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Euler Deconvolution and Source Parameter Imaging of Aeromagnetic Data to Delineate Sedimentary Thicknessover Lower Part of Sokoto Basin, Northwestern Nigeria

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***Abstract**: Quantitative interpretation of aeromagnetic data was carried out over the lower part of Sokoto basin northwestern Nigeria in order to determine the sedimentary thickness for possible hydrocarbon potential. The study area lies between latitude 10.5^{o}N to 11.5^{o}N and longitude 04^{o}E to 05^{o}E with an estimated total area of 12,100km^2. Four (4) high resolution aeromagnetic data were acquired from the Nigerian Geological Survey Agency (NGSA) and were processed in to total magnetic intensity (TMI) map using Oasis Montaj. The composite total magnetic intensity (CTMI) map revealed heterogeneity in the magnetic signature, ranging from -64.1nT to 123.6nT. Regional-residual separation was performed on the composite total magnetic intensity map using polynomial fitting. The residual map was subjected to Euler deconvolution and source parameter imaging. The result obtained from the Euler deconvolution revealed a maximum depth of 2015.9m around Kao'je and some parts of Konkwesso and Yelwa and a minimum depth of 3.1m occurring majorly around Shanga, Konkwess and some parts of Yelwa while the result from source parameter imaging revealed a maximum depth of 904.9m also around Kao'je and some parts of Konkwesso and Yelwa and a minimum depth of 91.9m. Hence, the sedimentary thicknesses obtained from both the two techniques are insufficient for hydrocarbon maturation. Seismic reflection may further be employed in order to authenticate the result.*

***Keywords-**Aeromagnetic,Anomaly, Euler deconvolution, Hydrocarbon, Sedimentary thickness,*

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I. Introduction

The quest for man to assume absolute control of his environment and transform it to suit his needs, compelled him to explore the subsurface for natural resources such as hydrocarbon, solid minerals and ground water. Enormous amount of human labor has been spent by geoscientists in exploring the subsurface for solid minerals, hydrocarbon and even ground water. Different geophysical methodshave been employedby geophysicists in their attempt toexplore the Earth for natural resources. There are many methods of geophysical exploration, each method investigates a unique physical property of the crustal earth which tend to solve a particular problem. For instance, magnetic method can objectively be used to search for earth's resources like solid minerals, oil and gas and perhaps ground water (Daniel, 2018). The method is based on detection of rocks possessing unusual magnetic properties that reveal themselves by causing disturbances or anomalies in the intensity of the earth's magnetic field (Jeffrey, 1997). Hence, magnetic method (ground or air borne) can be used to unravel the subsurface information.

This study therefore focuses on the quantitative interpretation of aeromagnetic data to determine the sedimentary thickness over the lower part of Sokoto basin northwestern Nigeria so as to identify areas with hydrocarbon potentials. This research work is relevant to the national needs because Nigeria operates a mono/petroleum based economy. Over 80% of the country's revenue is derived from oil and gas (Economic watch contents, 2010). As the hydrocarbon potential of the prolific Niger delta becomes depleted or may be come exhausted in the near future due to continuous exploitation, it is necessary to shift attention to other sedimentary basins as this will boast the economy of the nation, provide investment opportunities and consequently eradicate poverty. Sokoto basin is one of the basins in Nigeria presumed to have hydrocarbon potential. Hence, the four (4) aeromagnetic data sheets used in the study were subjected to Euler deconvolution and Source parameter imaging techniques in order to estimate sedimentary thickness for possible hydrocarbon maturation. The result of this research will provide more information on the hydrocarbon potential within the basin.

1.1 Geology and Location of the study area

The study areais part of the vast late Proterozoic-early Phanerozoic terrane separating the west African and Congo cratons (Muhammad and Abdul-Fatah, 2010). It comprises the late Proterozoic metasedimentary rocks (mainly sericite-chlorite phyllite) intruded by a pan-African granodiorite batholith and an associated narrow contact aureole (50-350m) of mainly pelitic hornfels. The metasedimentary rocks belong to the Zuru schist belt, one of the many NNE-trending belts to the low grade (mainly greenschist faces) supracrustal rocks that are believed to have been deposited as proterozoic cover on older basement rocks(Garba,1994).

The area is located in southwestern part of kebbi state, northwestern Nigeria and lies between latitude $10^{0}5'00"$N and $11^{0}5'00"$N and longitude $04^{0}00"$E and $05^{0}00"$E. It is accessible by road through Abuja (the Federal Capital|), via Minna-Kontagora-Mararrabaandto Yauri. Figure 1 is the geological map of Nigeria showing the location of the study area:

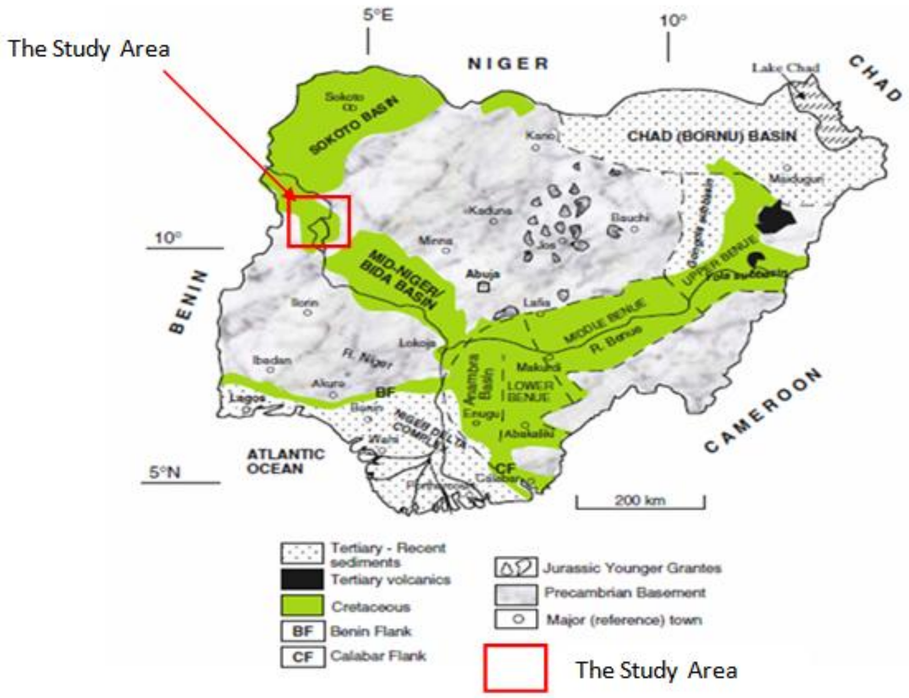


Figure 1. Geological map of Nigeria showing the study area (Obaje, 2004)

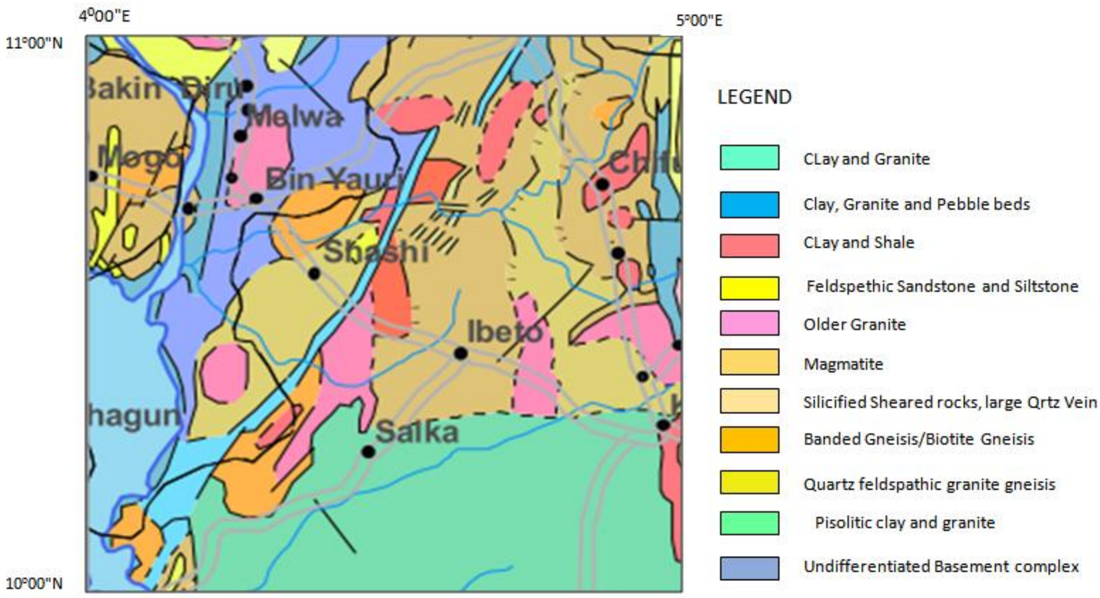


Figure 2: Geological map of the study area extracted from the Geological map of Nigeria

II. Materials And Methods

2.1Materials

Four high resolution aeromagnetic data sheets of total field intensity in $1/2^0$ by $1/2^0$ covering sheet 95, 96,117 and 118 corresponding to Ka´oje, Shanga, Konkwesso and Yelwawere acquired from the Nigerian Geological Survey Agency (NGSA), which is the agency that sponsored the nationwide airborne survey carried out by Fugro between 2013 to 2009. The data were obtained at an altitude of 100m along a flight line spacing of 500m oriented in NW-SE and a tie line spacing of 200m. The geomagnetic gradient was removed from the data using the international geomagnetic reference field (IGRF). The maps are numbered and names of places and coordinates (latitudes and longitudes) written for easy reference and identification.

In order to produce a unified 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.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

2.2Methods

Euler Deconvolution

The Euler deconvolution depth estimation technique is basically based on the Euler's homogeneity equation given by:

$$(x-x_0)\frac{\delta T}{\delta x} + (y - yo)\frac{\delta T}{\delta y} + (z - zo)\frac{\delta T}{\delta z} + N(B - T) \qquad 1$$

Where (x_o,y_0,$z_{0)}$ are the positions of the magnetic source whose total field intensity (T) is detected at (x,y,z). B is the regional magnetic field. N is the structural index which measures the rate of change of fields with distance from the source (fall off-rate) and is directly related to the source dimensions.

The Euler depth estimation technique involves setting an appropriate structural index value and using last-squares inversion to solve the equation for an optimum x_o,y_0,$z_{0 \text{ and } B.}$ Hence by changing N we can estimate the geometry and depth of the magnetic source (Umukoro and Akanbi, 2014). The method has proved useful for identifying source, positions and boundaries and for giving generalized indications of source depth.

Source Parameter Imaging (SPI)

Source parameter imaging (SPI) is a technique based on the extension of analytical signal to estimate magnetic depths; It is also known as local wave number. Thurston and Smith (1997) developed source parameter imaging and used it to estimate the depth from the local wave number of the analytical signal. The depth is displayed as an image which makes it better than other depth estimation methods. One more advantage of the source parameter imaging technique is that the estimation of depth is independent of the magnetic inclination, declination, dip, strike and any remnant magnetization (Thurston and Smith, 1997). Hence the technique has been used for depth estimation of magnetic sources by many authors. Salako (2014), Bello *et al.* (2017), Marwan *et al.* (2017) and Nwogwugwu *et al*. (2017) applied it for depth to basement determination. Solution grids using the Source Parameter Imaging technique show the edge location, depth, dips and susceptibility contrasts. Salako (2014) reported that, Thurston and Smith (1997) estimated the depth parameter using the local wave number of the analytical signal. The analytical signal A_1(X, Z) is defined by Nabighian (1972) as

$$A1(x, \quad z) = \frac{\partial M(X,Z)}{\partial x} - j\frac{\partial M(X,Z)}{\partial z} \qquad 2$$

where A_1(x, z) = Amplitude of Analytical signal

M (x, z) = magnitude of the anomalous total magnetic field

j = imaginary number

z and x= are gradients in the vertical and horizontal direction respectively.

Nabighian (1972) also showed that the gradient changes constituting the vertical and horizontal (real and imaginary) parts of the 2D analytical signal are related as follows:

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

Where ⟺ represents a Hilbert transform

The local wave number k_1 is defined by Thurston and Smith (1972) to be

$$k_1 = \frac{\partial}{\partial x}\tan^{-1}\left[\frac{\partial M}{\partial z}\Big/\frac{\partial M}{\partial x}\right] \qquad 4$$

According to Salako and Nwosu (2014) the signature illustrated by Thurston and Smith (1972) utilized Hilbert transformation pair in (3.11). The Hilbert transform and vertical derivative operators are linear, so the vertical derivative of (3.11) will give the Hilbert transform pair as

$$\frac{\partial^2 M(X,Z)}{\partial z \partial x} \Leftrightarrow -\frac{\partial^2 M(X,Z)}{\partial^2 z} \qquad 5$$

Thus the analytic signal could be defined based on second order derivative $A_2(x, z)$
Where

$$A_2(x, z) = \frac{\partial^2 M(X,Z)}{\partial z \partial x} - j\frac{\partial^2 M(X,Z)}{\partial^2 z} \qquad 6$$

This gives rise to a second order local wave number $k_{2,}$ where

$$k_2 = \frac{\partial}{\partial x}\tan^{-1}\left[\frac{\partial^2 M}{\partial^2 z}\Big/\frac{\partial^2 M}{\partial z \partial x}\right] \qquad 7$$

The first and second order local wave numbers are used to determine the most appropriate model and depth estimate independent of any assumption about a model.

III. Results And Discussion

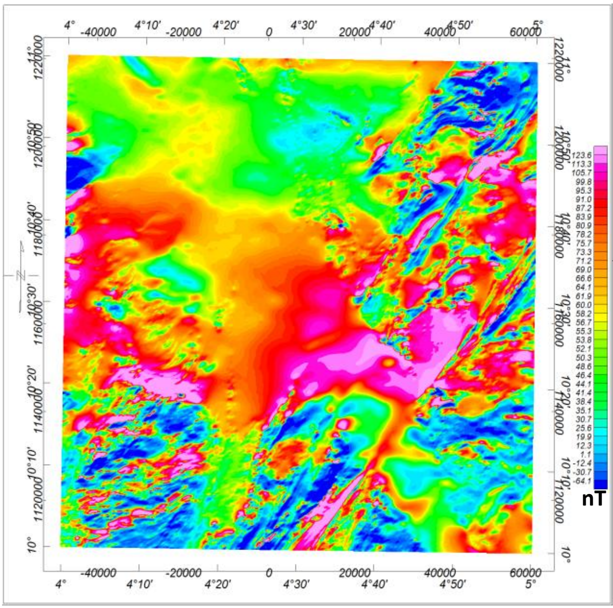
Total Magnetic Intensity Map

The total magnetic intensity (TMI) map of the study area (Figure 3) was produced in color aggregate using Oasis montaj. The map shows variation in magnetic signatures of highs and lows ranging from a minimum value of -64.1nT to a maximum value of 123.6nT. The orange-pink colors on the color legend depicts areas with high magnetic signatures and light-dark blue colors represent low magnetic signatures while green-yellow colors indicate medium magnetic signatures.

Although the total magnetic intensity (TMI) map of the study area is magnetically heterogeneous, it is however clear that the high magnetic signature (61.9nT-123.6nT) which implies basement complex, is more pronounced at the central part of the study area, trending east-west; With few traces of high magnetic signatures scattered virtually all over the area. The low magnetic signature (-64.1nT-35.1nT) is more prominent at the northern and southern parts of the study area corresponding to Ka'oje and some parts of Shanga, Konkwesso and Yelwa trending NE-SW while the medium magnetic intensity (38.4nT-60.0nT) which indicates alluvium deposition can be found virtually all over the area. The map also revealed NE-SW structural alignments which may probably be the host for minerals such as gold, uranium, tantalite,tourmaline etc

Interpretation of the Residual Map of the Study Area

Figure 4 is the residual map of the study area extracted from the total magnetic intensity map of the study area. The map reveals variation in magnetic signatures whose intensity values ranged between -110.4nT and 74nT respectively. The low intensity signature due to deep seated-low frequency-long wavelength anomalies with magnetic values ranging from -110.4nT to -19.6nT (deep-light blue colors) are more prominent at the northeastern and southern region of the area, the high intensity signatures depicted by red-pink colors (7.7nT -74nT) are more concentrated at the centre crosscutting the study area horizontally in similar manner with the TMI map (Figure 4.1) while the medium intensity signatures represented by green-yellow colors (-16.8nT to 5.2nT) are scattered virtually all over the area. Similar to the total magnetic intensity (TMI) map, the regional map also revealed structures such as fractures, faults and veins oriented majorly in NE-SW direction.



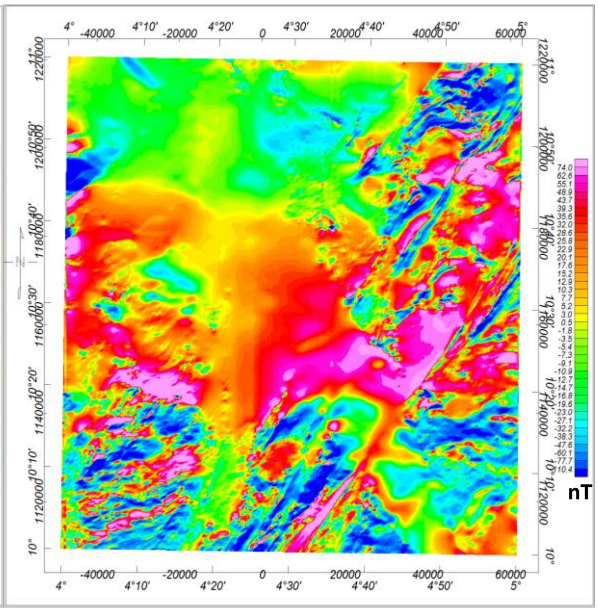


Figure 3: Total Magnetic Intensity Map of the study areaFigure 4: Residual Map of the Study Area

Euler Deconvolution

Euler deconvolution is a depth determination technique that highlights special location of magnetic source based on amplitudes and gradients. It windows an area, locates structures and evaluates the depth at which those structures exist by writing equations for the structures. Its degree of accuracy depends on the structures having a perfect shape and that the structures fall on the center of the window. The Euler depth map of the study area(Figure 5), revealed a maximum depth of 2105.9m occurring majorly at the northwestern part of the study area corresponding to Ka'oje (as indicated by the colour legend), and it extended diagonally towards the southeastern region, corresponding to some parts of Konkwesso and Yelwa. Minimum depth of 3.1m occurred at the northeastern and southwestern part of the area which corresponds to Shanga and some parts of Konkwesso, and Yelwa respectively. This result agrees with the result obtained by Udensi *et al*.(2014) using spectral analysis. Wright *et al.* (1985) asserted that, the maximum sedimentary thickness required for the commencement of oil formation from marine organic remains would be 2300m. Hence, the maximum sedimentary thickness obtained in the study area is insufficient for hydrocarbon accumulation.

Source Parameter Imaging (SPI)

Source parameter imaging highlights spatial location of different magnetic sources at various depths. The result of the source parameter imaging of aeromagnetic data generated from the residual data of the study area (Figure 6) revealed maximum depth of -904.9m occurring majorly at the northwestern part of the study area and extends diagonally toward the southeastern region corresponding to Kaoje, Konkwesso and some parts of Yelwa. Minimum depth of -91.1m occurred at the northeastern and southwestern part of the area which corresponds to Shanga and some parts of Konkwesso, and Yelwa respectively.Hence, the maximum sedimentary thickness obtained usingthis method also revealed that the area is not suitable for hydrocarbon prospecting.

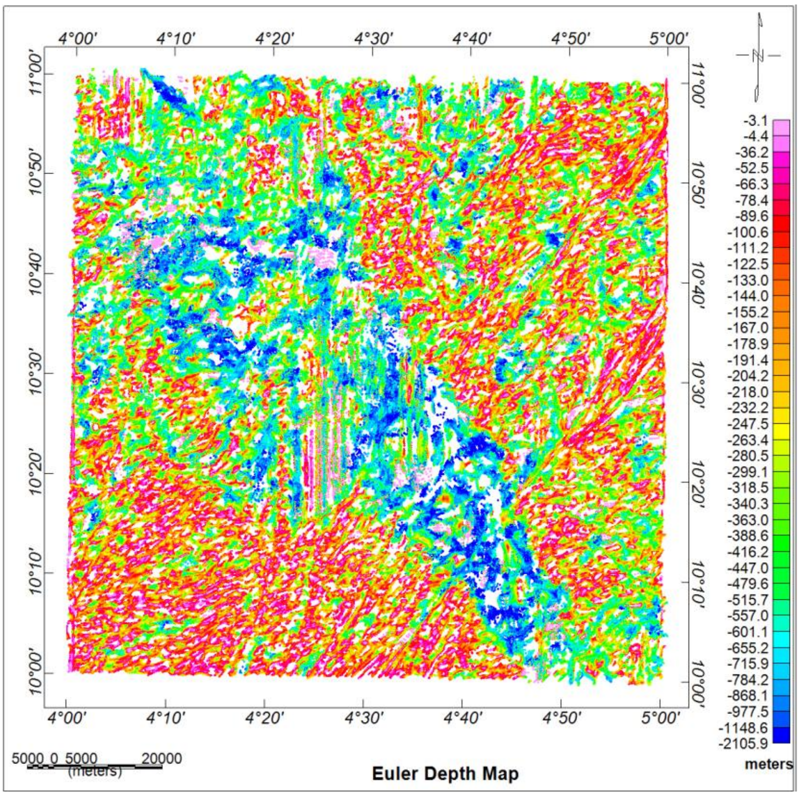


Figure 5 Euler depth Map of the study area

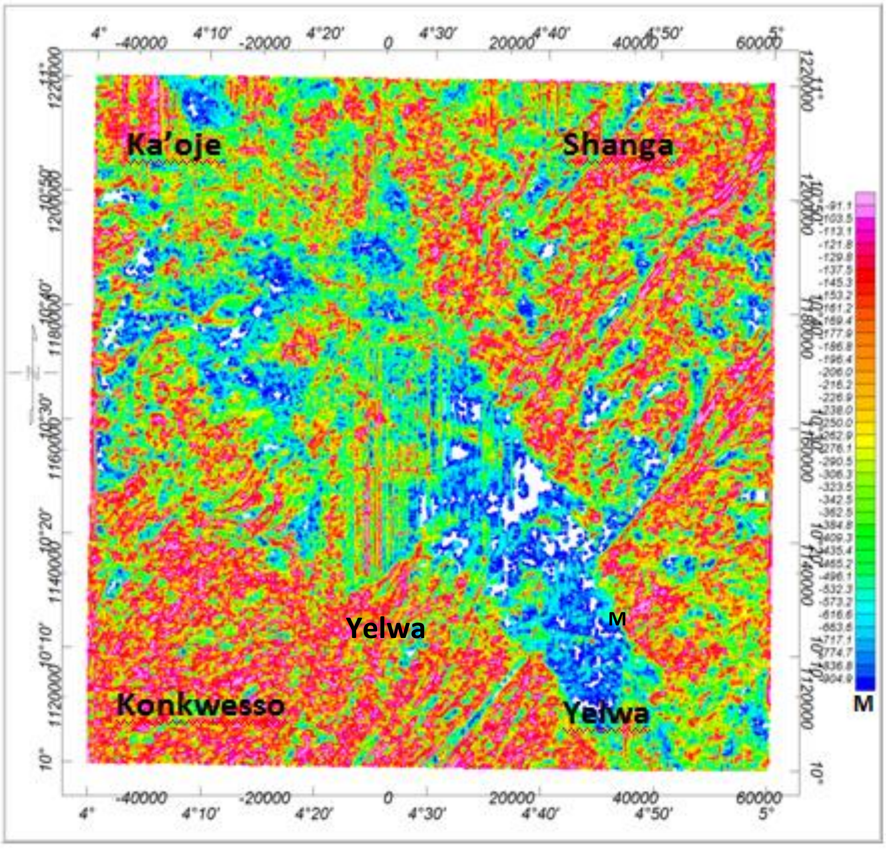


Figure 6 Source Parameter Imaging (SPI) Map of the study area

IV. Conclusion

Quantitative interpretation of aeromagnetic data over the lower part of Sokoto basin northwestern Nigeria was carried out with the aim of estimating the sedimentary thickness for hydrocarbon potential. Euler deconvolution and source parameter imaging (SPI) techniques were employed for this purpose.The maximum sedimentary thicknesses obtained from both the two techniques are insufficient for hydrocarbon maturation. Seismic reflection may further be employed in order to authenticate the result

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