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Geophysical survey of aerogravity anomalies over Lafia and Akiri regions of middle Benue trough, Nigeria, employing Power Spectrum and Source Parameter Imaging technique.

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Abstract:
Gravity anomalies in parts of the middle Benue trough, Nigeria, were investigated through the interpretation of aerogravity data with the objectives to determine the thickness of the sedimentary basin, establish the basement topography and density contrasts which will give information about variation of geological structures. Two sheets of digital airborne gravity data were used for the study. Power Spectrum and Source parameter imaging (SPI) techniques were employed in the quantitative interpretation. The Bouguer anomaly of the study area varied from -66.0 mGal to 28.4 mGal while the residual Bouguer anomaly of the study area varies from -30.5 mGal to 27.7 mGal. The result from the Power Spectrum analysis showed that the maximum estimated basement depth obtained is 5.6 km. Oasis Montaj software was employed using the first vertical derivatives and horizontal gradient in computing the SPI depth of the gravity data. The SPI gave depth values ranging from -983.2 to -5572.6 m for shallow and deep lying gravity anomalous bodies. The results obtained from Power Spectrum technique closely agrees with that of the source parameter imaging. This results from the study have shown that the depth to basement and density contrast have influence on the petroleum/hydrocarbon accumulation.
Key words: *Aerogravity, density contrast, Bouguer anomaly, Power Spectrum, Source Parameter Imaging.*

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I. Introduction

In recent times, the economic growth of a nation and the standard of living of her citizen depend on the nation's industrial science and her economic buoyancy. These two factors sometimes form the basis for classifying any country as "developed" (e.g. France and Germany) or "developing" (e.g. Nigeria & Senegal). Every country strives to attain the former status. The availability of the raw material which is needed by most industries is one of the most primary factors that affect the establishment of the industries in a place. Many raw material needs of most industries happen sporadically in one form or the other in the earth's crust and the search for these raw materials has been one of man's major concerns.

One way of harnessing these is by gravity exploration. It could be ground gravity survey or airborne (aero) gravity survey. Exploration of the subsurface requires innovative techniques and the gravity method offers an excellent opportunity to map the structure and lithology of the subsurface. The gravity method has good depth penetration compared to ground penetration radar, high frequency electromagnetic and dc-resistivity techniques and is not affected by high conductivity values of near-surface clay rich soils (Mickus, 2004; Ekpa et al., (2018)). Gravity data can be used in many ways to solve different exploration problems, depending on the geologic setting and rock parameters of the area (Ezekiel et al., 2013; Okiwelu et al., 2013; Obiora et al., 2016); the data when analyzed provide insight to elements of petroleum exploration and production (Johnson, 1998; Obiora et al., 2016).

The gravity fields change when the physical properties like density and porosity of the sub-terranean rocks change. Factors like grain density, interstitial fluids and porosity within materials affect density contrast.The gravity data finds wide applications and is able to provide very valuable subsurface information. Modern high-resolution gravimeters are able to collect data with high accuracy; this coupled with the major strides made in the acquisition, processing and interpretation of aerogravity data. This has made it possible to use the gravity method for identifying intra-sedimentary units associated with hydrocarbons. The mapping of the earth's gravity field has had a long and distinct history as part of the investigations of the structure and petrologic variation within the earth's lithosphere. Of particular importance are its various uses in the investigation of the structure of the earth, and in the search of metallic ores and energy sources such as oil and gas.

Airborne geophysics, form a critical part of geological mapping and mineral resource inventory programmes of many countries. The data they provide also aid in better geological knowledge within a country or region and form part of a larger initiative that helps to attract investments in the mining sector and grow GDP. They also contribute to groundwater resource management, tectonic reconstruction, petroleum and mineral exploration, mining and environmental protection application (Okonkwo et al., 2012**)**. 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 (Okwesili et al., 2019).

Several studies have been carried out on the Benue Trough of Nigeria including the middle Benue trough. The formation was first recognized by Shell-BP geologist. The mines development of Nigeria also carried out a preliminary survey of Lead-Zinc in 1948 and 1949 using student geologist from United Kingdom. Hence this study deals with an interpretation of the observed aerogravity data of Lafia and Akiri both in the Middle Benue Trough basement terrain. This interpretation is based on the application of Power spectrum and source parameter imaging method. The Power Spectrum and Source Parameter Imaging (SPI) of aerogravity fields over this area would aid in the differentiation and characterization of regions of sedimentary thickening from those of uplifted or shallow basement. The results could be used to suggest whether or not the study area has the potential for oil/gas and mineral deposits concentration (Okwesili et al., 2019).

Location and geology of the study area

The study area is geographically located in the middle Benue trough Nigeria within Latitude 8.0^{o}N to 8.5^{o}N and Longitude 8.5^{o}E to 9.5^{o}E. The middle Benue trough (the hatched area) links the upper and lower arms of the Benue trough sedimentary basin in Nigeria. It is part of a long stretch arm of the Central African rift system and one of about seven inland sedimentary basins in Nigeria (Figure 1) originating from the early Cretaceous rifling of the central West African basement uplift. The study area is underlain by the crystalline basement rocks, younger granites, sedimentary rocks and volcanic rocks (Offodile, 1976). Crystalline basement rocks of the Northern Nigerian Basement Complex and Eastern Nigerian Basement Complex underlie the northern and south-eastern parts of the area, respectively. These crystalline basement rocks are grouped into two kinds, namely Migmatite-Gneiss Complex and the Older Granites (or Pan-African granitoids). The Migmatite-Gneiss Complex is Mesoarchaean to Neoproterozoic (3200 Ma – 542 Ma) in age and composed of migmatites, gneisses and schists. The Older Granites (or Pan-African granitoids) are Pan-African (600 ± 200 Ma, i.e. Neoproterozoic to Early Palaeozoic) in age and consist mainly of granites, diorites and dolerites. The Migmatite-Gneiss Complex was deformed and intruded by the Older Granites (or Pan-African granitoids) during the 600 ± 200 Ma Pan-African tectonic episodes. The younger granites of the Mada and Afu ring complexes (210– 145 Ma, i.e. Triassic–Jurassic in age) occur close to margin of the Trough in the north-western part of the study area and are high-level, anorogenic granites; they mainly consist of micrograntes and biotite granites. Cretaceous sedimentary rocks underlie much of the study area and consist of the Asu River Group, Awe Formation, Keana Formation, Markudi Formation, Ezeaku Formation, Awgu Formation and the Lafia Formation and they underlie most parts of the area. Cretaceous sedimentary rocks older than the Santonian were deformed during the Santonian tectonic event (c. 86 Ma) to produce several uplifts, faults and numerous folds, generally trending in a NE–SW direction, parallel to the Trough margin.

Fig. 1: The map of Nigeria showing the location of Middle Benue Trough (Obaje, 2009).

II. Material and Methods

Source of Data

The high resolution airborne gravity data of Lafia and Akiri used for this study were obtained from the Nigerian Geological Survey Agency (NGSA). The airborne gravity data were obtained in 2013 using GRACE GRAVITY MODEL Sensor onboard 2 satellites by National Aeronautics and Space Administration (NASA) and German Aerospace Center.

Theory of Spectral Analysis (Power Spectrum)

Spectral analysis is the process of calculating and interpreting the spectrum of potential field data. The power spectrum of a surface field is used to identify average but maximum depth of source ensemble (Spector and Grant, 1970). Many researchers have used the calculation of the Power Spectrum from the Fourier coefficients to obtain the average depth to the disturbing surface or equivalently the average depth to the top of the disturbing body (Spector and Grant, 1970). We define the Power Spectrum of a potential field anomaly in relation to the average depth of the disturbing interface. For an anomaly with n data points the solution of Laplace equation in 2-D is:

$$M(x_{j,}z) = \sum_{j=0}^{n-1} A_k e^{i2\pi k x_j} e^{\pm 2\pi kz} \quad 1$$

Where wavenumber k is defined as $k = \frac{1}{\lambda}$ and A_k are therefore the amplitude coefficients of the spectrum,

$$A_k = \sum_{j=0}^{n-1} M(x_{j,}z) e^{-i2\pi k x_j} e^{\pm 2\pi kz} \quad 2$$

For $z = 0$, equation 2 can be written as,

$$(A_k)_0 = \sum_{j=0}^{n-1} M(x_{j,}0) e^{-i2\pi k x_j} \quad 3$$

Then equation (2) can be rewritten as,

$$A_k = (A_k)_0 e^{\pm 2\pi kz} \quad 4$$

Then the power spectrum P_k is defined as,

$$P_k = (A_k)^2 = (P_k)_0 e^{\pm 4\pi kz} \quad 5$$

Taking logarithm of both sides,

$$log_e P_k = log_e (P_k)_0 + 4\pi kz \quad 6$$

The plot of log P against frequency reflects the average depth to the disturbing interface. The interpretation requires the best-fit line through the lowest frequency of the spectrum. Therefore, the average depth can be estimated from the plot of equation 6 as:

$$m = \frac{\Delta LogP}{\Delta k} \quad 7$$

$$4\pi z = -m$$

$$h = z = -\frac{m}{4\pi} \quad 8$$

where h is the depth of potential field source

Theory of Source Parameter Imaging

The Source parameter imaging is a technique using an extension of the complex analytical signal to estimate potential field 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 potential source depths and for some source geometries, the dip and density 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

$$A_1(x, z) = \frac{\partial M(x,z)}{\partial x} - j\frac{\partial M(x,z)}{\partial z} \quad 9$$

Where M(x, z) is the magnitude of the anomalous potential 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;

$$\frac{\partial M(x,z)}{\partial x} \Leftrightarrow -j\frac{\partial M(x,z)}{\partial z} \quad 10$$

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

$$K_1 = \frac{\partial}{\partial x} tan^{-1}\left[\frac{\partial M}{\partial z} / \frac{\partial M}{\partial x}\right] \quad 11$$

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

$$A_2(x, z) = \frac{\partial^2 M(x,z)}{\partial z\, \partial x} - j\frac{\partial^2 M(x,z)}{\partial^2 z} \quad 12$$

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

$$K_2 = \frac{\partial}{\partial x} \tan^{-1}\left[\frac{\partial^2 M}{\partial^2 z} / \frac{\partial^2 M}{\partial z\, \partial x}\right] \quad 13$$

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

Methods

The two digitized aerogravity data of Lafia and Akiri regions were first merged to make a single composite sheet that formed the study area. The data was then converted to an equally spaced two dimension (2D) grid using the minimum curvature method in order to produce the Bouguer gravity map of the study area (Figure 2) (Briggs, 1974; Webring, 1981). This method helps to fit a minimum curvature surface (the smoothest possible surface that will fit the data values) to data points. The RANGRID GX of the Oasis Montaj software was used to achieve this. Then this was followed by the application of mathematical filters such as Polynomial fitting, first vertical derivative (FVD), second vertical derivative (SVD) and horizontal derivative (HD).

The qualitative interpretation was now done to map the surface and sub-surface regional structures (intrusive bodies, contacts, faults, basement rocks and mineralization) which may be responsible for the anomalies. This entails the description of the survey results and the explanation of the major features revealed by the survey in terms of the types of likely geological formations using the grids on which the anomalous values at different stations are plotted and at which contours are drawn at suitable intervals (Revees, 2005). Furthermore, the quantitative interpretation was done to have the estimates of depths and dimensions of sources of anomalies. The aerogravity quantitative interpretation techniques adopted in this study are: Spectral analysis and Source parameter imaging (SPI) (Biswas et al., 2017; Biswas, 2016, 2015).

Spectral analysis (Power Spectrum)

The Bouguer gravity data of Lafia and Akiri was subjected to Log Power Spectrum a filtering technique using MAGMAP tool of oasis montaj software. Here, the Bouguer gravity data is transformed from space to the frequency or wavenumber domain via Fast Fourier Transform (FFT) algorithm application. This art thereby generates the spectral energy curve from which the depth values relating the deeply seated and shallow related gravity features can be calculated by fitting lines on the high and low frequency components. The statistical mean depth determination of the burial ensemble was done using equations (1) - (8).

Source parameter imaging

The computation of the SPI image and depth was done using equations (9) – (13) employing Oasis Montaj software. The first and second-order local wave numbers were also used to determine the most appropriate model and a depth estimate independent of any assumptions about a model.

III. Result

Figure 2 shows the bouguer gravity map of the study area while Figure 3 shows the residual gravity map of the study area after having removed the regional anomaly from the bouguer gravity anomaly. Figures 4 to 6 show the first vertical derivative, second vertical derivative and the horizontal derivative map, respectively after the data reduction techniques. Furthermore, the results of the quantitative interpretation of Power Spectrum and Source Parameter Imaging are shown in Figure (7 -8) respectively. These could be seen in Power Spectrum map and Sources Parameter Imaging aerogravity map. Finally, Figure 9 gives the 3-D SPI view of the study area.

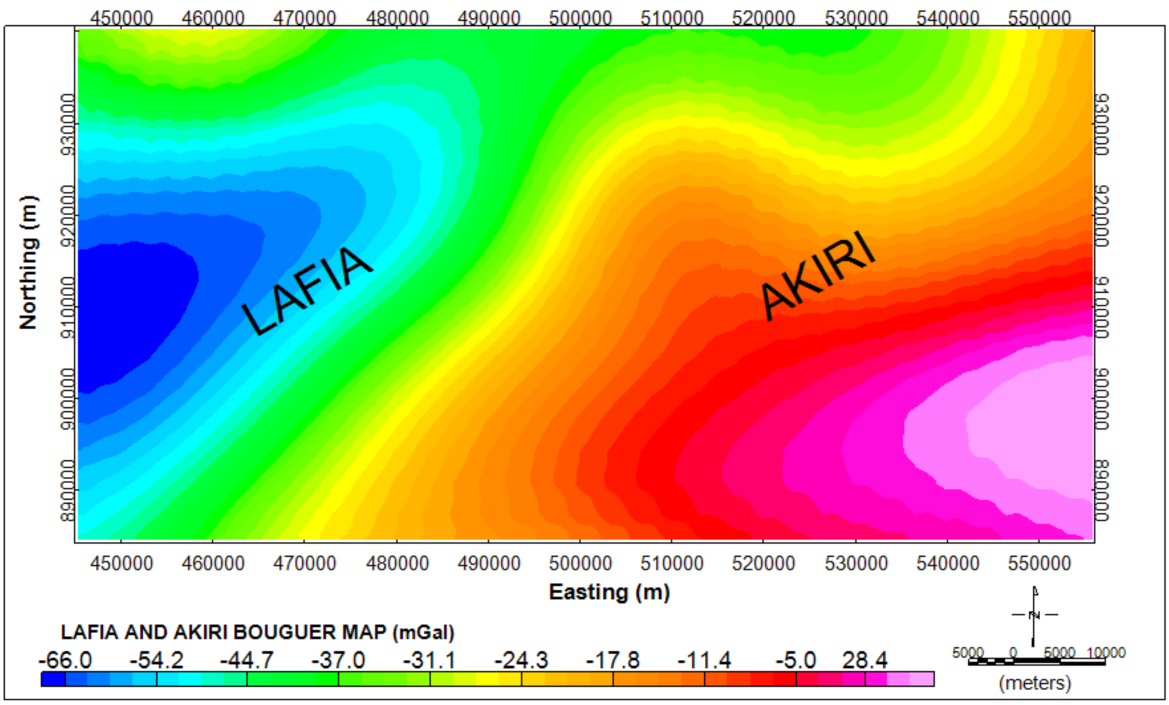

Fig. 2: Bouguer gravity map of the study area.

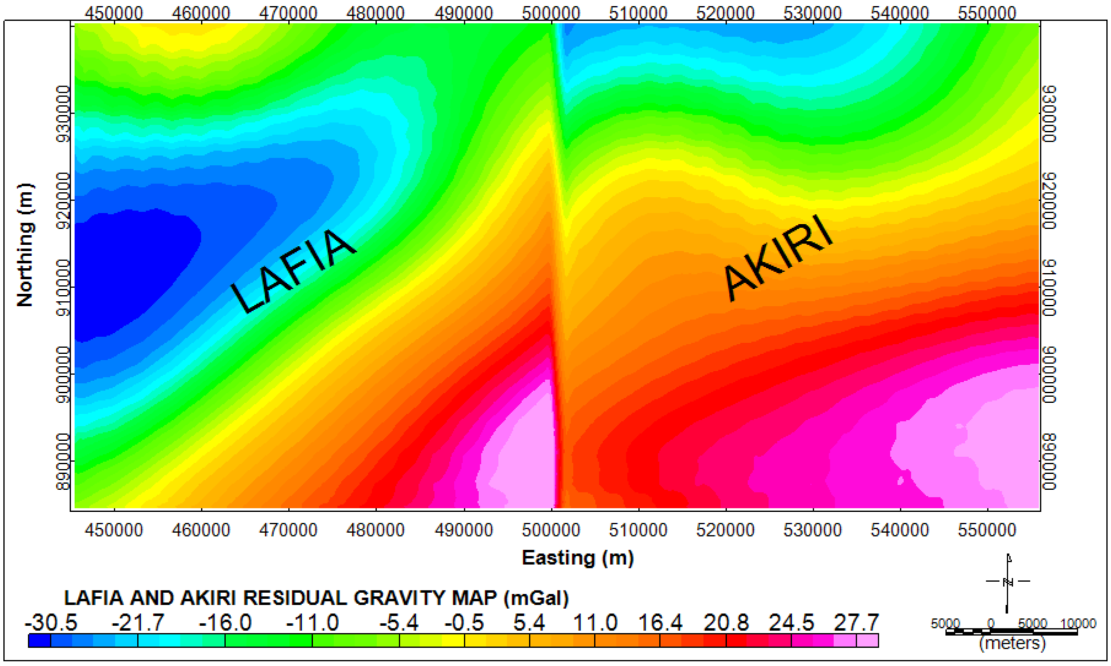

Fig. 3: Residual gravity map of the study area

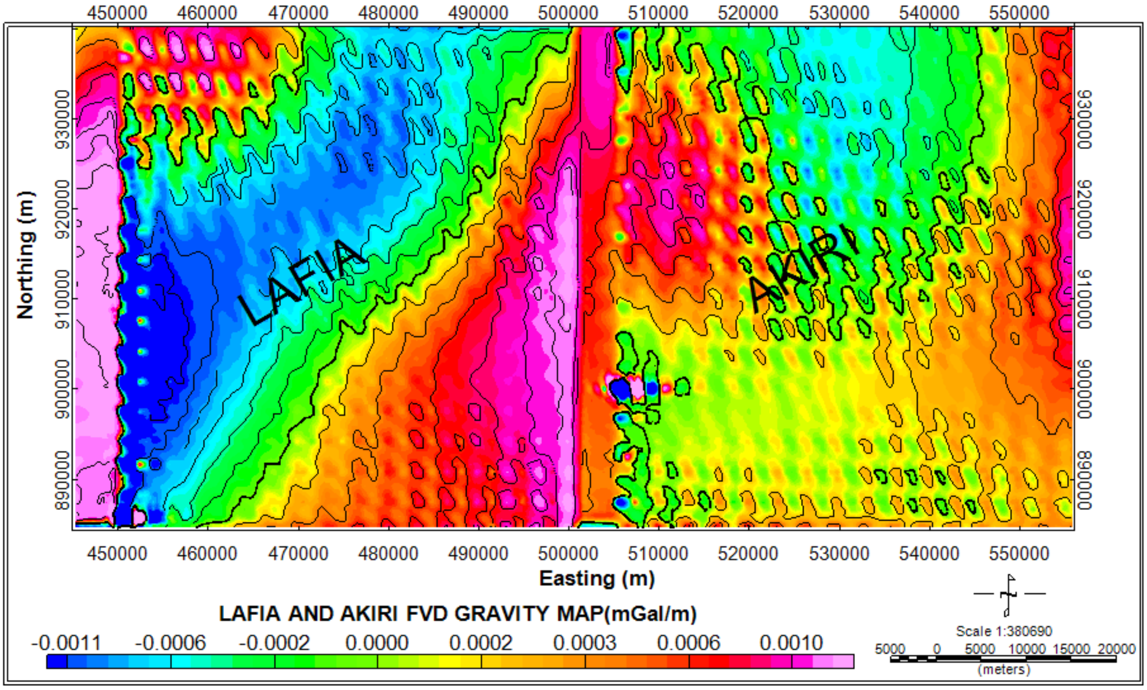

Fig. 4: Aerogravity First Vertical Derivative (FVD)

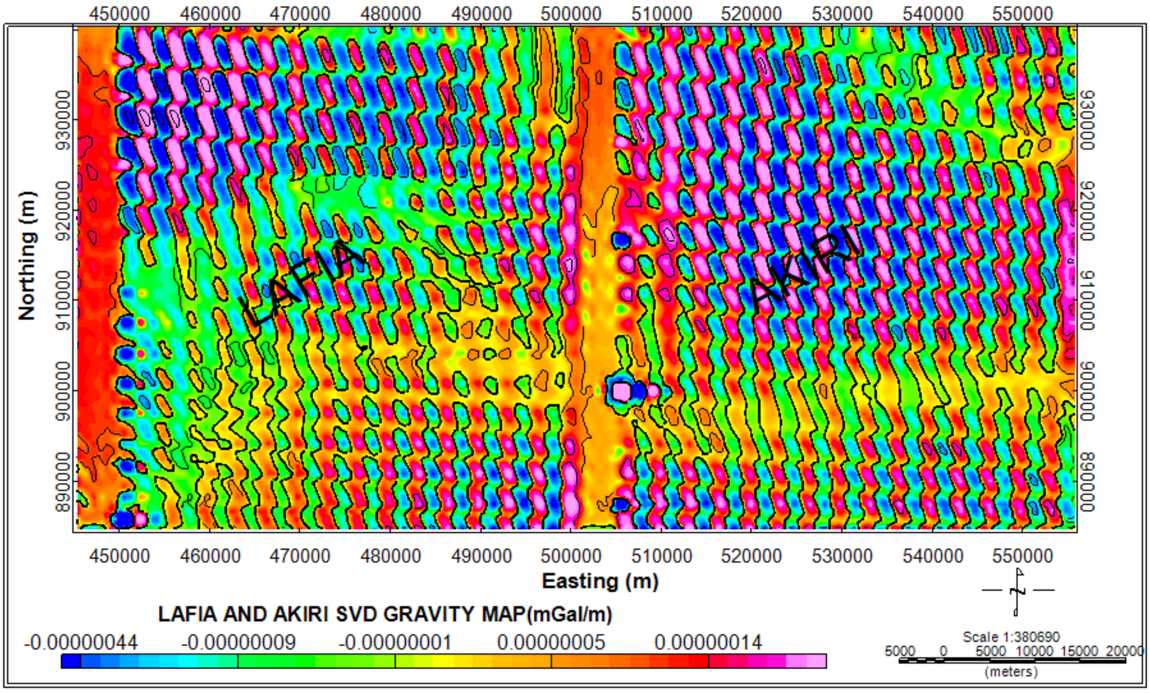

Fig. 5: Aerogravity Second Vertical Derivative (SVD)

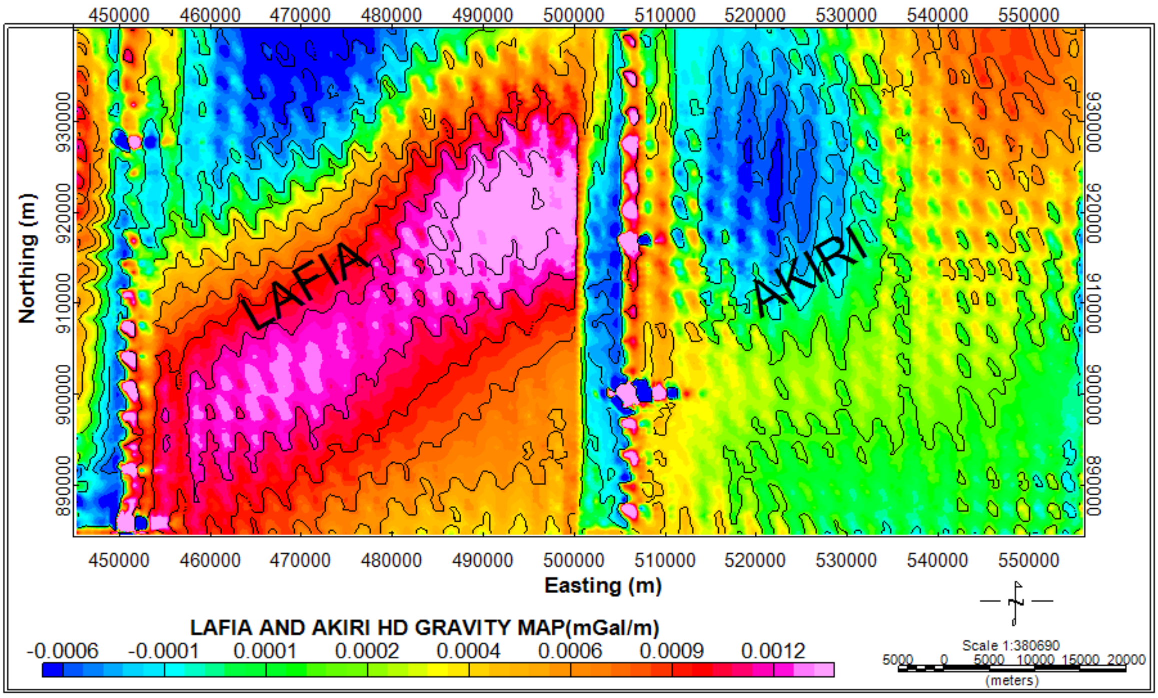

Fig. 6: Aerogravity horizontal derivative (HD)

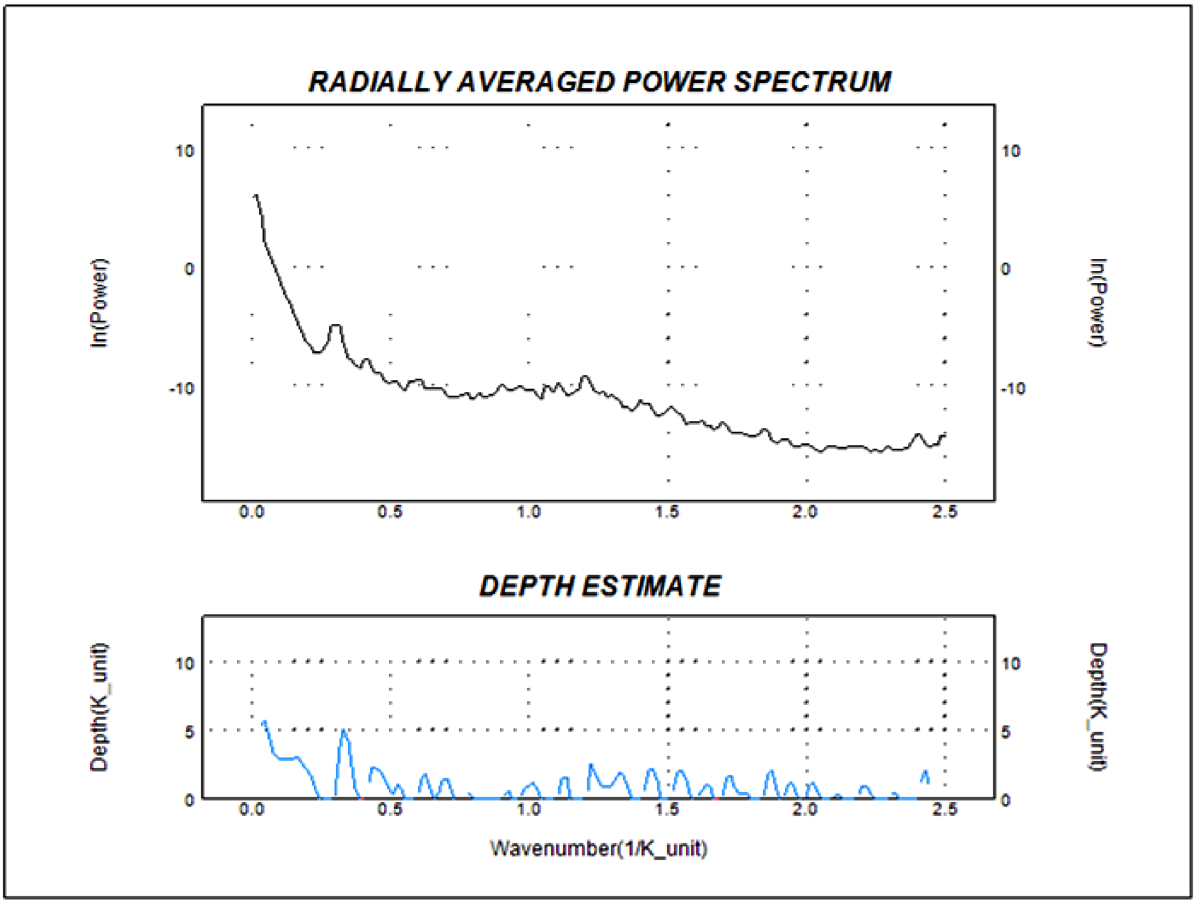

Fig. 7: Radial average power spectrum for the gravity data

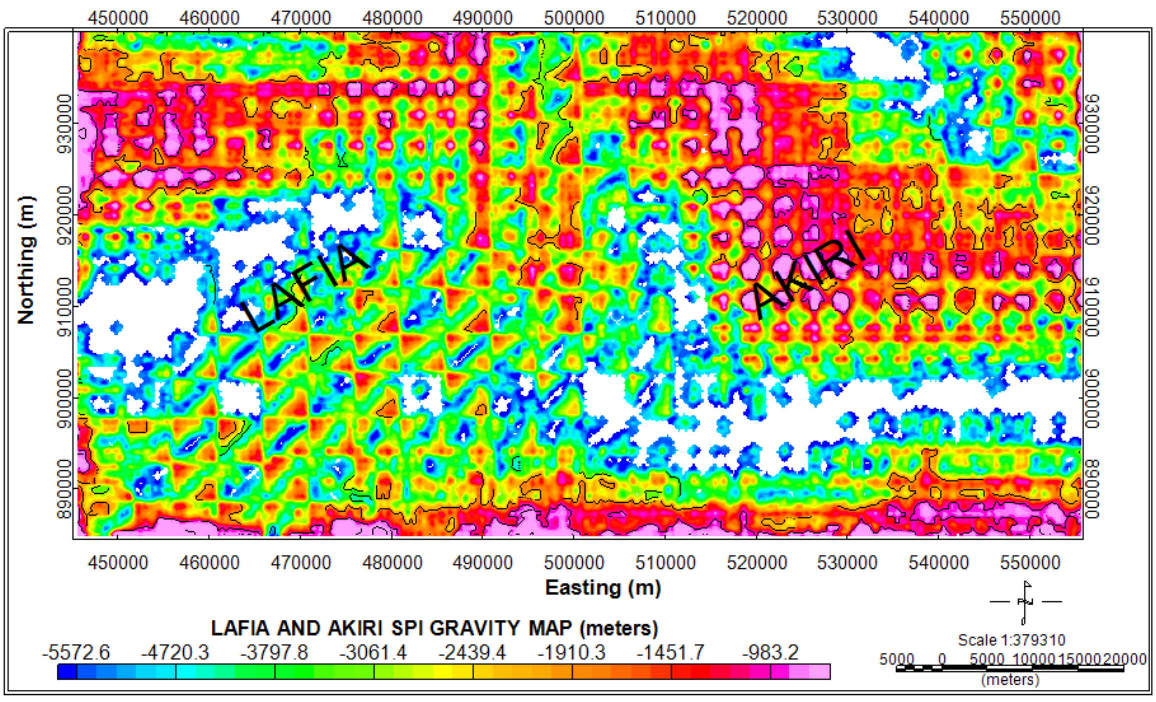

Figure 8: 2D Aerogravity SPI depth map and legend of the study area.

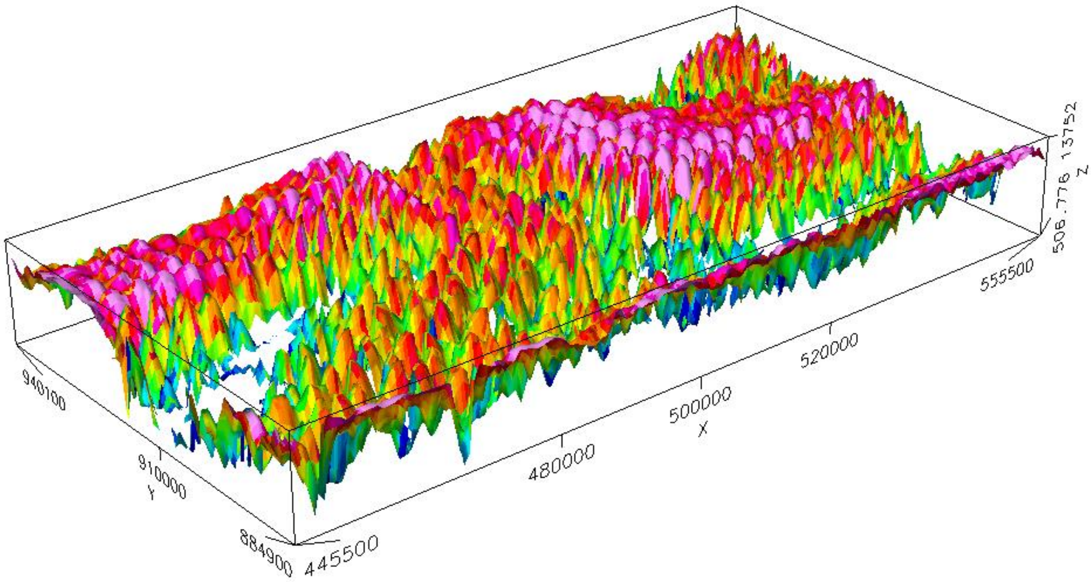

Figure 9: 3D Aerogravity SPI depth map and legend of the study area.

IV. Discussion

The result from the interpreted data shows that the Bouguer anomaly (Figure 2) of the study area varies from -66.0 mGal to 28.4 mGal; this indicates that the study area is characterized with low (blue colour), intermediate (green and yellow) and high (red and pinks) gravity anomaly signature and this variation in the gravity could be due to the differences in density or depth. The colour legend bar identifies regions of gravity high (red and pinks) around Akiri area, which corresponds to region with high density contrast beneath the surface. Also intermediate values (green and yellow) and gravity lows (blue colour) that correspond to regions of low density contrast where found around Lafia area. This indicates that Akiri area has more concentration of density contrast minerals than Lafia area which is more of lower density contrast minerals. In other words, the areas of strong positive anomalies likely indicate a higher concentration of density contrast minerals while areas with broad density lows are likely areas of lower density contrast minerals.

Furthermore, the Akiri area is dominated by bodies with high gravity anomalies in the southern part while the central part is dominated with both high and intermediate gravity anomalies especially in the south-central and north-central parts respectively. The northern part of Akiri is marked by low gravity anomalies which trends westward. The Lafia area is dominated with high gravity anomalies which trend SE in the south and with little patches of high gravity anomalies around NW in the northern part. Also Lafia area is marked by low gravity in the central part; intermediate gravity anomalies in the NW and southern parts.

The residual Bouguer anomaly map (Figure 3) varies from -30.5 to 27.7 mGal. The removal of the regional anomaly from the Bouguer anomaly gave a better resolution of the Bouguer anomaly map. The residual gravity field was used to bring into focus local features which tend to be obscured by the broad features of the regional field. The southern part of the study area has high density contrast beneath the subsurface and decreases towards the northern part. Figure 4 is the first vertical derivative computed from the residual Bouguer gravity grid using Oasis montaj^{TM} software. The first vertical derivative map (Figure 4) enhanced the shallow sources by suppressing the effect of the deeper ones, this helped to reveal near surface intrusions. Figure 5 shows the second derivative which sharpens the effect of the first vertical derivatives and helps to determine the edge of the anomalous body. The horizontal derivative Figure 6 shows more exact location for faults.

Figure 7 shows the radial average power spectrum for the gravity data, here the bouguer gravity data was subjected to Log Power Spectrum a filtering technique using MAGMAP tool of oasis montaj software. The maximum estimated basement depth obtained is 5.6 km. These depths are found to be within the range of depths predicted by earlier researchers that worked in middle Benue Trough (Igwesi and Umego, 2013). Also Figure 8 is the aerogravity SPI map showing the variation of depths to anomalous gravity bodies computed using the first vertical derivatives and horizontal gradient. In Figure 8, the negative depth values shown on the SPI legend depicts the depths of buried gravity bodies, which may be deep seated basement rocks or near surface intrusive. The pink colour generally indicates areas occupied by shallow gravity bodies, while the blue colour depicts areas of deep lying gravity bodies.

This shows that Akiri area has thick sedimentary thickness around the southern and north- eastern parts while Lafia area has thick sedimentary thickness around the central part with small patches in the southern and northern parts.The deep seated bodies are predominantly found everywhere with an intermingling of shallow seated bodies in the study area. These are clearly portrayed in the 3-D view (Figure 9) which is in different tilt position. The source parameter image (SPI) grid indicated the different density contrasts and gravity anomalies within the area. The SPI depth result ranges from -983.2 m (shallow gravity anomalous bodies) to -5572.6m (deep lying gravity anomalous bodies). This is in agreement with the 5.6 km depth obtained from the spectral analysis (power spectrum) over the study area. The high depths indicate thick sediment which is suitable for hydrocarbon accumulation (Wright et al., 1985, Obiora et al., 2016). Therefore, integrating the results obtained from both spectral analysis(power spectrum) with those from SPI, it could be seen that Lafia and Akiri areas with basement depths of about 983.2 to 5600 m has enough sedimentary thickness to favour hydrocarbon accumulation, assuming all other conditions are met (Wright et. al., (1985)).

More attention should be paid to the Lafia and Akiri area because it has more favourable geologic features/sediments. Previous studies have confirmed that the geology of the Benue Trough offers promises to prospective investors and researchers in general. This middle Benue trough was considered to be the most prospective area for hydrocarbon exploration by Nwachukwu, (1985) with estimated depths to the mature zones of (2-4) km. Geological and geophysical studies carried out by Ofoegbu,(1984,1985,1986) in the Benue trough have shown that the area possessed qualities like thick sedimentary sequence, marine source bed, block faulting and suitable traps notable with oil producing regions of the country (Nwosu et al., 2013).

V. Conclusion

The airborne gravity data of the Lafia and Akiri area have been interpreted qualitatively and quantitatively. The bouguer gravity anomaly map varies from -66.0 mGal to 28.4 mGal while residual Bouguer anomaly map varies from -30.5 to 27.7 mGal. These contour maps reveal regions of gravity high which corresponds to regions with high density contrast and gravity lows which correspond to regions of low density contrast. The Horizontal derivative showed the occurrence of subsurface linear structures which could be the presence of faults in the study area. Power Spectrum and Source Parameter Imaging (SPI) were employed in quantitative interpretation with the aim of determining depth/thickness of the sedimentary Basin, density contrast and type of mineralization prevalent in the area. The minimum depth to basement obtained from the Power Spectrum method is 5600 meters while the depth to basement obtained from Source Parameter Imaging (SPI) ranges from -983.2 m to -5572.6m. The depth to basement from both the methods seems to be approximately equal. These sedimentary thickness obtained in this work has revealed that the study area has potential for mineral deposit, which could serve as raw material(s) for many factories and industries in Nigeria.

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