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Euler Deconvolution and Source Parameter Imaging of aeromagnetic data of Guzabure and Gudumbali regions, Chad Basin, North Eastern Nigeria.

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Abstract: *The Guzabure and* Gudumbali regions, *within the Chad Basin, Northeastern Nigeria have been interpreted qualitatively and quantitatively using the aeromagnetic data of the area. Euler deconvolution technique and source parameter imaging method were employed in the analysis of the work. Application of minimum curvature in gridding the total magnetic field intensity was done using the Oasis Montaj 6.4.2 software. First order polynomial fitting was applied in Regional - residual separation. The residual magnetic intensity map shows the existence of intrusive bodies in the study area. From the aeromagnetic result, the depth to basement estimated using the Euler depth technique range from 721.1m (shallow gravity bodies) to 4187.5 m (deep lying gravity bodies), while the depths estimated using source parameter imaging (SPI) ranges from 491.4 (shallow magnetic bodies) to 4102.1 m (deep lying magnetic bodies) m. The results obtained from aeromagnetic Euler deconvolution technique closely agrees with that of the source parameter imaging. The sedimentary thicknesses of 4187.5m and 4102.1m obtained in this work show sufficiently thick sediments suitable for hydrocarbon accumulation. This implies that the area has the potential for hydrocarbons exploration.*

Keyword: *Aeromagnetic data, basement depth, Chad basin, Euler deconvolution, Source parameter imaging.*

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I. Introduction

The mineral resources (metallic and non-metallic minerals), which the skill of man extracts from the bowels of the earth and his way of fashioning it into raw materials for our great industries aids in the development of any nation (Okwesili et al., 2019). Nigeria for instance is favoured with various minerals both in metallic and non-metallic forms. Nigeria's vast population and rapid urban development pattern demands investment opportunities to exist in these mineral projects for which there are abundant raw materials but which are presently not being exploited because of lack of required technology.

Mining and the search for these metallic and non-metallic minerals dates from time past. The continued expansion in the demand for metals of all kinds and the enormous increase in the use of petroleum products since the turn of a new century have led to the development of many geophysical techniques of ever increasing sensitivity for the detection and mapping of unseen deposit and structure (Umukoro, and Akanbi, 2014). The detection of great majority of mineral deposits beneath the Earth's surface depends on those characteristics that differentiate them from surrounding media. It should be noted that geophysical techniques detect only a discontinuity, which is where one region differs sufficiently from another in some property. This however is a universal limitation, because one can only discern that which has some variation in time and space and cannot perceive that which is homogenous in nature;. Certain geological conditions generally are associated with metallic ores, others with gas and oil.

The search for metallic ores generally is concentrated in areas of known igneous and metamorphic rocks while coal, oil and gas from sedimentary basin. The choice of technique to locate certain minerals depends on the nature of the mineral and the surrounding rocks. Sometimes a method may give a direct indication of the presence of the mineral being sought; for example, the magnetic method being used to find magnetic ores of iron or nickel, at other times the method may indicate only whether or not conditions are favourable to the occurrence of mineral sought.

Aeromagnetic survey is a rapid method of finding geophysical anomalies, and anomalies of interest. It is a complex phenomenon arising from complex distributions of magnetization in the earth crust. In aeromagnetic survey there are two types of magnetization that contribute to the external magnetic fields caused by geologic features. The most common component arises from magnetic minerals immersed in the ambient field of earth known as induced magnetization (Likkason, 2007). Another less common contribution which is of equal or in same case the dominant effect, is a response left-over from ancient geological events known as remnant magnetization. In most cases, many magnetic anomalies are a combination of both types of magnetization, in most of these cases the remnant and induced field vectors point in different direction, the ratio of the remnant to induced magnetization is koennigsberger ratio and this expresses the relative contribution of each of these two vectors to the anomaly shapes and amplitude.

Therefore, these need to investigate the economic minerals and hydrocarbon potentials of particularly the Nigerian sector of Chad Basin which is one of the inland Basins in Nigeria presumed to have high hydrocarbon potential aside other Earth minerals with high economic values (Akiishi et al., 2018). In addition, the order by the federal government of Nigeria that national petroleum cooperation (NNPC) should resume exploration activities in the Nigerian Chad Basin, triggered off the interest to investigate this sedimentary Basin(Fagbenle, P.K ,2016).This research is very useful for a reconnaissance survey for oil and mineral deposits in this 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.

Location and geology of the study area

The study area (shown in Figure 1a) is located in the Chadbasin, Nigeria within 12.5^0 to 13^0 N (longitude) and 12.5^0 to 13.5^0 E (latitude). The Chad Basin(Figure1b) lies within a vast area of central and west Africa at an elevation of between 200 and 500m above sea level and covering approximately 230,000km2 (Ajana *et al.,* 2014). It is the largest area of inland drainage in Africa (Barber, 1965; Matheis, 1976; Avbovbo *et al.,*1986). It extends into parts of the republic of Niger, Chad, Cameroon, Nigeria and Central Africa. The Nigerian Chad Basin (Figure 1b) is about one tenth of the Basin (Wright, 1976; Falconer, 1911). This Bornu-Chad Basin is a broad sediment-filled depression spanning northeastern Nigeria and adjoining parts of the Republic of Chad. The stratigraphy of Bornu-Chad Basin has been reported by several workers (Avbovbo *et al.,* 1986; Obaje, 2009; Nwankwo and Ekine, 2009). The stratigraphic sequence (Table1) shows that Chad, Kerri-kerri and Gombe formations have an average thickness of 130 to 400 m. Below these formations are the Fika shale which is a dark grey to black in color, with an average thickness of 430 m. Others are Gongila and Bima formations with an average thickness of 320 m and 3500m, respectively.

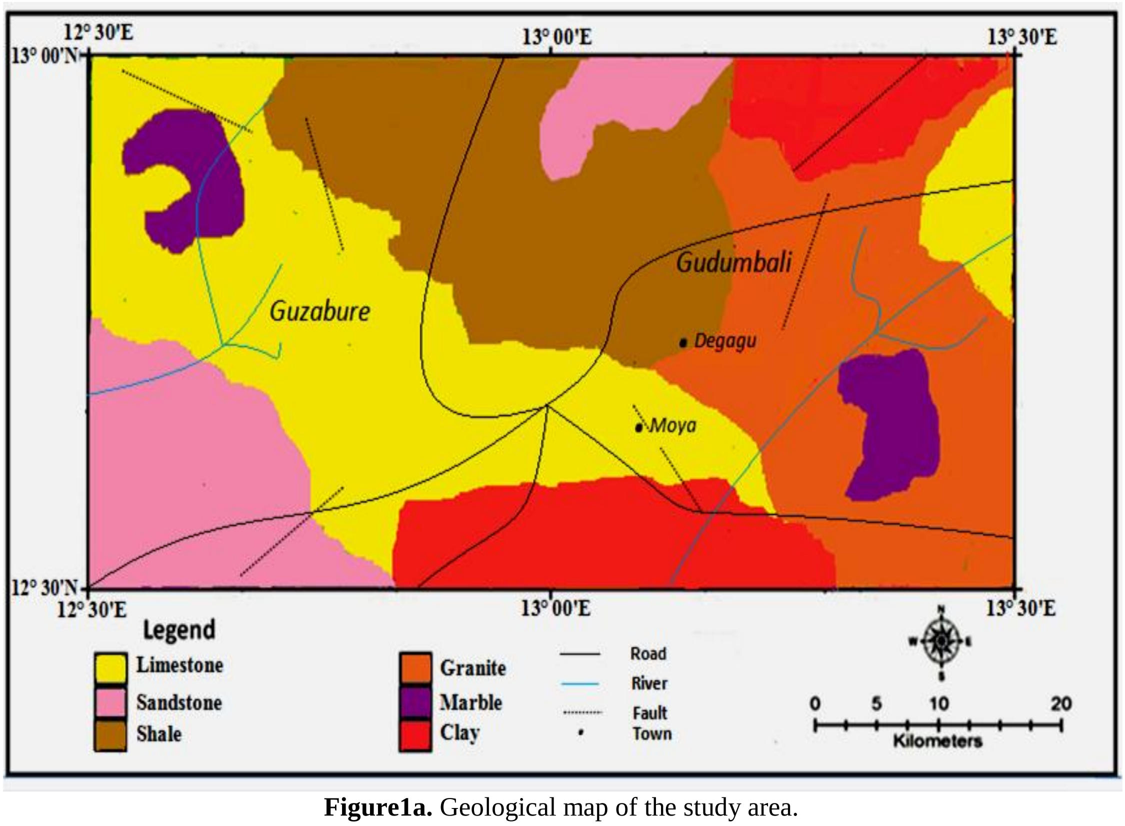

Figure1a. Geological map of the study area.

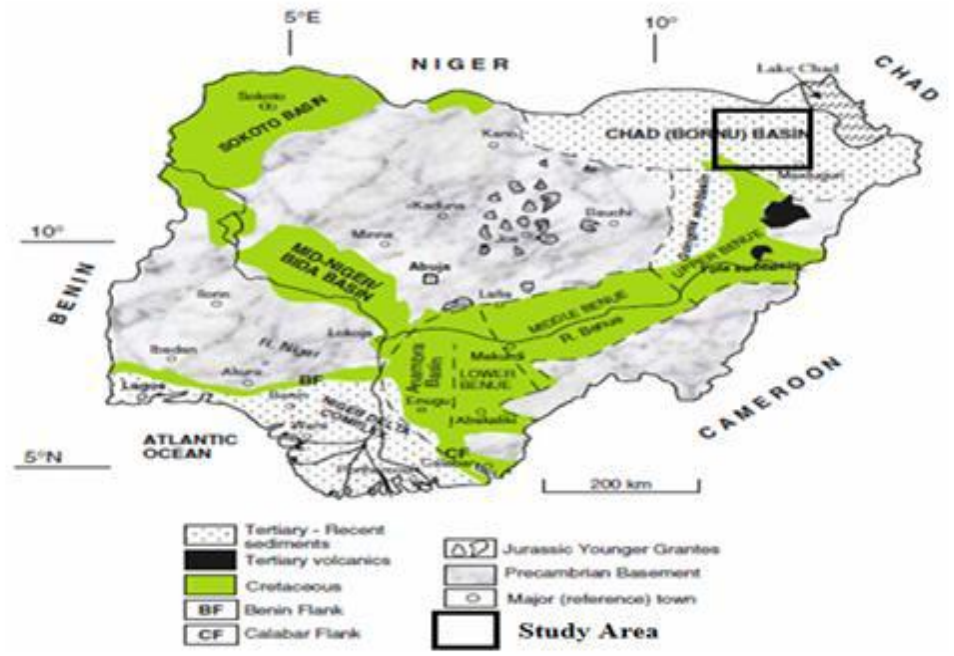

Figure 1b: The Map of Nigeria Showing the Location of Chad Basin (Obaje, 2009).

Table 1: Generalized Stratigraphic Sequence of Nigerian Chad Basin (Okpikoro, and Olorunniwo, 2010)**.**

Age	Formations	Lithology	Depositional Environment	Thickness (m)**
Pliocene-Pleistocene	Chad		Continental (Lacustrine)	50 – 425
Paleocene	Kerri-Kerri		Continental	455 – 545
Maastrichtian	Gombe Sandstone		Deltaic, Estuarine	301 – 402
Turonian-Santonian	Fika Shale		Shallow marine	606 – 2012
Turonian	Gongila		Marine, Estuarine (Transitional)	226 – 1363
Albian-Cenomanian	Bima		Continental	408 – 1397
Pre-Cambrian			Crystalline Basement	

INDEX: Sand; Clay; Claystone; Limestone; Siltstone; Coal; Shale; Sandstone; Igneous sills; Basement rocks; .... Unconformity; ** Thickness from well logs

II. Material and Methods

Source of Data

The high resolution airborne magnetic used for this study were obtained from Nigerian Geological Survey Agency (NGSA). The aeromagnetic data were obtained using a 3 x Scintrex CS2cesium vapour magnetometer by Fugro Airborne Surveys in 2009. The airborne magnetic survey was carried out at 80 m elevation along flight lines spaced 500 m apart. The flight line direction was 135°, while the tie line direction was 225°. A correction based on the international Geomagnetic Reference Field (IGRF) 2010 was applied.

Theory of Euler deconvolution

Euler deconvolution technique is employed in magnetic interpretation because it requires only a little prior knowledge about the magnetic source geometry (Thompson, 1982; Reid *et al*., 1990). It is used for depth estimation and location of features that represent structures. The Euler deconvolution method is based on Euler's homogeneity equation. This is an equation that relates the potential field and its gradient components to the location of the source, with the degree of homogeneity, N which may be interpreted as a structural index, SI (Thompson, 1982). The SI is an exponential factor corresponding to the rate at which the field falls off with distance, for a source of a given geometry. Euler's homogeneity equation can be defined as (Reid *et al*., 1990):

$$(x - x_0)\frac{\partial M}{\partial x} + (y - y_0)\frac{\partial M}{\partial y} + (z - z_0)\frac{\partial M}{\partial y} = N(B - M) \qquad 1$$

Where B is the regional value of the total magnetic field and x_0, y_0, z_0 is the position of the magnetic source, which produces the total magnetic field M, measured at (x, y, z). N is the structural index. The most critical parameter in the Euler deconvolution is the structural index, N (Thompson, 1982). Essentially, N measures the rate of change of the fields with distance from the source (fall off-rate) and is directly related to the source dimensions. Therefore, by changing N, we can estimate the geometry and depth of the magnetic sources (Umukoro, and Akanbi, 2014). A poor choice of the structural index has been shown to cause a diffuse solution of source locations and serious biases in depth estimation. Both Thompson (1982) and Reid et al. (1990) suggested that a correct N gives the tightest clustering of the Euler solutions around the geologic structure of interest. For magnetic data, physically plausible N values range from 0 to 3. Due to the kind of structures (dykes and granite plutons) in the study area, a structural index of 1 and 2 was used.

The value of the SI depends on the type of source body under investigation (Whitehead and Musselman, 2005). For example N = 0 for a horizontal contact with infinite dimensions, N = 0.5 for a vertical contact, N= 1 for top of a vertical dyke or the edge of a sill, N = 2 for the centre of a horizontal or vertical cylinder and N = 3 for the centre of a magnetic sphere or dipole (Thompson, 1982; Reid et al., 1990).

Theory of Source Parameter Imaging

The Source parameter imaging is a technique which uses an extension of the complex analytical signal to estimate magnetic depths (Thurston and Smith, 1997; Nwosu, 2014). This technique developed by Thurston and Smith (1997) sometimes referred to as the local wave number method, is a profile or grid-based method for estimating magnetic source depths and for some source geometries, the dip and susceptibility contrast. The method utilizes the relationship between source depth and the local wave number (K) of the observed field, which can be calculated for any point within a grid of data via horizontal and vertical gradients (Thurston and Smith, 1997). The depth is displayed as an image. The SPI method requires first and second order derivatives and is thus susceptible to both noise in the data and to interference effects (Nwosu, 2014). The analytic signal $A_1(x, z)$ is defined by Nabighian (1972) as

$$A_1(x,z) = \frac{\partial M(x,z)}{\partial x} - j\frac{\partial M(x,z)}{\partial z} \qquad 2$$

Where M(x, z) is the magnitude of the anomalous total magnetic field, j is the imaginary number, and z and x are Cartesian coordinates for the vertical direction and the horizontal direction perpendicular to strike, respectively. Nabighian (1972) showed that the horizontal and vertical derivatives comprising the real and imaginary parts of the 2D analytical signal are related;

$$\frac{\partial M(x,z)}{\partial x} \Leftrightarrow -j\frac{\partial M(x,z)}{\partial z} \qquad 3$$

Where $\Leftrightarrow$ denotes a Hilberts transform pair. The Local wavenumber K_1 is defined by Thurston and Smith (1997) to be

$$K_1 = \frac{\partial}{\partial x}tan^{-1}\left[\frac{\partial M}{\partial z}/\frac{\partial M}{\partial x}\right] \qquad 4$$

Thus, the analytic signal could be defined based on second-order derivatives, $A_2(x, z)$, where

$$A_2(x,z) = \frac{\partial^2 M(x,z)}{\partial z\,\partial x} - j\frac{\partial^2 M(x,z)}{\partial^2 z} \qquad 5$$

This gives rise to a second-order local wave number K_2, where

$$K_2 = \frac{\partial}{\partial x}\tan^{-1}\left[\frac{\partial^2 M}{\partial^2 z}/\frac{\partial^2 M}{\partial z\,\partial x}\right] \qquad 6$$

Methods

The two digitized sheets of Guzabure and Gudumbali regions were merged to make a single sheet that formed the study area. The data were imported into Oasis Montaj software and gridded using minimum curvature in order to produce the total magnetic intensity (TMI) map of the study area (Figure 2). A grid size of 200 was used in order to avoid over or under sampling based on the sampling distance of the two data. Then this was followed by the polynomial fitness of the data so as to get rid of the regional irregularities from the total magnetic concentration, to get the outstanding residual anomaly (Figure 3). The first order polynomial fitting directive was applied in the data. Other methods used include the first vertical derivative, second vertical derivative and horizontal derivative (Biswas et al., 2017). Depths estimation to anomalous bodies was carried out using two different methods: Euler deconvolution and SPI.

Euler deconvolution

Automatic estimation of magnetic source location and depth was carried using Euler deconvolution method. The Euler depths were estimated using vertical derivatives in three dimensions (x, y, and z). This technique uses first order, x, y and z derivatives to determine location and depths to anomalous targets like sphere, cylinder, thin dyke, etc (Obiora et al., 2018). Each of the shapes is characterized by specific structural index. Euler deconvolution is not limited to bodies that have known structural indices as Reid et al. (1990) extended the technique to 3D data by applying the Euler operator to windows of gridded data sets. For the purpose of this work, Oasis Montaj software was employed in the computing and gridding of Euler 3D using equation (1), wherein images were produced and depth to the suspected magnetic bodies was estimated. Using two structural indices (SI = 1, 2), two Euler 3D grids were generated.

Source parameter imaging

Oasis Montaj software was employed in the computation of the SPI image and depth using equations (2) – (6). Also the first and second order local wave numbers were used to determine the most appropriate model and depth estimate of any assumption about a model.

III. Result

The results of the qualitative interpretation processes of the magnetic data were presented in Figure 2 and Figure 3. They are seen in the Total magnetic intensity map and residual magnetic intensity map. Furthermore, the results of the quantitative interpretation of Euler deconvolution and source parameter imaging are shown in Figure (4 -6) respectively. These are seen in Euler deconvolution map and Sources parameter imaging aeromagnetic map. Finally, Figure 7 gives the 3-D SPI view of the study area

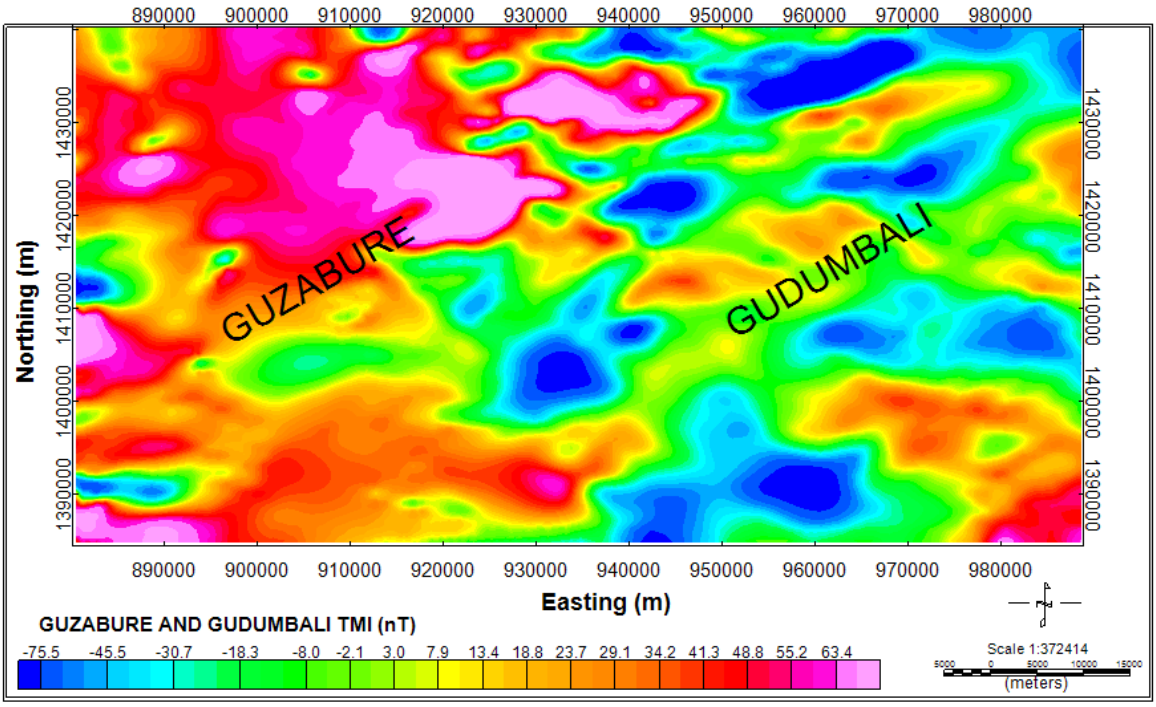

Figure 2: Total magnetic intensity (TMI) map of the study area.

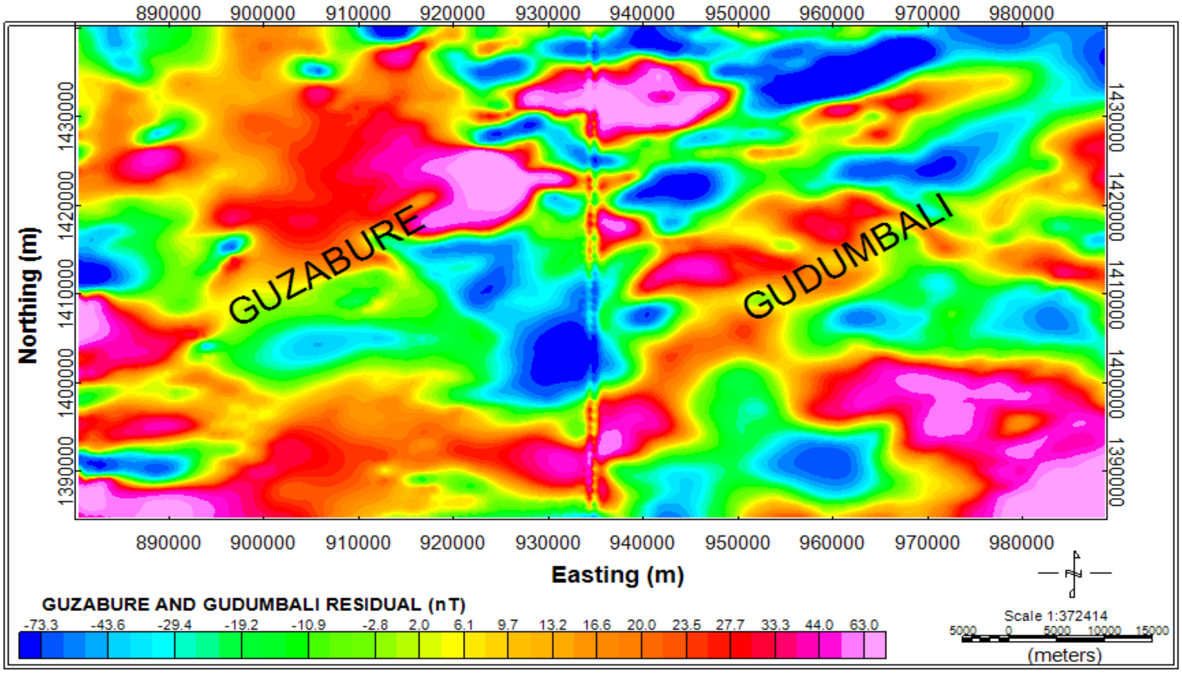

Figure 3: Residual magnetic map of the study area.

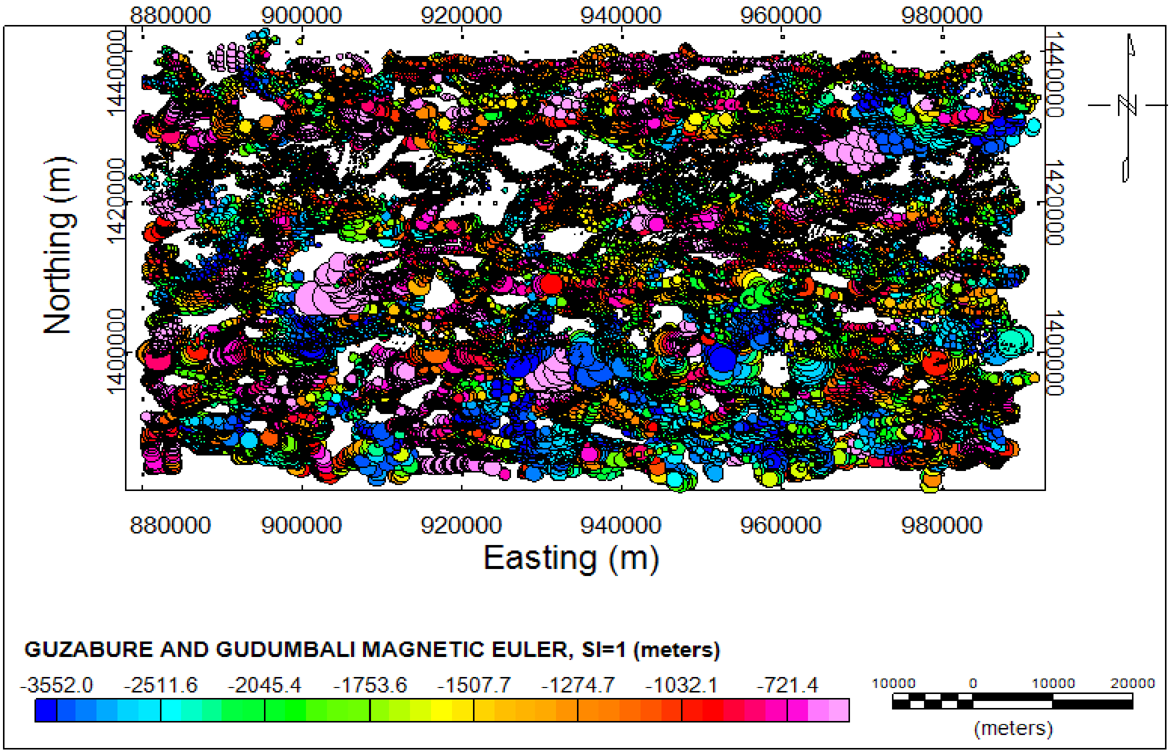

Fig. 4: Aeromagnetic Euler 3D depth map, SI=1

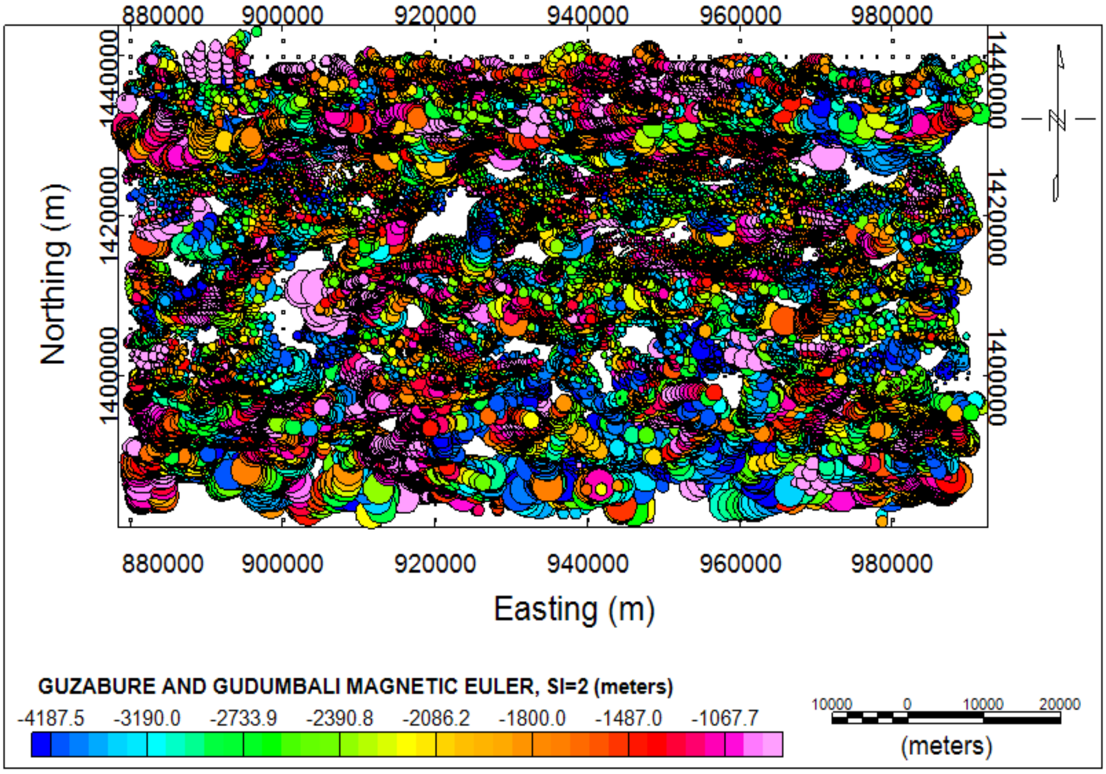

Fig. 5: Aeromagnetic Euler 3D depth map, SI=2

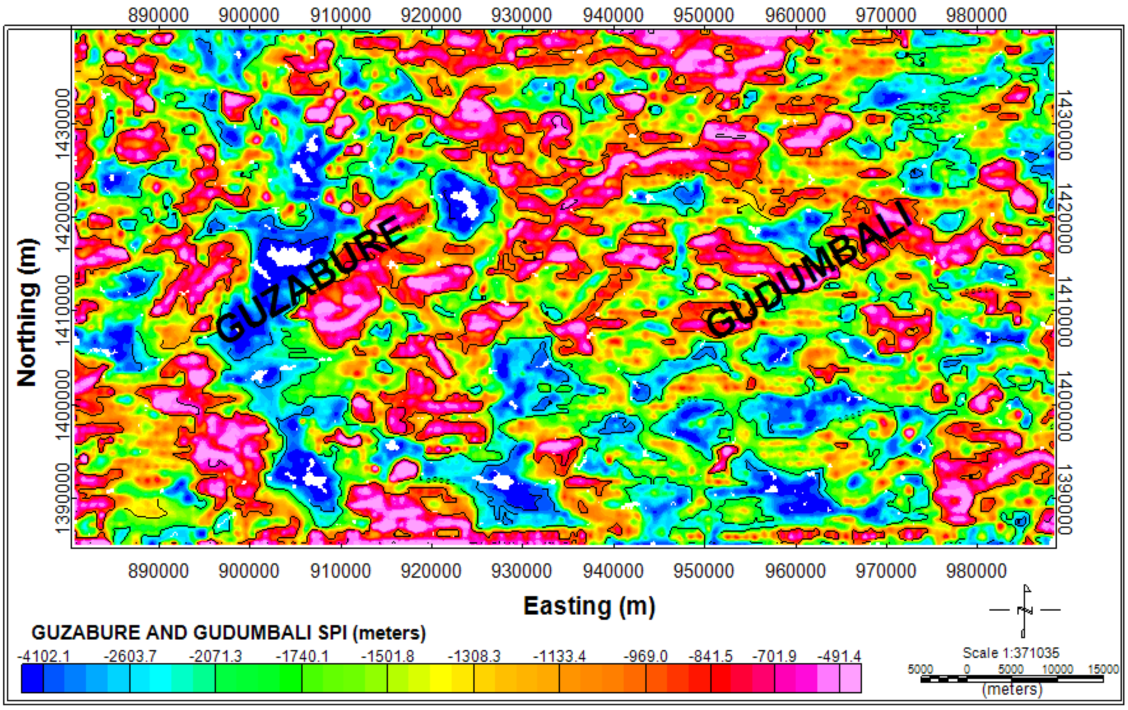

Figure 6: Source parameter image (SPI) map of the study area.

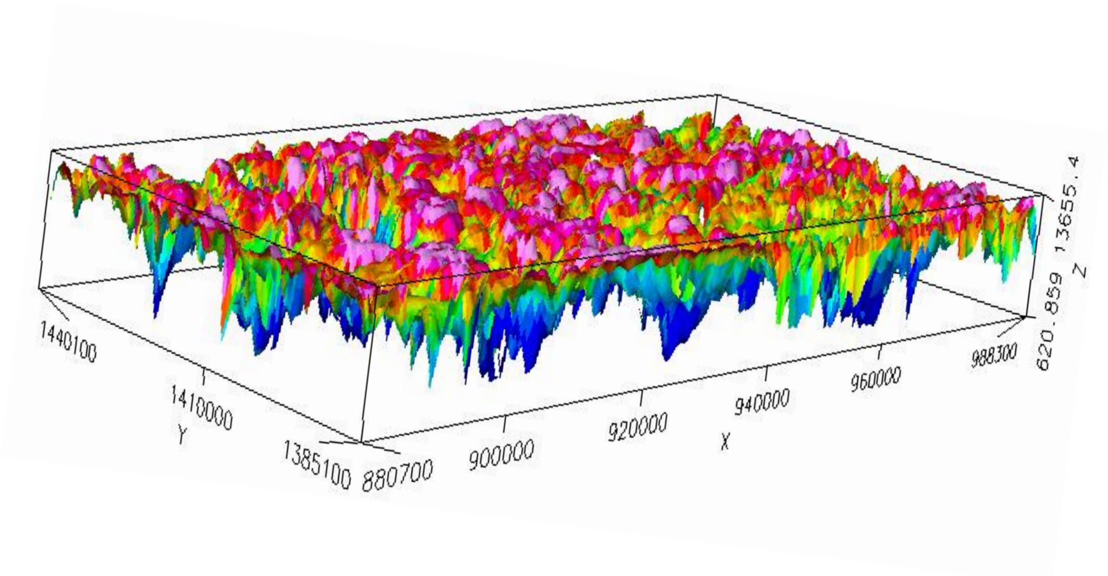

Figure 7: The 3-D SPI view of the study area

IV. Discussion

Qualitatively it could be seen that the total magnetic intensity (Fig. 2) of the study area shows range of magnetic anomalies which vary from -75.5 nT to 63.4 nT. Therefore the area is marked with high (pink and red colours) and low (blue colour) magnetic signatures. The Guzabure area is dominated more with bodies with high magnetic signatures everywhere with little patches of low magnetic signatures in the central part of Guzabure which trended southwards. The Gudumbali area is dominated more with low intensity anomalies everywhere with small patches of high intensity magnetic signatures around SE, SW and in the central area part of the study area. Areas of strong positive anomalies (pink and red colours) likely indicate a higher concentration of magnetically susceptible minerals (principally magnetite). Similarly, areas with broad magnetic lows (blue colour) are likely areas of low magnetic concentration, and therefore lower susceptibility.

The 2D residual magnetic map (Fig. 3) of the study area shows magnetic anomalies ranging from-73.3 nT to 63.0 nT. High residual magnetic anomaly is observed in the northern parts into the central part and decreases towards the southern parts. This indicates the study area is predominantly of high residual magnetic anomalies and small area of low residual magnetic anomalies. This implies that the area is more of intrusive bodies. This could be due to near surface rocks containing large magnetic response (Anakwuba et al., 2011). Low residual magnetic anomaly values appear in the southwest, southcentral and southeast of the study area. This could likely be due to the presence of sedimentary rocks (likely sandstones and limestone) or weak magnetic bodies in the area.

High residual magnetic anomaly is observed more in the Guzabure region than in the Gudumbali region which has more of low residual magnetic anomalies. This agrees with the work of (Oghuma, et. al., 2015) who observed that high residual magnetic intensity in most part of Chad basin is caused by near surface rocks. The residual magnetic map agrees well with the total magnetic intensity map, thereby showing that the area is more of residual magnetic anomalies than the regional magnetic anomalies.

The Euler depths were estimated using vertical derivatives in three dimensions (x, y, and z). Vertical derivatives enhance shallow magnetic bodies. Hence, depths of shallow magnetic anomalies for different structural index are displayed by Euler method. Different structural index numbers were tried but it was found that the index number 1 and 2 were the best for the data as it reflected the geological information of the area. Two Euler deconvolution maps were generated as shown in Figure (4 -5). The pink colour indicates shallow magnetic bodies, while the blue colour indicates deep lying magnetic bodies. The Euler depth result ranges from -721.4 m (shallow magnetic bodies) to -4187.5 m (deep lying magnetic bodies).

The depths estimation result from source parameter imaging (SPI) ranges from -491.4 m (shallow magnetic bodies) to -4102.1 m (deep lying magnetic bodies). The generated SPI grid image and SPI legend show varied colours displaying different magnetic susceptibilities contrast within the studied area, and could also portray the undulations in the basement surface. The negative sign shown on the source parameter imaging (SPI) legends of Figures 6 depicts the depths of buried potential field bodies, which may be deep seated basement rocks or near surface intrusive. The pink and red colours generally indicate areas occupied by shallow bodies, while the blue colour shows areas of deep lying potential field bodies. The deep seated bodies are predominant everywhere with an intermingling of shallow seated bodies in the study area. These are clearly portrayed in 3-D view in Figure 7 which is in different tilt positions. The results obtained from aeromagnetic Euler deconvolution closely agrees with that of the source parameter imaging. These depths are found to be within the range of depths predicted by earlier researchers that worked in Chad Basin. Akiishi *et al.*, (2018) got a depth range of 479.9 to 6507.6 m from aeromagnetic data of Chad Basin North Eastern Nigeria.

Therefore, the highest sedimentary thicknesses obtained from both methods in this work are sufficient enough for hydrocarbon accumulation due to the assertion made by Wright et. al., (1985) that the minimum thickness of the sediment required for the commencement of oil formation from marine organic remains would be 2300 m (2.3km). This implies that Guzabure and Gudumbali regions have the potential for hydrocarbon accumulations.

V. Conclusion

The aeromagnetic data of Guzabure and Gudumbali regions within the Nigerian Chad Basin have been interpreted qualitatively and quantitatively. The total magnetic intensity of the study area shows range of magnetic anomalies which vary from -75.5 nT to 63.4 nT showing that the area is marked with high (pink and red colours) and low (blue colour) magnetic intensities. Euler depth and Source parameter imaging analysis were employed in quantitative interpretation with the aim of determining depth/thickness of the sedimentary basin. The depth to basement obtained from the Euler depth method ranges from -721.4 meters to -4187.5 meters while the depth to basement obtained from source parameter imaging ranges from -491.4 meters to -4102.1 meters. The depth to basement from both the Euler depth and source parameter imaging methods seems to be equal, though the Euler depth is higher than source parameter imaging. These sedimentary thickness obtained in this work indicate the possibility of hydrocarbon accumulation in the study area. This implies that the study area has the potential for hydrocarbon accumulations.

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