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SOURCE PARAMETER IMAGING OF AEROMAGNETIC MAP OF SOKOTO BASIN, NORTHWESTERN NIGERIA

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ABSTRACT: *Recent aeromagnetic data of some parts of the Sokoto basin, an arm of the Iullemmeden Basin, north-western Nigeria was analyzed using source parameter imaging (SPI). The analyses were aimed at determining the depth to magnetic sources based on the total magnetic intensity (TMI) map of the basin and ascertain whether the basin has a good hydrocarbon potential. The area under study is situated between latitudes 10°30'' N and 14° 00" N and longitudes between 3° 30" E and 7° 00" E covering area of 59,570 km^2. Results of the analysis showed that the deepest and the shallowest magnetic sources are about 1.55 km and 0.12 km respectively. The deepest magnetic sources represent the magnetic basement whereas the shallow magnetic sources represent sedimentary layer. A significant variation is observed in the sedimentary thickness and this is shown to be dipping north-westwards giving the basement a rugged topography. The basement surface is also marked with a number of sediment-filled troughs and depressions and these were noted to have formed targets for groundwater. The interpreted SPI showed that the Sokoto Basin is shallow depth to basement sedimentary basin hence, exploration hydrocarbon which requires a minimum of about 3km sedimentary thickness in West African coastal area is not plausible.*

KEYWORDS: Aeromagnetic, Source Parameter Imaging, Sedimentary, Basement, Hydrocarbon

INTRODUCTION

In Nigeria, oil and gas industries contribute largely to the economy of the country by profiting immensely from revenues that have accrued from their sales. However, in recent times, there is an upsurge of challenges and limitations experienced in the industry. These include oil theft and vandalism of pipelines especially in the Niger Delta which is adversely affecting the Nigerian economy. In order to step up its revenue base and consequently, provide uninterrupted service to its citizenry, the Nigerian Government embarked on investigation the hydrocarbon and solid mineral potentials of the other basins using high resolution geophysical and geological techniques. Sokoto basin in particular is one of those basins in the country suspected to have indication of hydrocarbon potential even as a sedimentary basin. Particularly in recently times, the petroleum potential of the trough has been of great interest of indigenous geologists and geophysicists in the country. The Nigerian government through the Nigerian National Petroleum Corporation (NNPC) and some oil companies invested substantially in Sokoto Basin part of Iullemmeden Basin along with other basins in northern part of Nigeria for exploration of oil and gas potentials. However, efforts and more money which may be sunk in exploring the area with the hope of finding hydrocarbon deposits in the near feature once hydrocarbon is confirmed in the area would be wasted if sufficient geophysical surveys are not carried out there prior to the investment. The essence of geophysical surveys both reconnaissance and precision is to ensure that first of all, to ascertain the plausibility of the occurrence of suspected deposit and secondly to ascertain where there is sufficient evidence, that the occurrence is an economic deposit and viable for exploitation.

Source Parameter Imaging (SPI) method has been used widely in the recent years to estimate the depth to magnetic sources. 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 whole control. This accuracy is similar to that of Euler deconvolution (Thurston and Smith, 1997). However, SPI has the advantage of producing more complete set of coherent solution points and it is easier to use. The Source Parameter Imaging (SPI) of aeromagnetic fields over an area would differentiate and characterize regions of sedimentary thickening from those of uplifted or shallow basement and also determine the depths to the magnetic sources. Results obtained from SPI of aeromagnetic map could be used to suggest whether or not a study area would have good potential for oil and gas or other mineral deposits (Obaje and Yusuf, 2013). Therefore, the aim of this study is to analyse the aeromagnetic data of Sokoto basin to determine its depth to magnetic layers with a view of finding certain lithologies of economic importance within the basement complex.

The Study Area

The study area is known as the Sokoto one of the sedimentary arms of Iullemmeden Basin in north-western Nigeria (Figure1). The Sokoto Basin forms the south-eastern segment of the Iullemmeden Basin which is a large synclinal basin (After Kogbe, 1981).

Sokoto Basin lies between longitudes 3°30’E and 7°00’E and latitudes 10°20’N and 14°00’N covering an area of about 59,570 km^2. The Iullemmeden Basin in which the Sokoto Basin is located lies entirely within the Pan African province of West Africa which encompasses parts of Algeria, Mali, and Republic of Benin and Niger. The Basin is bounded to the north by the massifs of the Adrar des Iforas, Hoggar and Air regions. (Obaje and Yusuf, 2013). Iullemmeden Basin consists predominantly of a gently undulating plain with an average elevation varying from 250 to 400 m above the mean sea-level. This plain is occasionally interrupted by low mesas. Sediments of Iullemmeden Basin were accumulated during four main phases of deposition and overlying the Pre-Cambrian Basement unconformably. The phases are Illo and Gundumi Formations, made up of grits and clays. Gundumi Formations are overlain unconformably by Taloka and Wurno Formations which consist of mudstones and friable sandstones and separated by the fossiliferous, shelly formation known as Dukamaje Formation. The Taloka and Wurno Formations underlie other formations namely;

Dange and Gamba Formations which are mainly shales and separated by a calcareous Kalambaina Formation and constituting *Sokoto Group* which is of *Paleocene*. Overlying the Dange and Gamba Formations is a continental Gwandu Formation forming the *Post-Paleocene Continental Terminal*. These sediments of the Basin dip gently and thicken gradually towards the northwest, with a maximum thickness of over 1,200 m near the frontier with Niger Republic (Kogbe, 1981). Figure 1a shows the geological map of Nigeria (Kogbe, 1981).

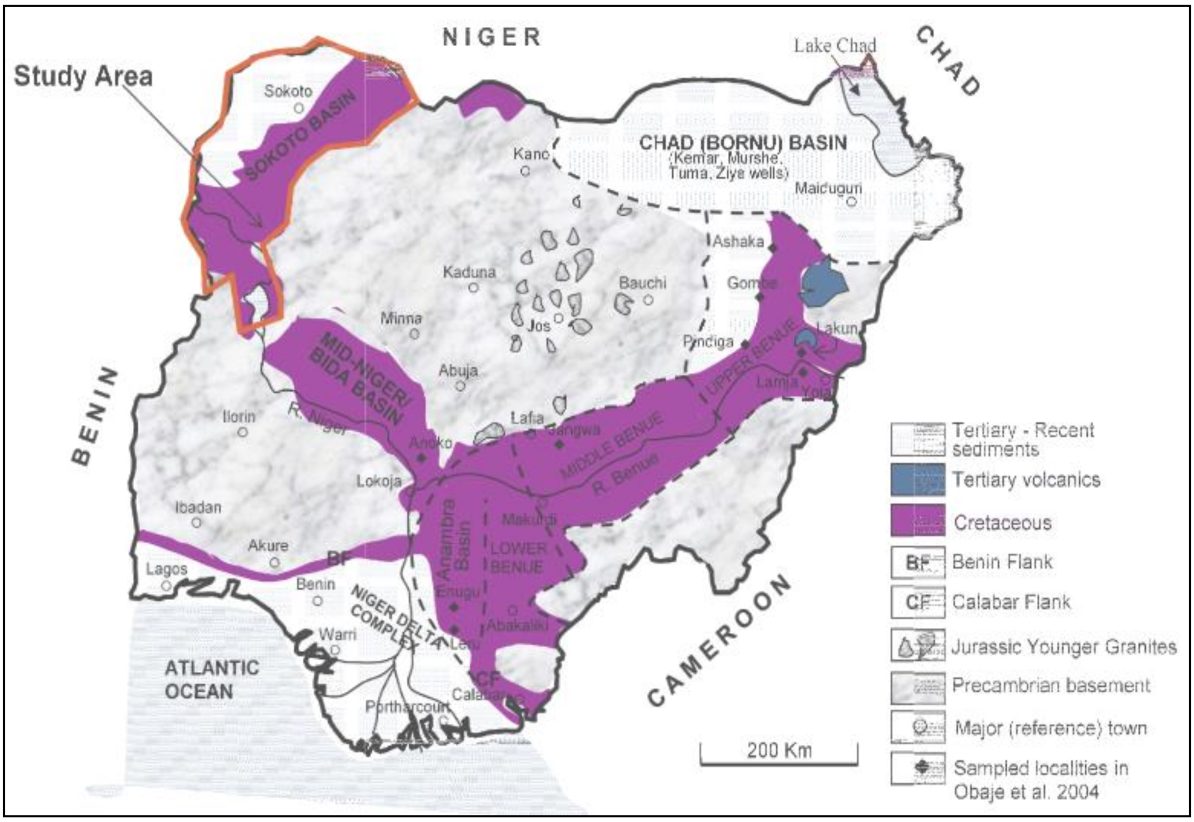

Figure.1a: Geological Maps of Nigeria showing the Sokoto Basin as cretaceous (After Kogbe, 1981).

Structurally, the basin is characterised by series of transcurrent faults at its basement rocks adjoining the Sokoto Basin. A system of NE–SW and NW-SE conjugate pairs of fractures existing everywhere within the Pan African Mobile Belts has been identified (Wright, 1968 and Ball 1980). It was also observed that in the Sokoto part of the Iullumeden Basement, a complex and its supracrustal cover of younger metasediments were subjected to two phases of tight Isoclinal folding during the Pan-African and these are responsible for a N-S trending structures common over most parts of Nigeria (McCurry, 1976). Economically, there are several solid mineral deposits in the Sokoto Basin which are of industrial importance (Huntings, 1976). Figure 1b shows the geological map of the southeastern sector (Sokoto Basin) of the lullemmeden Basin (After Obaje and Yusuf, 2013)

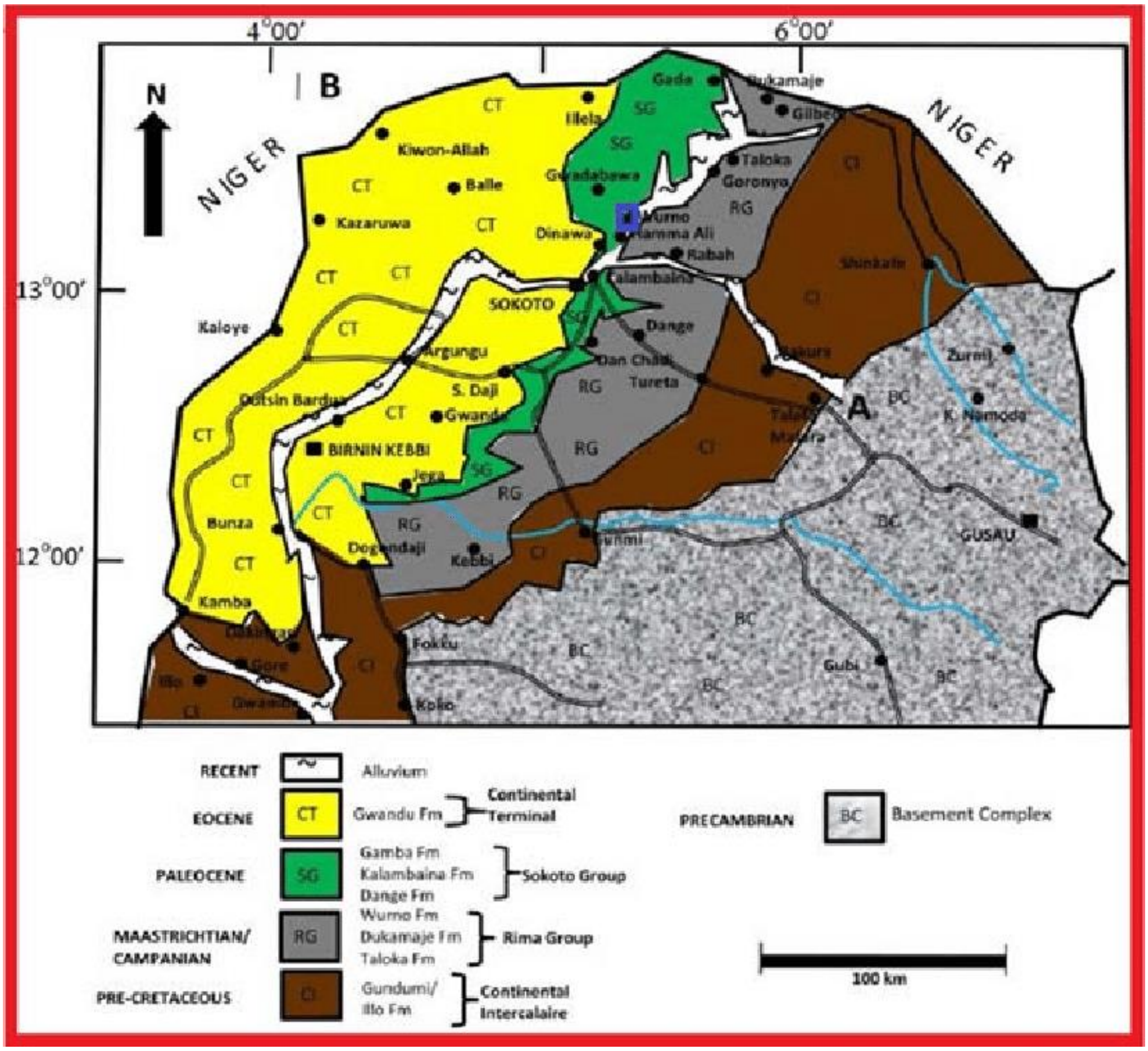

Figure.1b: Geological Map of the southeastern sector (Sokoto Basin) of the lullemmeden Basin (After Obaje and Yusuf, 2013)

MATERIALS AND METHOD

The aeromagnetic data used for this study was obtained from Nigerian Geological Survey Agency as a part of the nation-wide aeromagnetic survey between 1974 and 1980 (NGSA, 2005). The aeromagnetic data were collected at a nominal flight altitude of 154.2 m along approximately N-S flight lines considered to be (nearly perpendicular to predicted geological strikes in the area and spaced 2km apart. Total magnetic field Intensity data of four aeromagnetic maps namely sheet numbers 29, 30, 51, and 52 on a scale of 1:100,000 covering ½° by ½° sheets were collected. Hence, the magnetic values were plotted at interval of 10nT and the actual magnetic values were reduced by 25,000 gammas before plotting contour maps (Huntings, 1976). Edge effect was removed to produce a single map based on unified composite dataset of the study area. Afterwards, the data was imported to *Oasis Montaj* Version 7.0.1 software. The imported data comprising longitude, latitude and the total field magnetic values were used to produce the source parameter image (SPI) for interpretation as guided by the local geology of the study area (Thurston and Smith, 1997). The source parameter imaging method is used to estimate the depth from the local wave number of an analytical signal (Thurston and Smith, 1997). The analytical signal A1(x, z) is defined by Nabighian (1972) as:

$$Depth = \frac{1}{K_{max}} = \frac{1}{\sqrt{\left(\frac{\partial Tilt}{\partial x}\right)^2 + \left(\frac{\partial Tilt}{\partial y}\right)^2}} \qquad 1$$

$$Tilt = Arctan\left(\frac{\frac{\partial T}{\partial Z}}{\sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2}}\right) \qquad 2$$

$$Tilt = Arctan\frac{\frac{\partial T}{\partial Z}}{HGRAD} \qquad 3$$

Where **T** is the Total Magnetic Field; and **HGRAD** is the **Horizontal Gradient**

$$= \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2} \qquad \mathbf{4}$$

The contacts of thin sheet and horizontal cylinder which are two-dimensional models (infinite strike extent) are implicit assumption of the SPI method. The modeled bodies are two-dimensional such that there is no interference from nearby bodies. Hence, the depth estimate is reasonable and the structural index and there is no interference from nearby bodies, the depth estimate will be reasonable and the structural index should be constant over the entire area for which the response is anomalous. Estimate will be reasonable and the structural index was relatively constant over the entire area for which the response is anomalous. Also the estimated structural index was reasonable made constant over the entire area for which the response is anomalous.

RESULTS AND DISCUSSION

The total magnetic intensity (TMI) map of the study area in lower Sokoto sedimentary basin was produced from this study using Oasis Montaj version 7.0.1 (Figure 2). It can be observed that the map is generally, characterized by minor depressions minor depressions all over area However, the northern part of the area is noted to be signified by high magnetic intensity values range of about -48.1 to 10.2nT. The high magnetic intensity signature is represented by the red-purple color on the Legend tool bar. The southern part of the area can be observed to be predominantly characterized by low magnetic intensity values ranging from about -82.6 to -99.8nT. The low magnetic significance as indicated by colour range of sky-blue to dark-blue colour on the legend tool bar. The two significant zones were separated by a zone of average magnetic intensity values depicted by yellow to orange colour range.

Interpretation shows that the high magnetic intensity values, which dominate the northern part in of the study area in lower, are most probably by near surface igneous rocks of high values of magnetic susceptibility values. This assertion agrees with the geology of the area and previous studies in the area which had acclaimed that igneous and crystalline basement rocks occur at parts of Gunmi and Dange (Sambo, 1994). Conversely, the low amplitudes feature observed is most probably due to sedimentary rocks and other non-magnetic sources in the near surface. This assertion agrees with the geology of the area and previous works in the area whereby sedimentary rocks and altered basement rocks are laid unconformably with each other. However, the sedimentary thickness in general; appears to have increased from south to north at some parts of the study area.

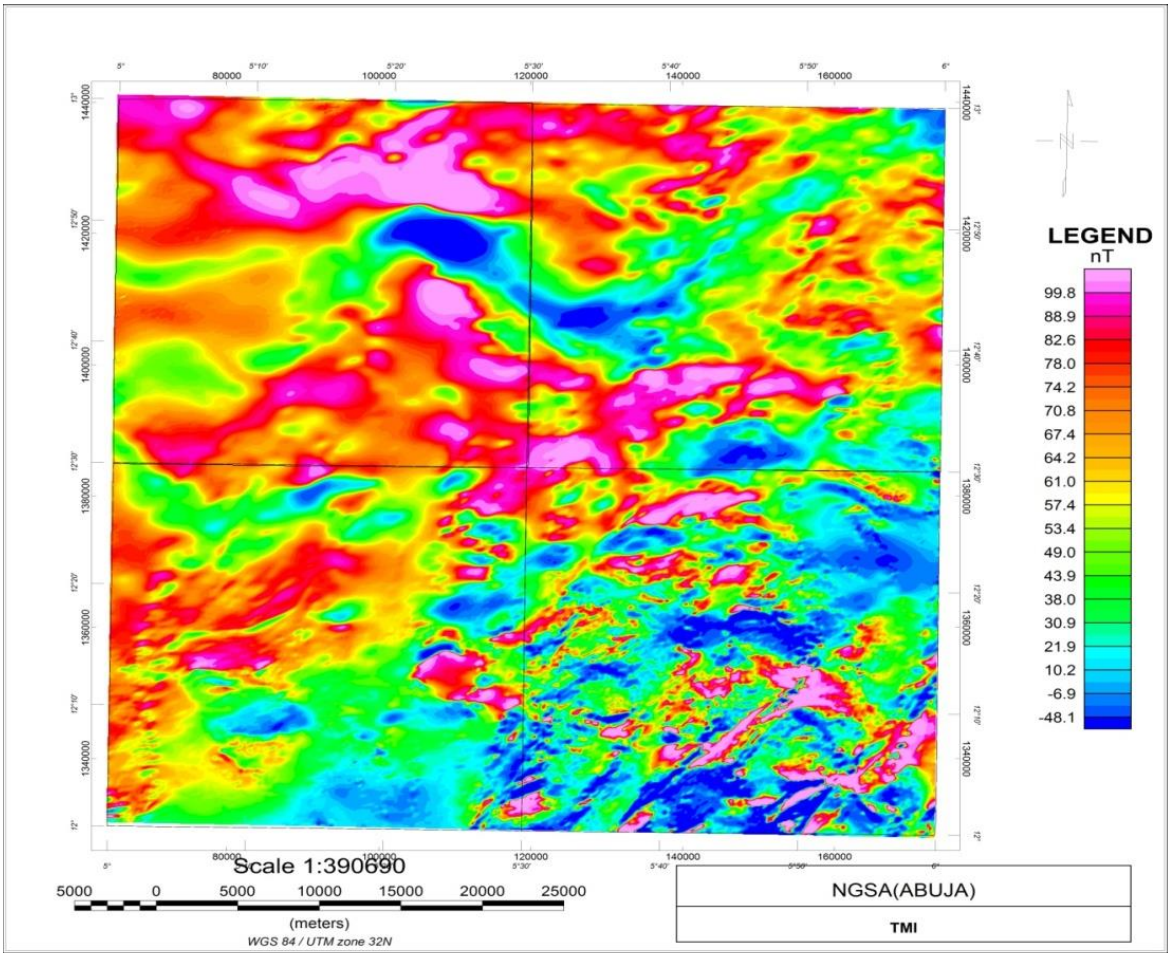

Fig. 2: Total Magnetic Intensity Map of the Study Area

Consequently, regional effect of the TMI was removed to unveil the residual magnetic intensity data and plot the residual map of the study area (Figure 3). The residual map is characterized by positive and negative magnetic susceptibility values. The legend of the map shows the high positive values represented by pink to red colour range, the high negative values represented by blue color while the pale-green and yellow color represent the lower negative and lower positive magnetic values respectively. The magnetic intensity values ranges from -48.1 to 99.8nT. Negative magnetic intensity values are more predominant in the southeast section of the study area while the northwest section has more of positive magnetic intensity values. Northeast–Southwest signals are observed in the North-central part of the TMI map.

Fig. 3 is the residual magnetic intensity map of the study area. The residual map is characterized with positive and negative magnetic susceptibility values. The pink and red color represents the high positive values while the blue color represents high negative values. The pale-green and yellow color represent the lower negative and lower positive magnetic values respectively. The magnetic intensity values ranges from -73.6 nano Tesla to 42.9 nano Tesla. Negative magnetic intensity values are more predominant in the southeast section of the study area while the northwest has more of positive magnetic intensity values. Northeast –Southwest trends are observed in the North-central part of the TMI map.

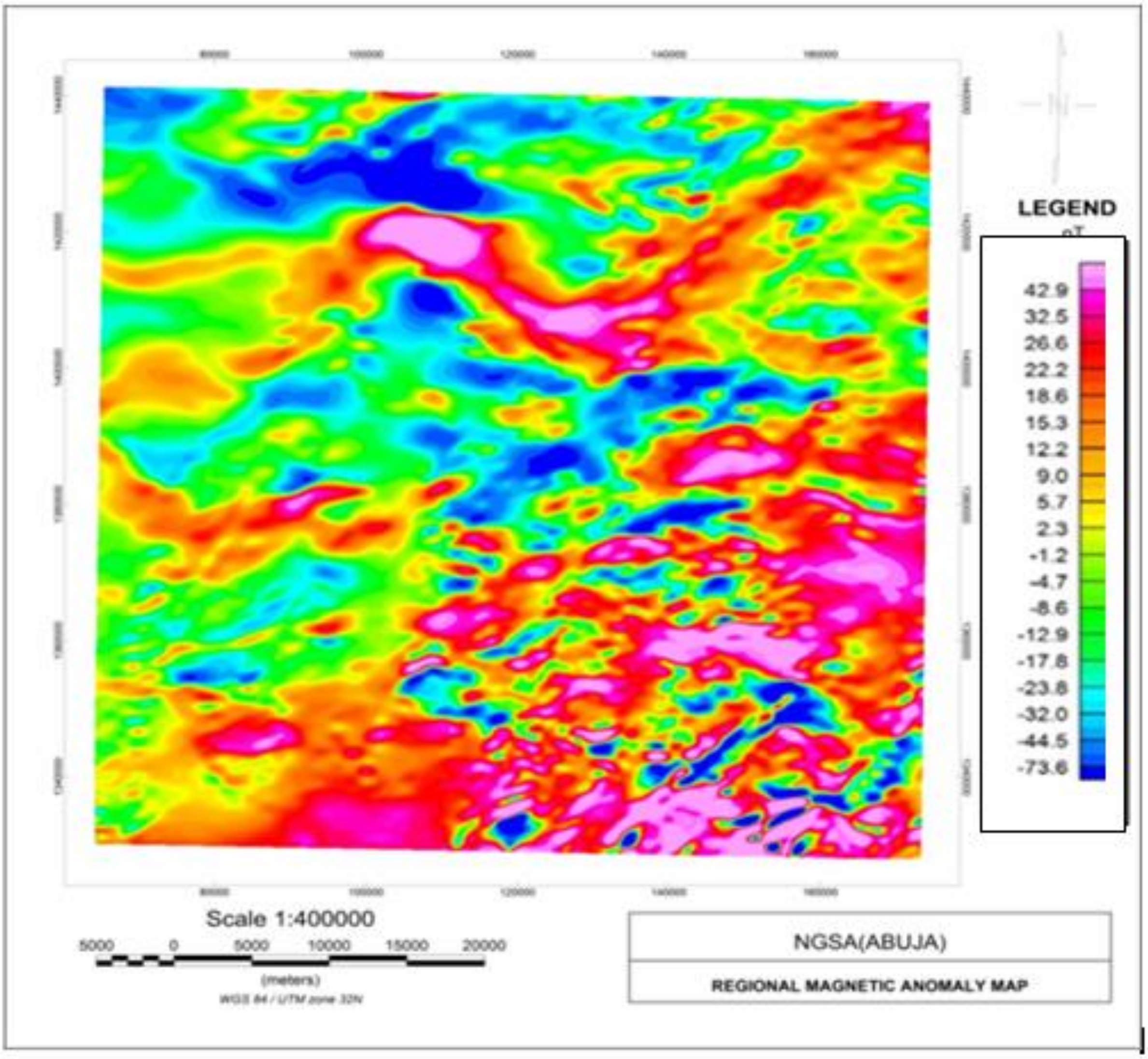

Fig. 3: Residual Magnetic Intensity Map of the study area

The Source Parameter Imaging (SPI) of the study area is shown in figure 4. The application of SPI method needs the following:

GRD1	Grid of the horizontal derivative in the X-direction
GRD2	Grid of the horizontal derivative in the Y-direction
GRD3	Grid of the first vertical derivative
GRD4	Grid of tilt derivative
GRD5	Grid of local wavenumber k grid (horizontal gradient of tilt derivative)

It is observed that it has its highest sedimentary thickness of about 1.0759 to 1.5536 km occur at the northern part of the map. This zone is identified at central part of Dange and Gunmi parts of the study area; the northern parts of Dange being the thickest of the entire sedimentary basin in view. The negative signs are of no significance to the figures rather, they symbolize the trend of the distance from the Earth surface to the basement. It can be observed from the SPI grid that the deepest and shallowest depths of the sediments as obtained by the SPI are 1.55km and 0.12km respectively.

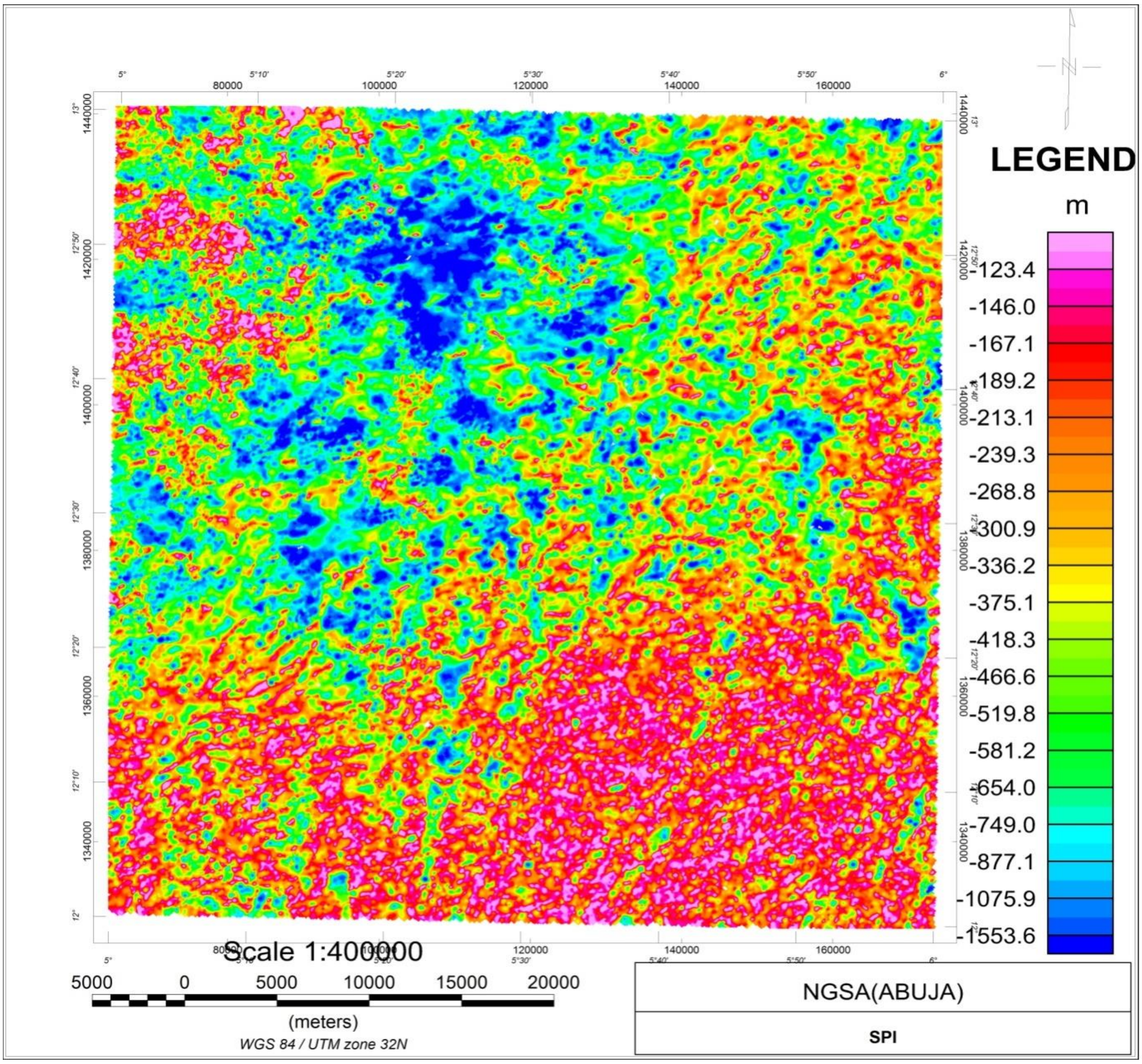

Fig.4: Source Parameter Imaging (SPI) Map of the Study Area

Using the software Oasis Montaj version 7.0.1, the (3D) plot and the underneath of the SPI of the area was plotted (Figures 5 and 6 respectively). They were still obtained from the original SPI grid by making a conversion of the grid from its surface forms to its 3D forms. This figures show the extent of the depth and the nature of the surface respectively. The 3D maps provide an overall picture of the structure of a large area and helps in qualitative interpretation of the study area revealing major magnetic characters of the basement (figure 6). Thus it is observed that the deepest part of the surface is indicated by the blue color from the underground signatures as presented by both the 3D plots of the Source Parameter Imaging (SPI) of the Area.

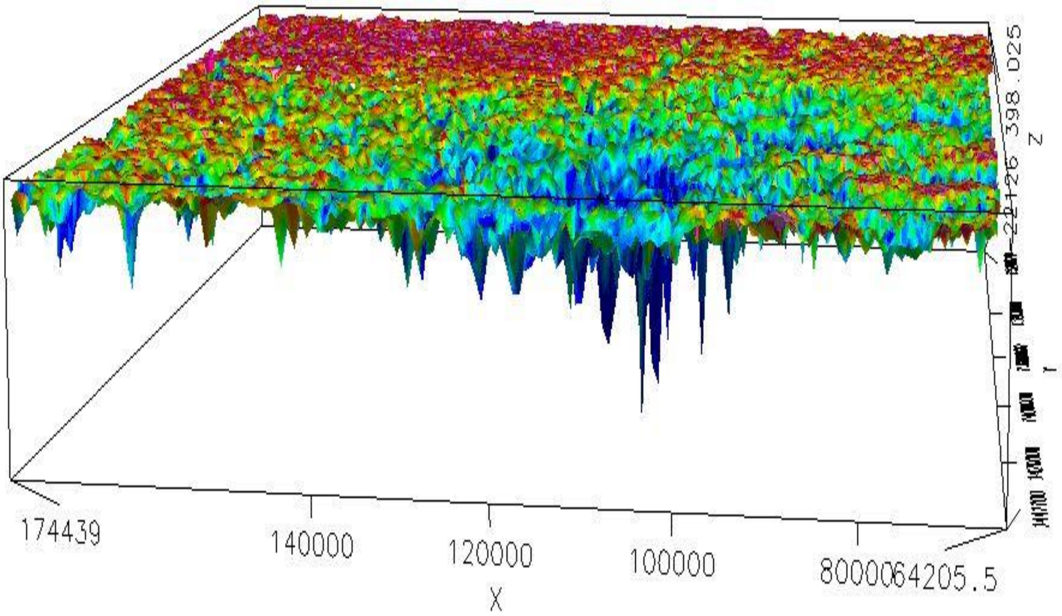

Fig. 5: 3D surface Plot of the Source Parameter Imaging (SPI) of the Area

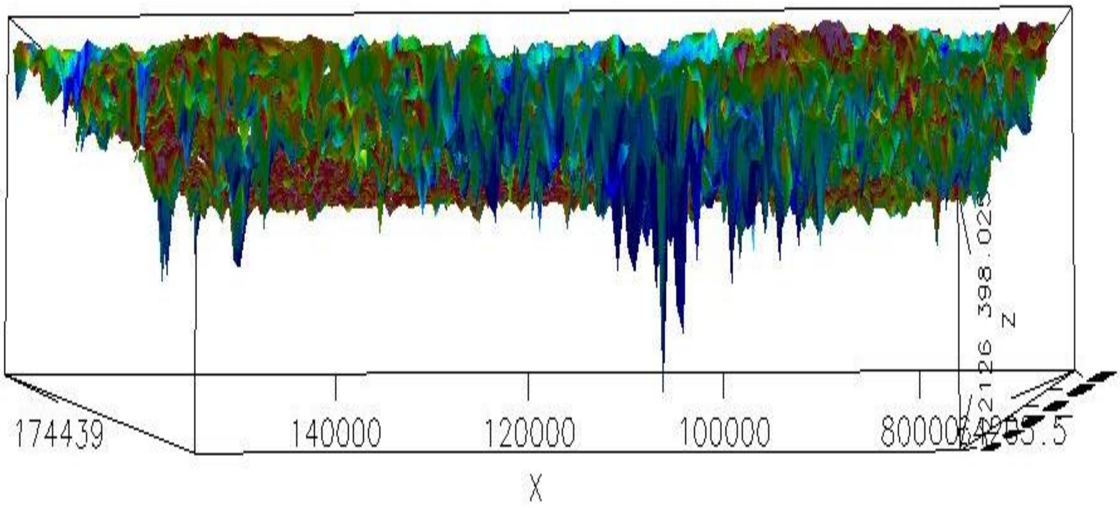

Fig. 6: 3D Inverted Plot of the Source Parameter Imaging (SPI) of the Area

CONCLUSION

Hydrocarbon potential across a sedimentary basin is usually enhanced by the thickness of the sediments of the basin, and the kind of geological structures existing in the area. It is primarily required that within the basin whereby oil and gas deposits are expected that there should be satisfactory form of traps for oil and gas. Based on the results of source parameter imaging of the Total Magnetic Intensity map of the part of lower Sokoto sedimentary Basin studied, it can be concluded that the maximum sedimentary thickness of about 1.5km. The sedimentary thickness required for the burial of organic matters for source rock formation, emplacement and trapping of reservoir rocks for accumulation of oil and gas must be sufficient. From literature, the minimum sedimentary thickness for adequate concealment of oil and gas formation from organic remains at threshold temperature of 115℃ would be 2.3km (Kamba and Ahmed, 2017). Therefore, based on the maximum depth of the sediment in the study area which is less than 2.3 km, the study falls short of the minimum requirements and prospect for hydrocarbon accumulation.

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