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Source Parameter Imaging and Euler Deconvolution of High Resolution Aeromagnetic data to Delineate Sedimentary Thickness of Sokoto Basin, North Western Nigeria

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ABSTRACT

This study presents the results of the analysis and interpretation of highresolutionaeromagnetic data over part of Sokoto basin with the aim of investigating the hydrocarbon potential of the area. The study area is located between longitudes 4.00^{0}E to 7.00^{0}E and latitudes 12.00^{0}N to 13.50^{0}N in the Northwestern Nigeria.Eighteen (18)total magnetic intensity map was subjected to regional/residual separation to produce residual map using Muntajsoft ware. The composite and residual mapsrevealed heterogeneity in the magnetic signature, ranging from -58.0nT to 120.6nT and -95.7nT to 66.5nT respectively. Regional-residual separation was performed on the composite total magnetic intensity map using polynomial fitting. The residual map was subjected to source parameter imaging and Euler deconvolution. The results of these two methods corroborate; the SPI and Euler Deconvolution shows a thick sedimentation of 1.5km and 1.7km at the north-western and some parts in the central and northeastern parts of the study area respectively. Also, the SPI and Euler Deconvolution revealed shallow thickness with 0.14km and 0.04km at south-eastern and southern parts respectively. The maximum sedimentary thickness of 1.7km in the study area is not sufficient for sufficient for hydrocarbon maturation and accumulation.

Keywords-Aeromagnetic data,Anomaly, source parameter imaging Euler deconvolution, Hydrocarbon, Sedimentary thickness

I. INTRODUCTION

Hydrocarbons have alwaysbeen important and essential natural resources to the general economic development of Nigeria. There is need to sustain the exploitation of this resources, so as to maintain and improve the general standard of living of the Nation.According to Oil and Gas Journal (OGJ, 2007), Nigeria had 36.2 billion barrels of proven oilreserves as of January 2007, while the government plan to expand its proven reserves to 50 billion barrels by 2030. The majority of reserves are found along the country's Niger Delta, in southern Nigeria and offshore in the Bight of Benin, Gulf of Guinea and Bight of Bonny. Therefore, it is important to explore for exploitation of crude oil in Sokoto Basin and other frontiers/inland basins of Nigeria.

Aeromagnetic survey technique is a notable geophysical method which has been usedeffectively to investigate subsurface geology in different capacity such as archeological,geothermal, hydrocarbon and mineral studies. Studies of aeromagnetic data with interest inhydrocarbon exploration have been performed in recent years. The study that employedaeromagnetic data of Muglad Basin in South Sudan discovered magnetic anomalies whichclustered along a prospective structure and coincided with the Jarayan oil field . A major advantage of aeromagnetic survey is the accessibility to cover major inaccessible areas that might prove expensive and slower to map out. For hydrocarbon resources, the aeromagnetic surveys are used at the initial stages to map out and evaluate the thickness of the sedimentary basin. This is achievable by

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analyzing and estimating the depths of the magnetic sources (i.e. the magnetic basement rocks causing the observed anomalies) within the study area. Largely, this is subjected to the fact that sedimentary rocks are non-magnetic for all intents and purpose. Therefore, the aeromagnetic anomaly is attributed to basement rocks.

The study area falls within Sokoto Basin, Northwestern Part of Nigeria which comprises of 18 sheets with 52 local governments areas of three states (Sokoto, Kebbi and Zmfara States) in the Northwestern Nigeria as shown in Fig 1. They are bounded by longitudes 4.00^0E to 7.00^0E and latitudes 12.00^0N to 13.50^0N in the Northwestern Nigeria.

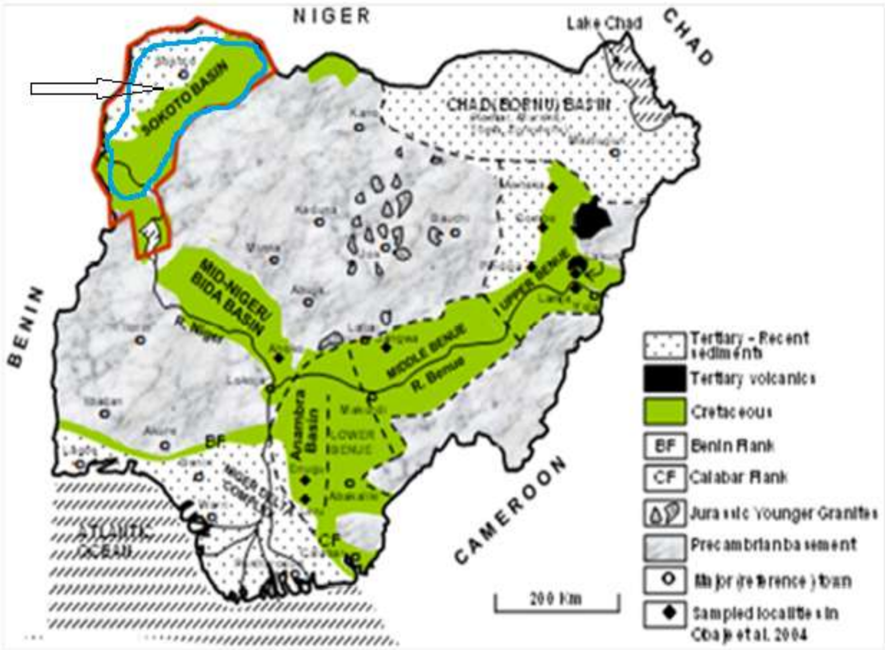

Fig. 1 Generalized Geological Map of Nigeria showing the location of the study area in Sokoto Basin

The geology of the Sokoto Basin has been greatly explained by different scholars , such as Obaje2009; Kogbe. 1976; the Sokoto Basin was extensively explained by Obajeet al 2013. The sediments of the Iullemmeden Basin were accumulated during four main phases of deposition. Overlying the Pre-Cambrian Basement unconformably, the Illo and Gundumi Formations, made up of grits and clays, constitute the Pre-Maastrichtian "**Continental Intercalaire**" of West Africa. They are overlain unconformably by the Maastrichtian **Rima Group**, consisting of mudstones and friable sandstones (Taloka and Wurno Formations), separated by the fossiliferous, calcareous and shaleyDukamaje Formation. The Dange and Gamba Formations (mainly shales) separated by the calcareous Kalambaina Formation constitute the Paleocene **Sokoto Group**. The overlying continental Gwandu Formation forms the Eocene **Continental Terminal**. These sediments dip gently and thicken gradually towards the northwest with maximum thicknesses attainable toward the border with Niger Republic. The figure 2 depicts the stratigrapy succession of sokoto basin, Northwestern Nigeria.

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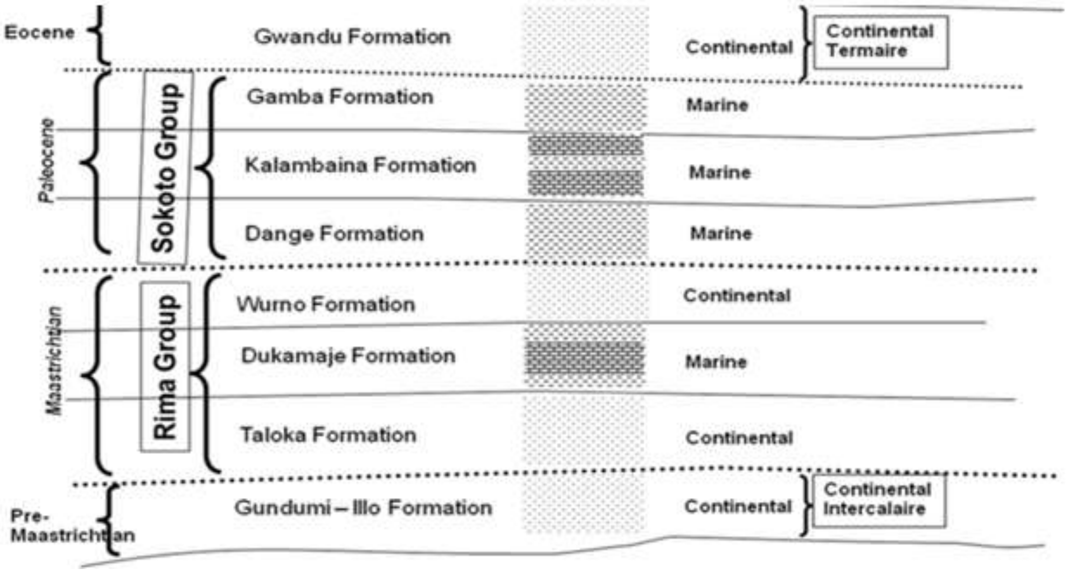

Fig. 2Generalized Stratigraphic Successions of Nigeria Sokoto Basin(Obaje, 2004)

However, the study area has five geological formations namely; Gwandu formation, Wurno formation, Dukamaje formation, Taloka formation and Ilo/Gundumi formation as shown in the Figure 3.

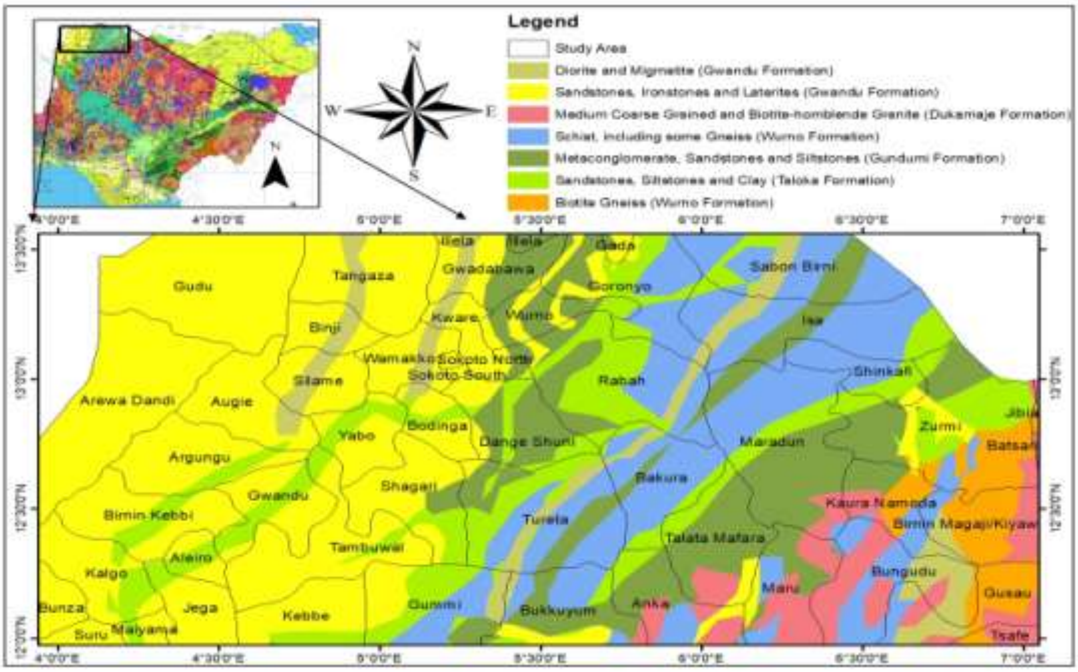

Fig 3. The Geological Map of the Study Area.

II. METHOD

Eighteen (18) half degree by half degree airborne radiometric data were acquired from the Nigerian Geological Survey Agency (NGSA) Abuja. The sheet numbers with their respective locations are; Sheet 8(Sakkwabe), Sheet 9(Binji), sheet 10(Sokoto), Sheet 11(Rabah), sheet 12(Isah), Sheet 13(Shinkafe), sheet 27(Leman), sheet 28(Arugungu), sheet 29(Dange), sheet 30(Gandi), sheet 31(Mafara), sheet 32(Kaura), sheet 49(Birnin Kebbi), sheet 50(Tambuwa), sheet 51(Gunmi), sheet 52(Ankah), sheet 53(Maru), sheet 54(Gusau). The aero-radiometric dataset was obtained as part of the airborne survey carried out

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between 2005 and 2009 by Fugro on behalf of the Nigerian Geological Survey Agency. The data were obtained at an altitude of 100 m along with 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 sheets.

In order to produce a composite map of the study area, the first step taken was to assemble the four maps covering the area. The map was then re-gridded to produce the total magnetic intensity (TMI) map of the study area usingOasis montaj software 8.3 version. The actual magnetic intensity value of 33,000nT which was reduced (for handling purpose) before plotting the contour map was added so as to get the actual value of the magnetic intensity at any point.

2.2. Methods

2.2.1 Source Parameter Imaging (SPI)

The Source Parameter Imaging (SPI) is a technique using an extension of the complex analytical signal to evaluate magnetic depths. The Source Parameter Imaging (SPI) function is a fast, simple, and capable method for computing the depth of magnetic sources. Its accuracy has been demonstrated to be +/- 20% in tests on real data sets with drill hole control. This accuracy is analogous to that of Euler deconvolution, however SPI has the advantage of delivering a more complete set of coherent solution points and it is easier to use (Salako, 2014). One merit of the SPI technique is that the depth can be visualized in a raster format and the true thickness can be determined for each anomaly. The Source Parameter Imaging (SPI) of aeromagnetic fields over the area would differentiate and characterize regions of sedimentary thickening from those of uplifted or shallow basement and also to determine the depths to the magnetic sources. SPI is a procedure for automatic calculation of source depths from gridded magnetic data (Thurston and Smith, 1997). The results could be used to suggest whether or not the study area has the potential for oil/gas and mineral deposits concentration.

SPI assumes a step-type source model. For a step, the following formula holds:

$$Depth = \frac{1}{K_{max}} \quad (1)$$

where Kmax is the peak value of the local wavenumber K over the step source.

$$K = \sqrt{\left(\frac{dA}{dx}\right)^2 + \left(\frac{dA}{dy}\right)^2 + \left(\frac{dA}{dz}\right)^2} \quad (2)$$

$$\text{Tilt derivative } A = \tan^{-1}\left(\frac{\frac{dT}{dz}}{\sqrt{\left(\frac{dT}{dx}\right)^2 + \left(\frac{dT}{dy}\right)^2}}\right) \quad (3)$$

T = the total magnetic fieldanomaly grid.

Euler Deconvolution

Euler deconvolution is a method to estimate the depth of subsurface magnetic anomalies and can be applied to any homogeneous field, such as the analytical signal of magnetic data. It is particularly good at delineating the subsurface contacts. It has been observed that the depth estimates from magnetic data are more accurate if the pole-reduced magnetic field is used, than when using the magnetic data themselves. Euler deconvolution was originally developed in exploration geophysics for rapidly estimating the location of and depth to magnetic or gravity sources. It is based on the fact that the potential field produced by many simple sources obeys
Euler's homogeneity equation (Hood, 1965). If a given component of the magnetic anomalous field ΔT(x, y, z) satisfies the following equations:

$\Delta T(x, y, z) = t^n \Delta T(x, y, z)$(4)

where n is the degree of homogeneity, then differentiating Equation 4 with respect to t gives Equation 5:

$x\partial\Delta T/\partial x + y\, \partial\Delta T/\partial y + z\, \partial\Delta T/\partial z = n\Delta T$(5)

where x, y, and z are the coordinates of the field observation points and assumed to be at the origin.

According to Thompson, (1982), considering the potential field data, Euler's deconvolution equation can be expressed as

$(x - x0)\, \partial\Delta T/\partial x + (y - y0)\, \partial\Delta T/\partial y + (z - z0)\, \partial\Delta T/\partial z = N(B - T)$(6)

where (x0, y0, z0) is the position of a magnetic source whose total magnetic field T is measured at (x, y, z) . The total field has a regional value B, and N is the degree of homogeneity (structural index), which is equivalent to n in Equation (5). The unknown coordinates (x0, y0, z0) are estimated by solving a determined system of linear equations using a prescribed value for N with the least squares method. And a solution with a minimum standard deviation is found through using different tentative values for N. In this study, the Euler deconvolution was used to determine the

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thickness of sediment for hydrocarbon potential of the study area.

III. RESULTS AND DISCUSSION

Digitized airborne magnetometer survey maps of total magneticfield intensity for 18 sheets of the study area in Sokoto basin were acquired, assembled andinterpreted.The total magnetic field intensity map derived from the datadigitization and enhancement is presented as total magnetic intensity map, residual map, source parameter imaging map and Euler deconvolution map respectively (Figures 4-7). The resultant total magnetic field mapobtained from the digitized aeromagnetic data shows a very complexpattern of magnetic anomalies of both short and long wavelengths. The total magnetic intensity map of the study area is shown in Fig. 4; the map can be divided in to three main sections though there are others minor depressions scattered all over the area. The low magnetic intensity value represented by dark green – blue color is found all around most areas in the map but concentrated toward the eastern and southeastern parts of the study area, ranging between -58.0 to 55.2 nT. The high magnetic intensity value represented by pink – red color scattered all over the study area but concentrated in the southwestern, northwestern and also little fragments in the northeastern parts of the study area with values varying between 79.2 to 120.6 nT, while the two sections are separated by a zone characterized by medium magnetic intensity value of (57.5 – 77.1 nT) and it is also represented by yellow- orange color with concentration towards central part of the study area.

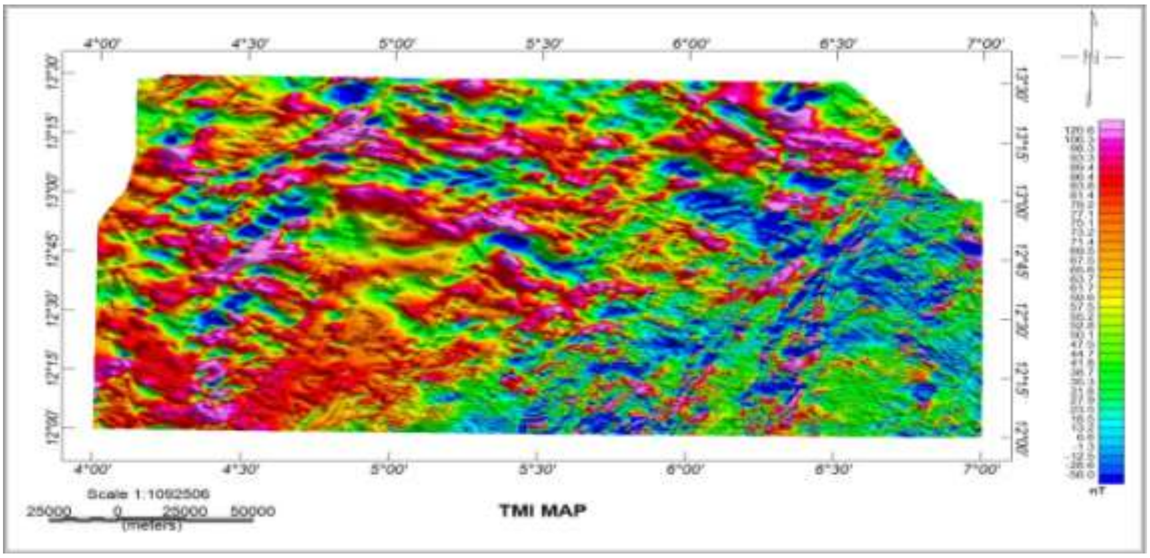

Fig. 4. The Total Magnetic Intensity Map of the Study Area

3.1. Residual Magnetic Intensity Map

Fig.5 is the residual magnetic intensity map of the study area obtained from the total magnetic intensity map produced using OasisMontaj version 8.3.The residual magnetic map shows magnetic anomalies with highmagnetic intensity is represented with pink-red colourwhich scattered all over the study area but trending to be more prominent in the northern and western parts with values ranging from 24.6 nT to 69.5nT and a low magnetic intensity is represented with blue-dark green colourwhich scattered all over the study area but more prominent in the south eastern part of the area withvalue ranging from -95.7 to 3.2 nT, while the section separating the two is medium magnetic intensity which is represented with yellow-orange colourand alsoscattered all over the study area but more prominent in the central part of the area withvalue ranging from 4.9 - 22.3 nT.

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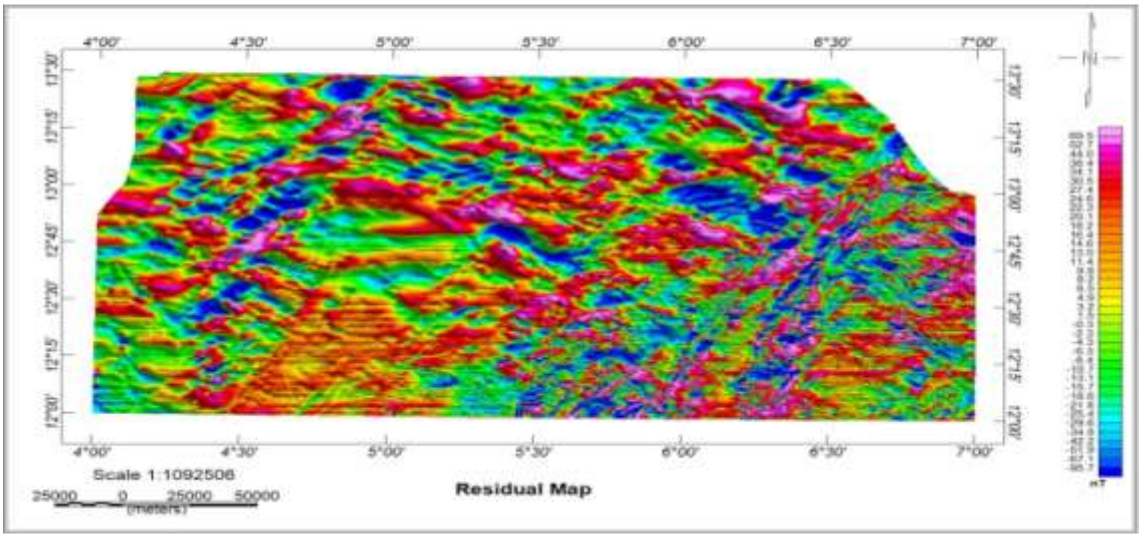

Fig. 5. The Residual Magnetic Intensity Map of the Study Area

3.2 Source Parameter Imaging

Figure 6 shows the result of the source parameter imaging of high resolutionaeromagnetic data generated from the residual data of the study area. The result depicts the maximum depth of 1531.1m. The depth to top of magnetic basement of the study area was estimated using source parameter imaging (SPI). SPI gives a clear image of the anomalies with respect to their depth. Figure 7 is the Source parameter imaging map and was produced in aggregates of colours; blue colour depicting thick sediments in the study area; green and yellow colour depicting intermediary depth and red and pinkcolour depicting shallow depth.

The deeper depths ranging from 703.6 m to 1531.4 m at the North western part, central and some parts of Northeast of the study area which corresponds to Gudu, ArewaDdandi,Augei, Binji and part of Tangaza, parts of DangeShuni and Sabon Birni areas of the study area. The intermediate depth is being represented by green to yellow colour with depth ranging from 229.3 to 662.7m which scattered all over the area except southeastern parts with very minute appearance in the study area. The shallow depth ranging from 139.8 to 218.5m which corresponds to Bugudu, TalataMafara, Anka, Tsafe,Gusau, KauraNamoda,Maradun, BirniMagaji, and Bukkuyum of southeastern and southern parts of the study area.Since the maximum depth of 3 km and above in a rift basin is sufficient for hydrocarbon maturation and accumulation (Adewumi et al., 2017). Hence, the deepest sedimentary thickness of 1531.4m obtained from the study area is not sufficient for hydrocarbon maturation and accumulation and which implies a bad pointer for petroleum exploration.

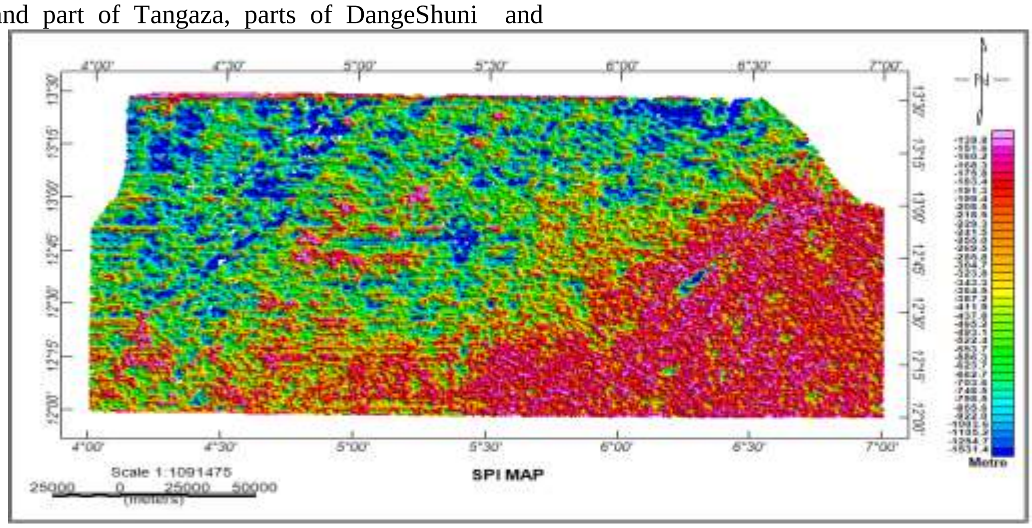

Fig. 6 The SPI Map of the Study Area

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3.3 Euler Deconvolution

The Euler depths were estimated and three categories of depths were determined. The Euler Deconvolution gives a clear image of the anomalies with respect to their depth. Figure 7 is the Euler Deconvolution map and was produced in aggregates of colours; blue colour depicting thick sediments in the study area; green and yellow colour depicting intermediary depth and red and pink colour depicting shallow depth.

The thickest sediments ranging from 969.7 to 1799.8m at the North western, parts, central and some parts of Northeast of the study areawhich corresponds to Gudu, ArewaDdandi,Augei, Binji and part of Tangaza, parts of DangeShuni and Sabon Birni areas of the study area. the intermediary depth ranging from 254.1 to 916.1m which also scattered all over the study area but more concentrated in the central part of the study area. While the shallow depth ranging from 36.9 to 230.6m which also corresponds to Bungudu, TalataMafara, Anka, Tsafe,Gusau, KauraNamoda,Maradun, BirniMagaji, and Bukkuyum of southeastern and southern parts of the study area. fig 6 which indicates the SPI map corresponds to fig 7 which indicates the Euler Deconvolution map. The two maps agree with small range in the figures in which the deeper depth in SPI corresponds with the deeper depth in Euler Deconvolution Map and shallow depth respectively.The maximum depth of 1799.8m obtained at the North western part, central and some parts of Northeast of the study area from the Euler solutions is notsufficient for hydrocarbon.

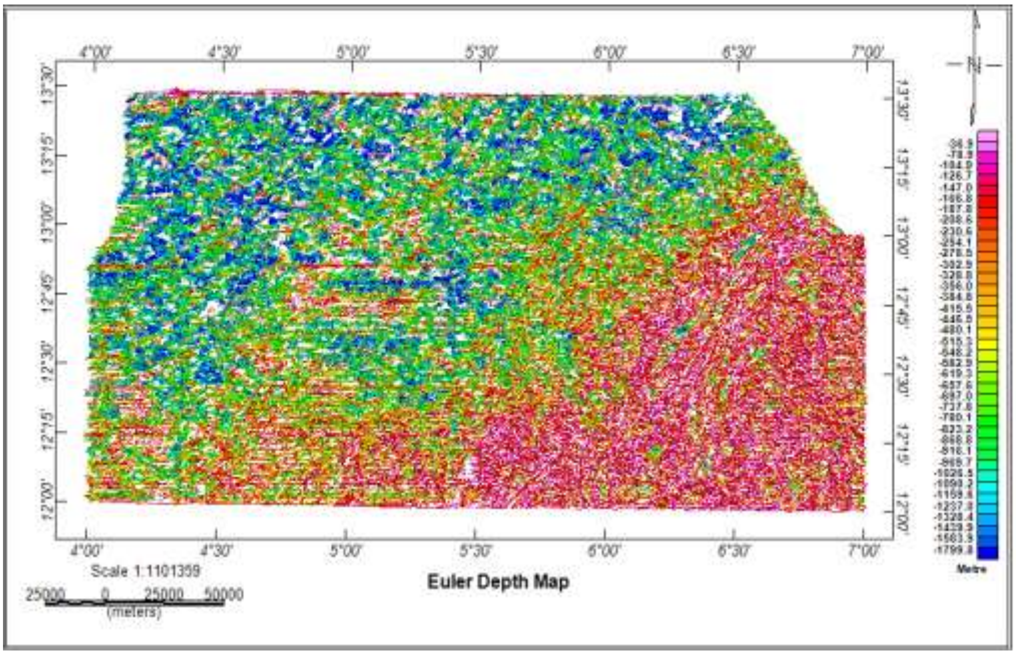

Fig. 7 The Euler Deconvolution Map of the Study Area

IV. CONCLUSION

Quantitative interpretation of aeromagnetic data over some parts of Sokoto basinin Northwestern Nigeria was carried out with the aim of estimating the sedimentary thickness for hydrocarbon potential. Source parameter imaging (SPI) and Euler deconvolution techniques were employed for this purpose.The maximum sedimentary thicknesses obtained from both the two techniques are1531.4m and 1799.8m respectively, are insufficient for hydrocarbon maturation since the maximum depth of 3 km and above in a rift basin (Sokoto Basin) is sufficient for hydrocarbon maturation and accumulation (Adewumi et al., 2017).. Seismic reflection may further be employed in order to authenticate the results.

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