DETERMINATION OF DEPTH TO MAGNETIC BASEMENT OVER BIU PLATEAU AND YOLA SUB-BASIN, NORTHEASTERN NIGERIA, USING SOURCE PARAMETER IMAGING (SPI) AND EULER DECONVOLUTION TECHNIQUES

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ABSTRACT

Quantitative analysis of aeromagnetic data covering total area of 48,000 km^2 on latitude 11.00^0 N to 13.00^0 N and Longitude 9.00^0 E to 11.00^{0}E, which corresponds to Basement Complex part of upper Benue trough northeastern, Nigeria was carried out with the aim of estimating the sedi mentary thickness using Source parameter imaging and Euler deconvolution. The study area is c overed by sixteen (16) aeromagnetic data sheet. Aeromagnetic data were analysed using the Oasi s Montaj 8.3 software. The total magnetic map was reduced to magnetic equator with geomagnet ic inclination of -4.3° and geomagnetic declination of -1.0° so as to get the actual position of the anomalies. The pre-processed grids dx, dy and dz from the reduced to magnetic equator map wer e used as input grids to calculate the source parameter imaging and Euler deconvolution. The res ults from the total magnetic intensity (TMI) and TMI - RTE shows that magnetic intensity values range from -94.1 nT to 235.5 nT and -80.261 nT to 234.153 nT respectively. The results indicate a dominant NE-SW, NW – SE and E – W orientation of faults and were also identified mostly at the edges of sediments-basement contacts. The result from SPI ranges from 0.110 km (shallow magnetic bodies) is observed at the northeast part of the study area which is made of crystalline rocks to 3.243 km (deep lying magnetic bodies) is observed at the Northwest, Southeast and Sou thwest part of the study area. The depths of the magnetic source bodies estimated from Euler dec onvolution for the structural index SI = 1 ranges from 0.094 km (out cropping magnetic bodies) t o 3.32 km (deep lying magnetic bodies). The shallower magnetic anomalies are as a result of bas ement rocks which intruded into the sedimentary rocks while the deeper magnetic anomalies are associated with magnetic basement surface and intra basement discontinuities like faults and frac tures. The maximum sedimentary thickness of about 3.24 km and 3.32 km from SPI and Euler d econvolution respectively might be sufficient for hydrocarbon maturation in the area.

Keywords: Aeromagnetic data; Analysis; Basement; Euler deconvolution; Magnetic equator; So urce Parameter Imaging.

1.0 INTRODUCTION

This study attempts to estimate the depth to ma gnetic basement using the quantitative analysis of aeromagnetic data covering total area of 48, 000 km^2 on latitude 11.00^0 N to 13.00^0 N and L ongitude 9.00^0 E to 11.00^{0}E. The area covered corresponds to Basement Complex and part of Upper Benue Trough northeast Nigeria. The st udy was carried out with the aim of estimating the sedimentary thickness using Source parameter imaging and Euler deconvolution.

Aeromagnetic survey is a powerful tool in delineating the lithology and structure of buried basement terrain. The detailed aeromagnetic map is very effective in cases where the geology of the study area is obviously identified. It is apply in a wide variety of geological studies and play an important role in tracing lithological contacts and for recognition of structures like faults, lineaments, dykes and layered complex (Reeves, 1989).

Aeromagnetic method essentially reflects the presence of subsurface structures, magnetic minerals and depth to causatives bodies in the earth's crust. Of all the airborne geophysical techniques, the aeromagnetic method has by far the highest resolution to detect features beneath the earth's surface (Hood *et al.,* 1979). The magnetic data is related to changes in magnetic susceptibilities and depths of their sources. So, these data are used to determining the location and the depth of the magnetic bodies that caused these data.

Aeromagnetic data are generally used in mapping of fracture and fault systems of the basement rock which often controls the mineralization of any area (Ananaba and Ajakaiye, 1987). The contribution of aeromagnetic survey in the regional interpretation of linear features and other geological structures has been of interest over the years. Aeromagnetic technique has therefore proven to be a veritable and potent tool for depth to magnetic source estimation and interpretation of geologic features that may lead to identification of mineral deposit areas (O'Leary, 1976; Gunn and Dentith, 1997). Interpretation of magnetic basement structures and depth can be delineated and mapped using aeromagnetic data and have been applied in different places world over with great success (Gunn and Dentith, 1997).

Some scholar such as Salako (2014), Kamba and Ahmed (2017), Nur *et al.* (2010), carried out studies based on aeromagnetic data interpretations in the Upper Benue Trough and Basement area of the North east Nigeria using various methods.

This aim has recently become particularly important because of the abundance of magnetic data that was applied for reconnaissance explorations of minerals and petroleum. Different approaches, based on the use of derivatives of the magnetic field, have been developed to determine magnetic source parameters such as locations of boundaries and depths (Salem *et al.,* 2008). Salako (2014), Kamba and Ahmed (2017) used Source Parameter Imaging (SPI) to determine the depth to basement. It was observed that deeper magnetic source ranging from 5 km and 3 km respectively. Megwara and Udensi (2014) carried out a structural analysis of the aeromagnetic data over the study area using the Werner and Euler deconvolution. The analyses which were carried out along profiles revealed depths to the magnetic sources of the range 0.01 km to 0.51 km with an average value of 0.128 km.

The application of the Euler deconvolution process in this study is to generate a map that shows the locations and the corresponding depth estimations of geologic sources of magnetic anomalies in a two-dimensional grid. Aeromagnetic data presented in grid form may be interpreted rapidly for source positions and depths by deconvolution using Euler's homogeneity relation (Reid *et al*., 1990). The Source Parameter Imaging (SPI) and Euler deconvolution of aeromagnetic fields over the study area would differentiate and characterize regions of sedimentary thickness from those of uplifted or shallow basement and also to determine the depths to the magnetic sources. The results could be used to suggest whether or not the study area has the potential for oil/gas and mineral deposits concentration.

2.0 LOCATION AND GEOLOGY OF THE STUDY AREA

The study area is located at the northeast part of Nigeria. It is bounded by latitudes $9^0\, 00'\, 00''$ N to $11^0\, 00'\, 00''$ N and longitudes $11^0\, 00'\, 00''$ E to $13^0\, 00'\, 00''$ E (Figure 1). The area is generally hot, with the average temperature of 32°C.

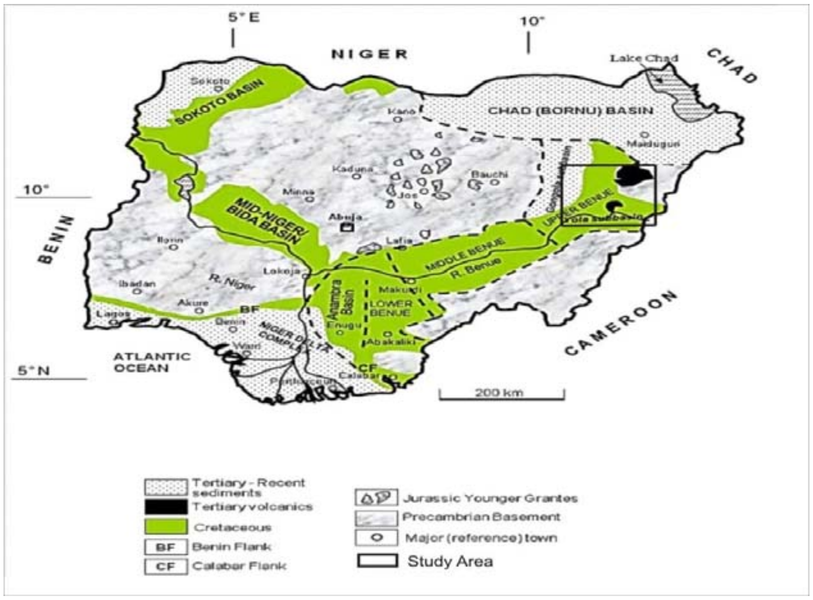

Figure 1: Geological Map of Sedimentary Basins of Nigeria showing study area (After Obaje, 2004)

The main controlling factors of temperature in the area are amount of rainfall and elevation (Udo, 1970). The amount of precipitation generally decreases as the elevation increases from the southern parts of the study area northwards. Consequently, the vegetation cover of the area is the sandy and sparse grass patches Sahel type Savannah (Kogbe, 1983). The arid conditions of the study area are attributable to the persistence of the dry season, which last for six months long every year. The highest point is about 683.04 m above mean sea level (msl) and is therefore the coldest in the area and the lowest point above sea level is about 134.72 m in the study area.

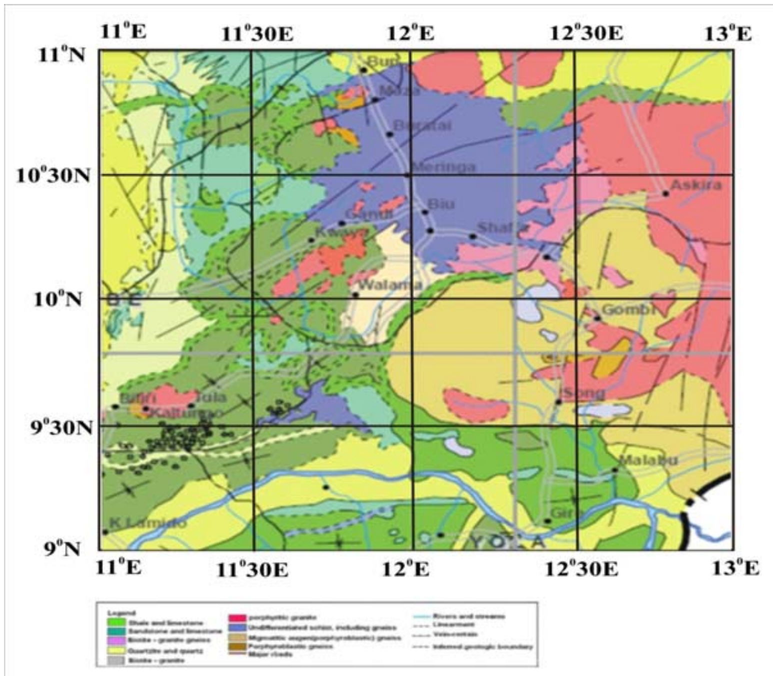

Figure 2: Geology of the study area

The geology of the area is made up of the Precambrian Basement Complex rocks which are considered to be undifferentiated basement complex (McCurry, 1979 and Bassey *et al.,* 1999), mainly gneisses, migmatite and granites outcropping in different parts of the study area which include, Garkida, Shani, Zumo, Chibok and even in Girei. Cretaceous sediment belonging to Bima sandstone and Yolde Formation outcrops at the northern part of the study area (Figure 2). The Tertiary to Recent volcanics (Biu basalt) are third most widespread rocks in the study area belonging to northern arm of Cameroon volcanic line. The volcanic vary in composition from basalt to trachyte and rhyolite.

The Keri-Keri Formation is composed of sandstones, siltstones and shale underlying the Gombe sand stone. The formation which outcrops in this part of the study area is Palaeocene in age. The Yolde Formation is considered to be transitional between the continental Bima and marine Gongola formations. This formation shows lateral variation of Sandstone and Calcareous shale. The Bima unit varies in thickness between 100-300 m.

The Pan-African Older Granites are the second wide-spread group of rocks in the study area. They intruded into the Gneiss-migmatite complex. The gneiss-migmatite complex is the most widespread and occupies more than half of the area and is the oldest rock here. They are heterogeneous rock group, which is composed gneiss migmatite of various origin and series of metamorphosed basic and ultrabasic rocks (Grant, 1971).

Pindiga formation is a sequence of Marine shale with a number of limestone beds towards the base of the Formation. The Tertiary- Recent volcanic rocks in the study area consist of the basalts, trachyte, rhyolite, and newer basalts of eastern arm of Cameroon volcanic line.

3.0 MATERIALS AND METHODOLOGY

3.1 Materials

Sixteen aeromagnetic data sheets were acquired, assembled and knitted for this study, these are: 131(Bajoga), 132 (Gulani), 133 (Biu), 134 (Chibok), 152 (Gombe), 153 (Wuyo), 154 (Shani), 155 (Garkida); 173 (Kaltungo), 174 (Guyok), 175 (Shellen), 176 (Zumo); 194 (Lau), 195 (Dong), 196 (Numan) and 197 (Girei). These sheets were obtained as part of the nationwide airborne survey carried out by Fugro, sponsored by the Nigerian Geological Survey Agency and published in the year 2009. The data were obtained at an altitude of 80 m along a flight line spacing of 500 m oriented in NW-SE and a tie line spacing of 2000 m. The maps are on a scale of 1:100,000 and half-degree gridded sheets. The geomagnetic gradient value of 33,000 nT was removed from the data using the International geomagnetic Reference Field (IGRF) 2010. The sixteen maps covering the study area were combined as a composite map Figure 3.

3.2 Methodology

3.2.1 Reduction to Magnetic Equator (RTE)

RTE filter was applied in accordance with International Geomagnetic Reference Field (IGRF) reduction technique to the total magnetic field map (Figure 3), using a geomagnetic inclination and geomagnetic declination so as to get the actual position of the magnetic anomalies. To produce anomalies that depends on the inclination and declination of the body's magnetization, inclination, and declination of the local earth's field and orientation of the body with respect to the magnetic north (Baranov, 1957), it is usually necessary to perform a standard phase shift operation known as Reduction-to-Pole (RTP) on the observed magnetic field. As discussed by Macleod *et al.* (1993), problems can arise in the reduction to the pole process at magnetic latitudes less than 15°, as the Fourier domain transformation process becomes unstable, owing to the need to divide the spectrum by a very small term, thereby introducing north-south alignment of the anomalies into the data.

$$L(\theta)=\frac{[\sin(I)-i.\cos(I).\cos(D-\theta)]^2*(-\cos^2(D-\theta))}{[\sin^2(I_a)+\cos^2(I_a).\cos^2(D-\theta)]*[\sin^2(I)+\cos^2(I).\cos^2(D-\theta)]} \quad (1)$$

If $(|I_a|<|I|)$, $I_a = I$

where $L(\theta)$ is the TMI reduction to equator (RTE), I is the geomagnetic inclination, I_a is the inclination for amplitude correction and D is the geomagnetic declination. First vertical derivative (FVD) is performed on the TMI reduced to equator data to enhance shallow geological features of the area.

3.2.2 Source Parameter Imaging (SPI)

The Source Parameter Imaging ™ (SPI™) function is a quick, easy, and powerful method for calculating the depth of magnetic sources. Its accuracy has been shown to be +/- 20% in tests on real data sets with drill hole control (Li, 2006). This accuracy is similar to that of Euler deconvolution, however SPI has the advantage of producing a more complete set of coherent solution points and it is easier to use than other methods (Salako, 2014).

A stated goal of the SPI method (Thurston and Smith, 1997) is that the resulting images can be easily interpreted by someone who is an expert in the local geology. The SPI method (Thurston and Smith, 1997) estimates the depth from the local wave number of the analytical signal. The SPI depth of magnetic data was determined using oasis montaj software and employing the first vertical derivatives and horizontal gradient. This model was displayed on an image and correct depth for each anomaly is determined.

3.2.3 Euler Deconvolution

Applying Euler deconvolution technique (Thompson, 1982) to the aeromagnetic data grid of the study area offers a good means of interpreting contacts, faults and causative source types d epending on the preselected structural index (SI), which identifies the rate of change of the potential field with the distance (Reid et al., 1990). One structural indice has been selected as 1 characterizing dikes and plots has been constructed (Figure 6) with different colour corresponding to different depths of the source positions.

The basic theory of Euler deconvolution technique is given as: Any three dimensional function f(x, y, z) is said to be homogeneous of degree n if the function obeys the expression:

$$f(tx, ty, tz) = t^n f(x, y, z)$$

From this, it can be shown that the following (known as Euler's equation) is also satisfied:

$$x\frac{\partial f}{\partial x} + y\frac{\partial f}{\partial y} + z\frac{\partial z}{\partial z} = nf$$

The degree of homogeneity, n, can be interpreted as a structural index (SI). A magnetic dike and an anomalous pipe mass correspond to n = 1.

The main advantage of using this technique is that it provided a fast method for imaging approximate depths to subsurface bodies. The identified locations and depths to the causative sources are independent of magnetization directions or distortion of field caused by remanent magnetism (Reid *et al.*, 1990). The form of the feature was also inferred from the optimum structural index applied.

4.0 RESULTS AND DISCUSSION

4.1 Total Magnetic Intensity Map (TMI)

The total magnetic field map (Figure 3) shows variation of magnetic signatures and is produced in different colours; pink to red colour and green to blue colour depicting positive anomalies and negative anomalies respectively. The TMI map of the study area reveals both positive and negative anomalies ranging from -94.1 nT to 235.5nT after the removal of IGRF of 33,000 nT.

The eastern part of the study area is made of short wavelength anomalies which corresponds to crystalline basement rocks while the southern and northwestern part are made up of long wavelength anomalies which corresponds to deposition of sediments with basement intrusion into the sediments. The extreme upper part of the study area is predominantly of negative (low) anomalies while the western to the middle portion of the areas is dominated by positive (high) magnetic anomalies. Major structures observed from Fig. 3, probably faults, trends NE-SW, NW-SE and E-W directions.

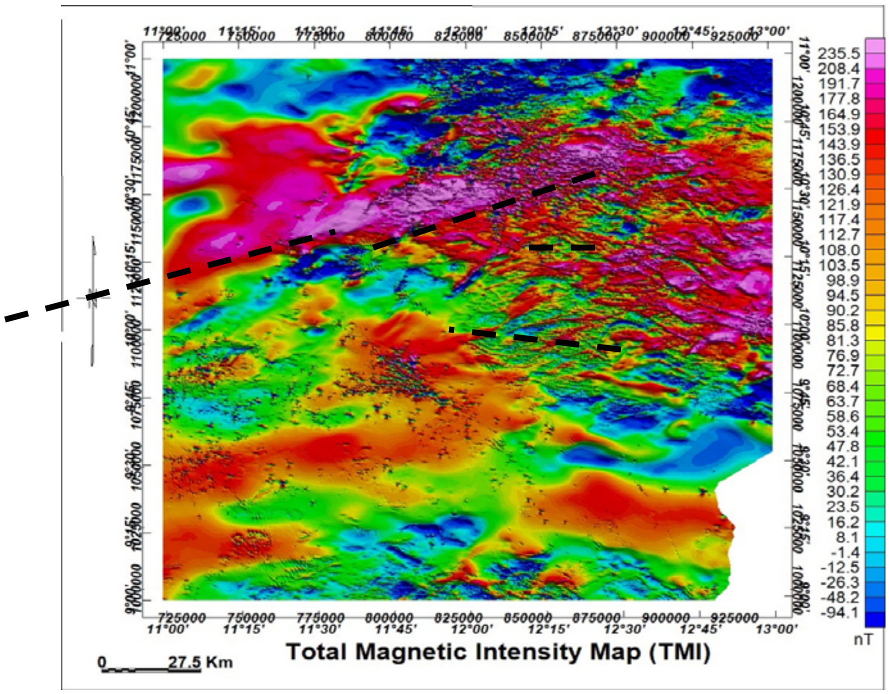

Figure 3: Total Magnetic Intensity Map (TMI) of the Study Area

4.2 Reduce to Magnetic Equator Map (RTE)

The total magnetic field map of the study area was reduced to magnetic equator with geomagnetic inclination -4.3° and geomagnetic declination – 1.0° to get the actual position of the magnetic signatures without losing any geophysical meaning (Figure 4). The RTE map was further used for the depth analysis. The TMI_RTE map show a slight variation in intensity compared to the TMI and varies from -80.261 to 234.153 nT. The locations of low and high magnetic anomalies observed on the TMI (Figure 3) correspond to that of RTE map (Figure 4) in terms of location and distribution. The maps revealed the trends of the TMI anomalies were mostly oriented along NE-SW, NW-SE and E-W directions.

As it can be observed on the map (Figure 3 and 4), faults systems were observed with trends of NE-SW, E-W and NW-SE direction. According to a study, the variation in trends of the faults was attributed to deeper heterogeneity of the earth crust during the sequence of events.

The total magnetic intensity reduced to equator map agrees with the geological map of the study area. The geology of the area is divided into two formations; the basement complex and the sedimentary basin. The basement complex occupies major areas in the north east, e.g, Gulani, Wuyo, Biu etc; these are areas with promising solid minerals of economic potentials like, limestone, uranium, gypsum, granite, quarzt etc. While the sedimentary basin occupies the south to south west which also hosts some industrial minerals like Sands, Clay, coal, and the formation is also potential for hydrocarbon exploration.

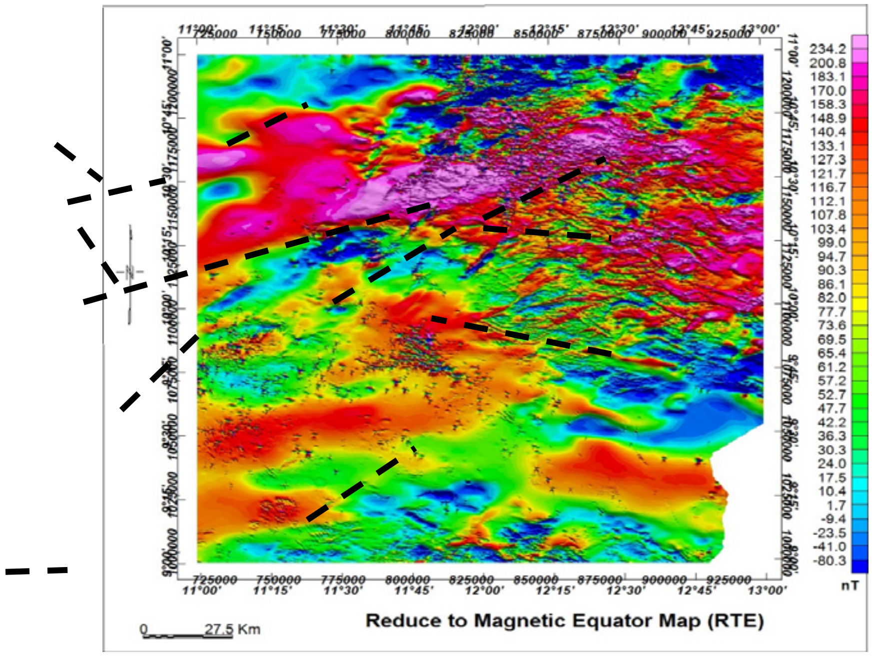

Figure 4: Total magnetic intensity map reduced to equator (TMI_RTE)

The positive anomalies of NE-SW direction tend to slightly decrease in amplitude and wavelength to the NE causing those to the NW to increase in these aspects. The strong anomalies in the NW reveal the presence of accumulation of minerals of strong susceptibilities in the faults. This could be due to diamagnetic minerals such as quartz and on the other, ferromagnetic minerals of strong residual magnetization such as that of the gneiss with biotites and compound gneisses with biotites in the basement complex area.

Structural trends within the study area are NE-SW, NW-SE and E-W directions. High Frequency (short wavelength) signatures observed at the north east and southern edge portion of the study area revealed a shallow depth to magnetic source typical of Basement Complex. The north edge, west, south east and south parts of the study area are dominated by both intermediate and low magnetic intensity. These areas were interpreted as the sedimentary formations which comprises the limestone and sandstone.

4.3 Depth Analysis

4.3.1 Source Parameter Imaging (SPI)

The SPI image map highlights spatial location of various magnetic sources at various depths. According to (Nwosu, 2014), the colour variation found in the SPI model (Figure 6) portrays undulations within the basement. The negatives found beside the numbers signify depth. The magnetic bodies are evenly distributed as revealed by the image map. Maximum depth of 3.243 km can be observed at the north western, south east and south west parts of the map (Figure 6), while minimum depth values of 0.110 km occur at the northeastern, south west and southern edge of the map.

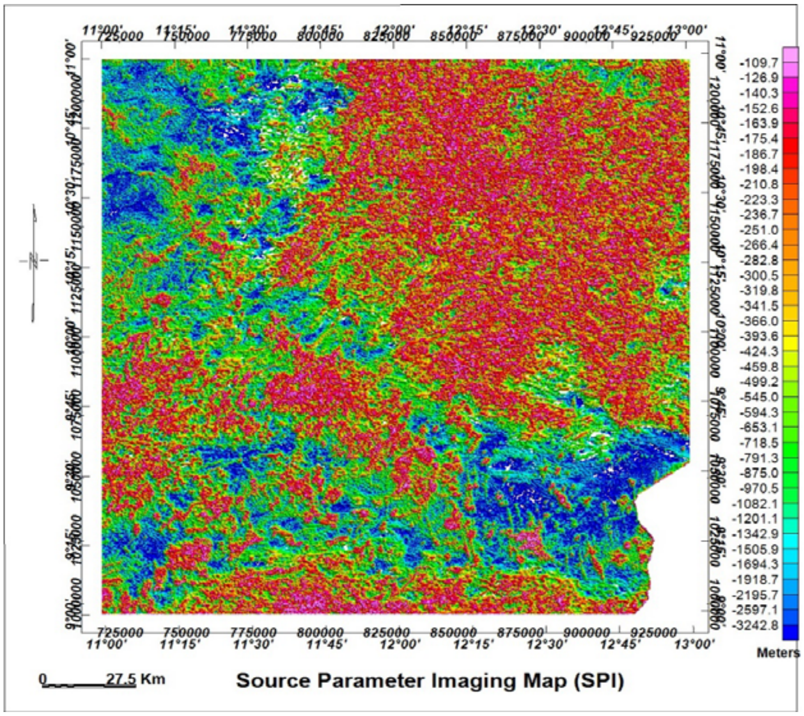

Figure 5: Source Parameter Imaging Map (SPI)

4.3.2 Standard Euler Deconvolution Map

Figures 6 represent the map for the Euler depth for structural index 1.0 of the magnetic anomalies over the study area. The Euler Depth map shows that the depth to magnetic sources (anomalies) ranges from 0.094 to 3.32 km, while the maximum depth of the located anomalies to be about 3.32 km around Bajoga, Gombe and Gulani in the north west of the study areas and within the Yola sub-basin in the south east and also in the south west. The result this magnetic basement depth, according to (Nwosu 2014), is synonymous to depth of over burden sediment is sufficient enough for hydrocarbon maturation or accommodation.

The shallow sources also exist in the most part of north east, south west and in the southern edge of the map with an average depth ranging from 0.094 km to about 0.437 km.

The value of the structural index, 1.0 is typical for a sill or dyke (Adetona, and Abu, 2013) and this could be attributed to feldspar which always crystallize in intrusive igneous rocks that have intrude layers of sedimentary bed and also feldspar are part of the mineral found in this part of the basement complex.

The colour legend helps in locating the deep seated features represented by the blue colour on the map with limit of the intrusive bodies. The findings correlate the result of other researchers within the northeast basement and sedimentary formation. The sedimentary thickness of over 3.2 km found at the NW, SE and SW portion of the study area could be potentially viable for hydrocarbon maturation (oil and gas).

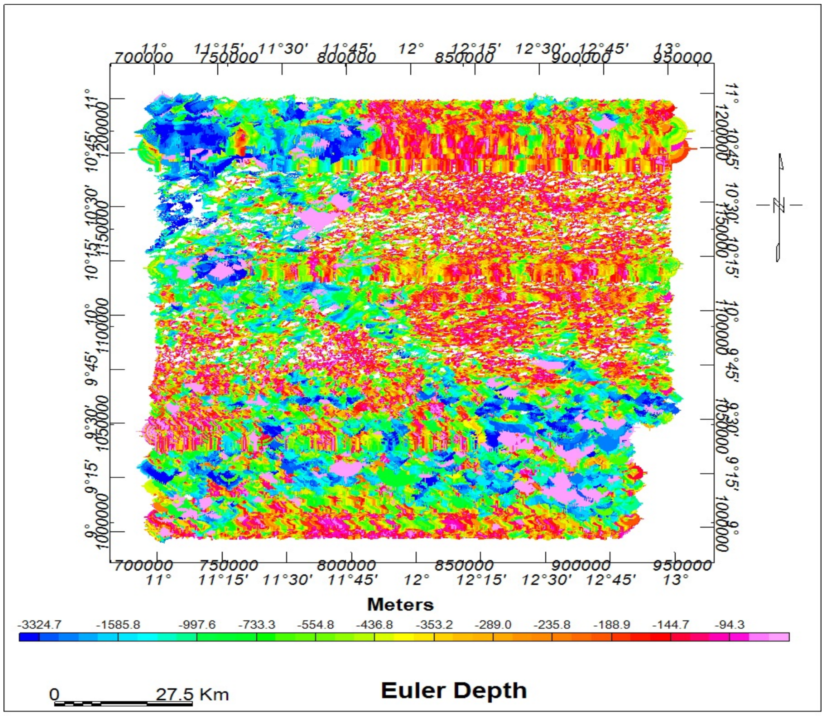

Figure 6: Euler Deconvolution Map of the Study Area

5.0 CONCLUSION

Quantitative analysis and interpretation of aeromagnetic data of Biu and Yola Sub-Basin had been carried out with aim of estimating depth to magnetic basement for possible hydrocarbon maturation using Source parameter Imaging and Euler deconvolution. The depth result from Source Parameter Imaging (SPI) has its highest sedimentary thickness of about 3.243 km at the Northwest, Southeast and Southwest part of the study area. The shallow sedimentary thickness of about 0.10973 km is observed at the northeast part of the study area which is made of crystalline rocks (the Biu basalt). The depths of the magnetic source bodies estimated from Euler deconvolution for the structural index SI = 1 ranges from 0.0943 km to 3.3247 km. The maximum sedimentary thickness obtained from Euler deconvolution agrees with the high sedimentary thickness from SPI which corresponds to the northwest and the southeast part of the study area. The maximum sedimentary thickness of about 3.24278 km and 3.320 km from SPI and Euler deconvolution respectively might be sufficient for hydrocarbon maturation.

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