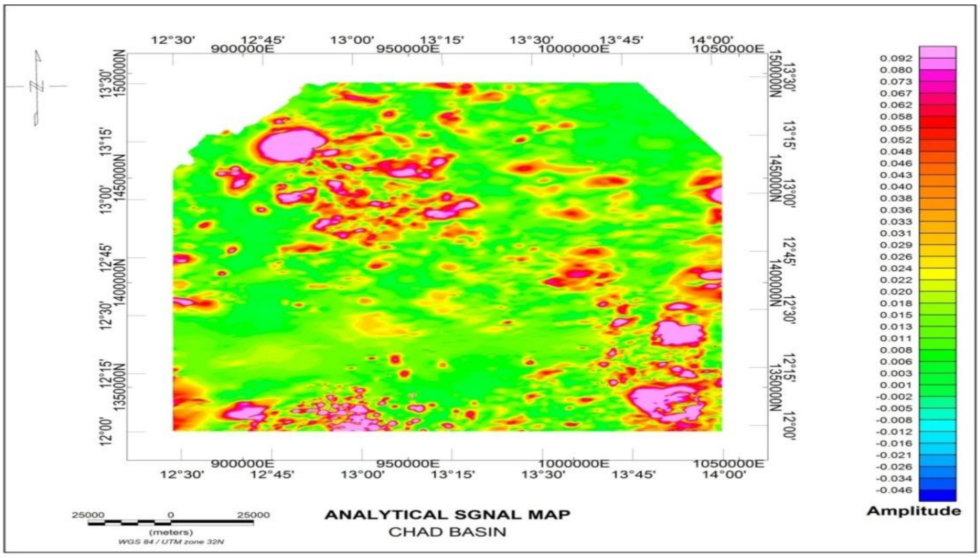

Fig. 11 Analytical Signal Map of the Study Area

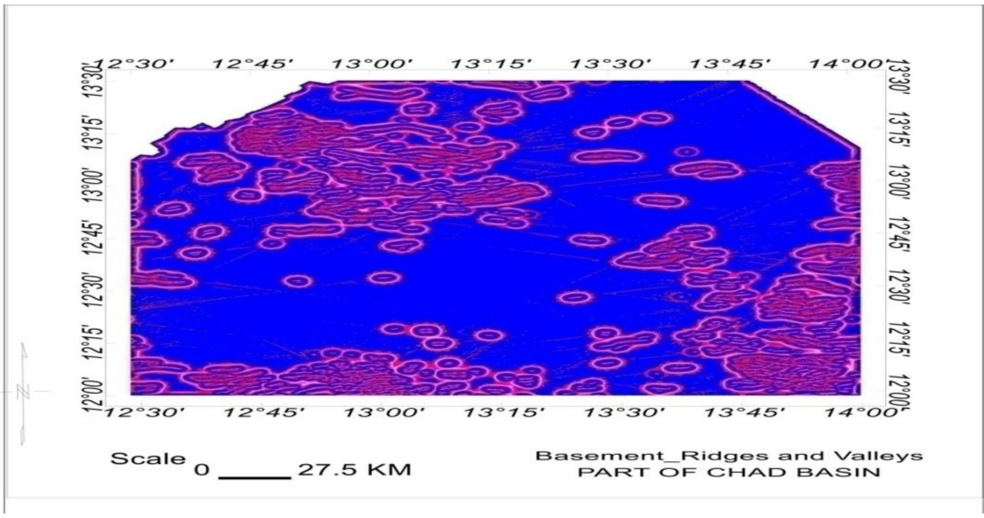

Fig. 12 Structural Map of the Study Area from CET Plug-in

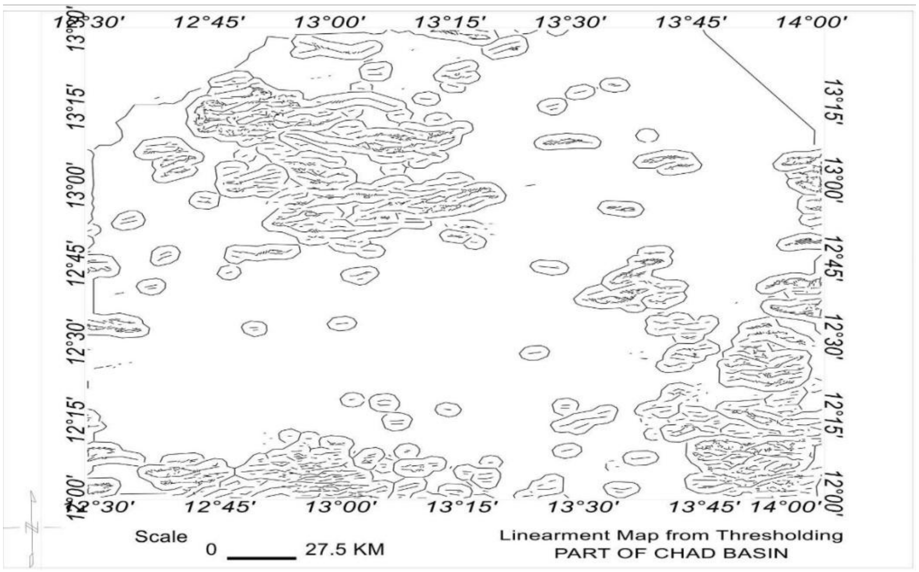

Fig. 13 Lineament Map of the Study Area from CET Plug-in

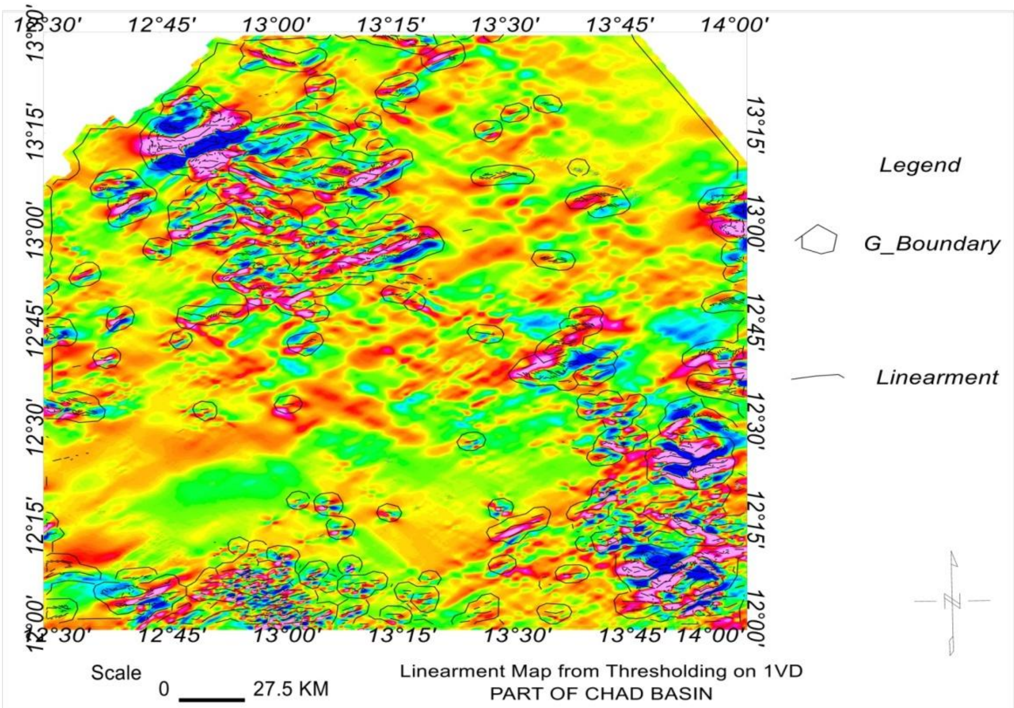

Fig: 14 Lineament Map superimposed on 1VD map.

V. Conclusion

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 (figure 3). The result of the Vertical derivatives shows that the major magnetic features (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, 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.

General derivatives (figure 10) is quite revealing major linear features labeled $F_1 – F_7$. It also observed that most of these structures trend in the E-W direction which can be attributed to the stress generated due to the tectonic effect resulting from American plate separated from the African plate as also observed by Awoyemi et al. (2016).

The analytical Signal shows both high and low amplitude anomaly. The high amplitude anomaly might be as a result of wide variation in susceptibility of rock-units in areas of fracturing/faulting. While the low amplitude anomaly is associated with sedimentary region, the high amplitude anomaly trends NE-NW and the low amplitude anomaly trends E-W. Faults and structures delineated through analytical signal and vertical derivatives were in agreement and the economy mineral present in the area may be confined along the faults and structures identified.

From the result of CET Grid analysis, the basement floor signifies a lot of tectonic activities. Intrusive bodies are noted at the northwestern corner, the eastern edge and the lower edge of the southern part of the study area. The remaining part of the basin is plain devoid of volcanic activities. Geological boundaries could be infer from CET map, some linear structures that signify fault lines are shown though other lineaments are closely located to the geological boundaries which could be classify as mineral vains,for mineralization that could be of economic and scientific importance.

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