ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2521-5035 (Print)
ISSN: 2521-5043 (Online)
CODEN: ESMACU

Earth Sciences Malaysia (ESMY)

DOI: http://doi.org/10.26480/esmy.02.2024.143.150

CrossMark

RESEARCH ARTICLE

AEROGRAVITY DATA ANOMALIES INVESTIGATION WITHIN LAFIA AND AKIRI AREAS, MIDDLE BENUE TROUGH, NIGERIA EMPLOYING FORWARD AND INVERSE MODELLING TECHNIQUE

Ngozi A. Okwesili*, John A.Yakubu, Ngozi M. Ossai

Department of Physics and Astronomy, University of Nigeria, Nsukka, Enugu State, Nigeria.
****Corresponding author email: ngozi.okwesili@unn.edu.ng***

ARTICLE DETAILS

Article History:

Received 09 February 2024
Revised 12 March 2024
Accepted 25 April 2024
Available online 28 April 2024

ABSTRACT

The aerial gravity data of Lafia and Akiri areas were interpreted qualitatively and quantitatively to map surface and deep earth structures responsible for the gravity anomalies within the study area. This entails using grids on which the anomalous values obtained at different stations are plotted and contours drawn at appropriate intervals using Oasis Montaj software. The Bouguer anomaly obtained from the study varies from -66.0 mGal to 28.4 mGal while the residual Bouguer anomaly is from -30.5 mGal to 27.7 mGal. The Bouguer gravity data was subjected to forward and inverse modeling analysis using PotentQ 3D software. The results obtained from the forward and inverse modeling of the airborne gravity data shows the density values as: 2.550, 2.630 and 0.074 g/cm^3 for the modeled profiles 1 – 3 respectively, with respective depths of -2943, -1156 and 25 m. The highest depth of -2943 m obtained within the south-eastern part (Akiri) of the study area exhibits thick sediment able to hold more solid mineral than Lafia area with the lowest depth. This study serves as a guide to the mining industries to determine the area with high concentration of solid minerals for economic and sustainable development of the nation.

KEYWORDS

Grids; Oasis Montaj software; Bouger anomaly; Density values; Solid minerals

1. INTRODUCTION

The most essential factors affecting the establishment of an industry within a place are the availability and nearness of the raw materials which is needed by the industry in that location. The raw materials needed by most industries exist in various forms within the Earth's subsurface and searching for these raw materials are seen as a major concern for mankind. Mono-economy has being the case of Nigeria for a very long time now and due to its effect on the economic growth of the country, Federal Government of Nigeria (FGN) developed an urgent policies on the rejuvenation of the solid mineral industry aiming at diversifying the economy. Nigeria as a whole has its own shares of solid minerals of different varieties which cut across different states of the federation.

The study areas Lafia and Akiri are located within the Nasarawa state, north-central region of Nigeria. Nasarawa state is found in the middle Benue trough of Nigeria. The state is known as "Home for Nigeria's Solid Minerals "because of its huge deposits of mineral resources. It's among the most endowed states within Nigeria in terms of commercially and economically viable natural mineral resources availability. In fact, Soluap Technologies Ltd discovered during their research that all the local government areas within the state have a solid mineral deposit of some kind that is marketable both domestically and internationally.

These minerals include clay, silica sand, topaz, aquamarine, emerald, amethyst, mica, heliodor, quartz, granite, marble, iron ore, copper ore etc. Among these minerals are copper ore, zinc, lead, granite, marble etc, which are found in Akiri and topaz, silica, clay in Lafia area of Nasarawa state.

Therefore, the need to harness these solid minerals for poverty reduction and wealth creation in line with the FGN's policy made Nigerian geological survey agency (NGSA) and Soluap Technologies Ltd to carry out geophysical survey for solid mineral deposits in some towns in Nasarawa state.

Innovative techniques are necessary for subsurface exploration and mapping the lithology and structure of the subsurface can be effectively achieved through the use of the gravity method. Depending on the local geology and rock characteristics, gravity data can be used in a variety of ways to address various exploration issues. When evaluated, the data can reveal information about subsurface materials (Okwesili et al., 2020). It is possible to measure gravity in two different ways. Either an aerial (airborne) or ground-based gravity survey could be used. Airborne gravity evaluates the potential for mineral exploitation across wide regions using data gathered from aerial surveys. Early in the exploratory process, measurements are typically taken, which can be quite helpful in classifying the local soil types. Compared to ground penetration radar, high frequency electromagnetic, and dc-resistivity techniques, it has good depth penetration and is unaffected by high conductivity values of near-surface clay-rich soils.

Measurements of the earth's gravitational field are used to map the subsurface variations in density in a variety of geosciences applications, including engineering explorations and large-scale regional and geological structure studies (Biswas and Sharma, 2016; Biswas et al., 2014a; b; Mandal et al., 2015; 2013). With the goal of identifying and characterizing subterranean structures from the gravity effects brought on by their anomalous densities, a gravity-based technique detects differences in the

Quick Response Code	Access this article online	
	Website: www.earthsciencesmalaysia.com	**DOI:** 10.26480/esmy.02.2024.143.150

earth's gravitational field (gravity anomalies) (Lowrie, 2007; Telford et al., 1990). The difference in density, or density contrast, between a body of rock and its surroundings is what causes gravity anomalies. While the fluctuations brought on by earth's gravity are generated by variations in the area's subsurface geology, the sign of the density contrast determines the sign of the gravity anomaly. Density contrast is influenced by various factors such as interstitial fluids, porosity, and grain density in materials. Depending on the local geology, gravity data can be used to search for valuable solid minerals, water, gasses, and oil. (Ekpa et al., 2018).

So far, several geophysical explorations have been conducted on Nigeria's Benue trough, encompassing the middle Benue trough. Because there are no direct geologic or economic benefits, geophysics specialists have paid little attention to the middle Benue trough in particular. Nonetheless, it has grown in importance as a result of increased efforts to search Nigeria for new and more mineral locations (Ajayi and Ajakaiye, 1986; Akande et al., 2011; Bako, 2010; Kasidi and Nur, 2012; Nwosu, 2014; Offodile, 1976; Ofoegbu, 1985; Onuoha et al., 1994; Salako et al., 2020).

A geologist from Shell-BP was the first to identify this formation. Also, utilizing British geology students, Nigeria's mine development conducted an initial survey of lead-zinc in 1948 and 1949. Moreover in 2019, the Economic Geology Department of the Nigerian Geological Survey Agency (NGSA) carried out preliminary assessment of the copper deposits of the Akiri and Azara metalogenic province. From the unpublished report, the potential copper resources fall within the middle Benue trough. During the assessment of the deposit, twenty-five (25) samples were collected from pits and trenches at mining sites in the area and analyzed. It was observed that the occurrence of copper in the project area trends towards the southwest-northeast direction with highest concentration (19.01%) in the Akiri area. Nickel, Lead and Zinc mineralization is almost in the same trend (SW-NE) as the copper sampled in the studied area. They used magnetic, electromagnetic (EM-VLF), resistivity and IP methods to map out mineralized veins in the area. Integration of these methods can delineate Copper mineralization with a high degree of confidence. Chalcopyrite is the predominant copper ore in the region, with corresponding amounts of malachite and azurite.

In addition, some researchers used forward and inverse modelling technique to study the aeromagnetic data over some towns in middle Benue trough Nigeria in which Lafia and Akiri were inclusive (Onyishi et al., 2019). A group of researchers used spectral analysis and source parameter imaging methods to study the aeromagnetic data over Lafia and Akiri (Okwesili et al., 2019). Furthermore, others used power spectrum and source parameter imaging method to study the aerogravity data of Lafia and Akiri, in middle Benue trough Nigeria (Okwesili et al., 2020). These three researches obtained deep depth with thick sedimentation around Akiri area as was also observed in the present study. Thus, the study focuses on interpreting the aerial gravity data of Lafia and Akiri using the application of forward and inverse modelling technique. These findings could be used to bolster the findings of previous studies that have alreadybeen conducted nearby, demonstrating the study area's potential for substantial mineral reserves.

2. Location And General Geology Of The Study Area

The study area is situated between latitudes 8.0°N and 8.5°N and longitudes 8.5°E and 9.5°E in the middle of the Benue across Nigeria (Figure 1a). The upper and lower arms of Nigeria's Benue trough sedimentary basin are connected by the middle Benue trough. One of roughly seven inland sedimentary basins in Nigeria (Figure 1b) that resulted from the early Cretaceous rifling of the central West African basement uplift, it is a segment of the extensive stretch arm of the Central African rift system. The research region is composed of volcanic rock, older granites, newer granites, sedimentary rocks, and crystalline basement rocks. The migmatites, gneisses, and schists that make up the Migmatite-Gneiss Complex date from the Mesoarchaean to Neoproterozoic (3200 Ma to 542 Ma).

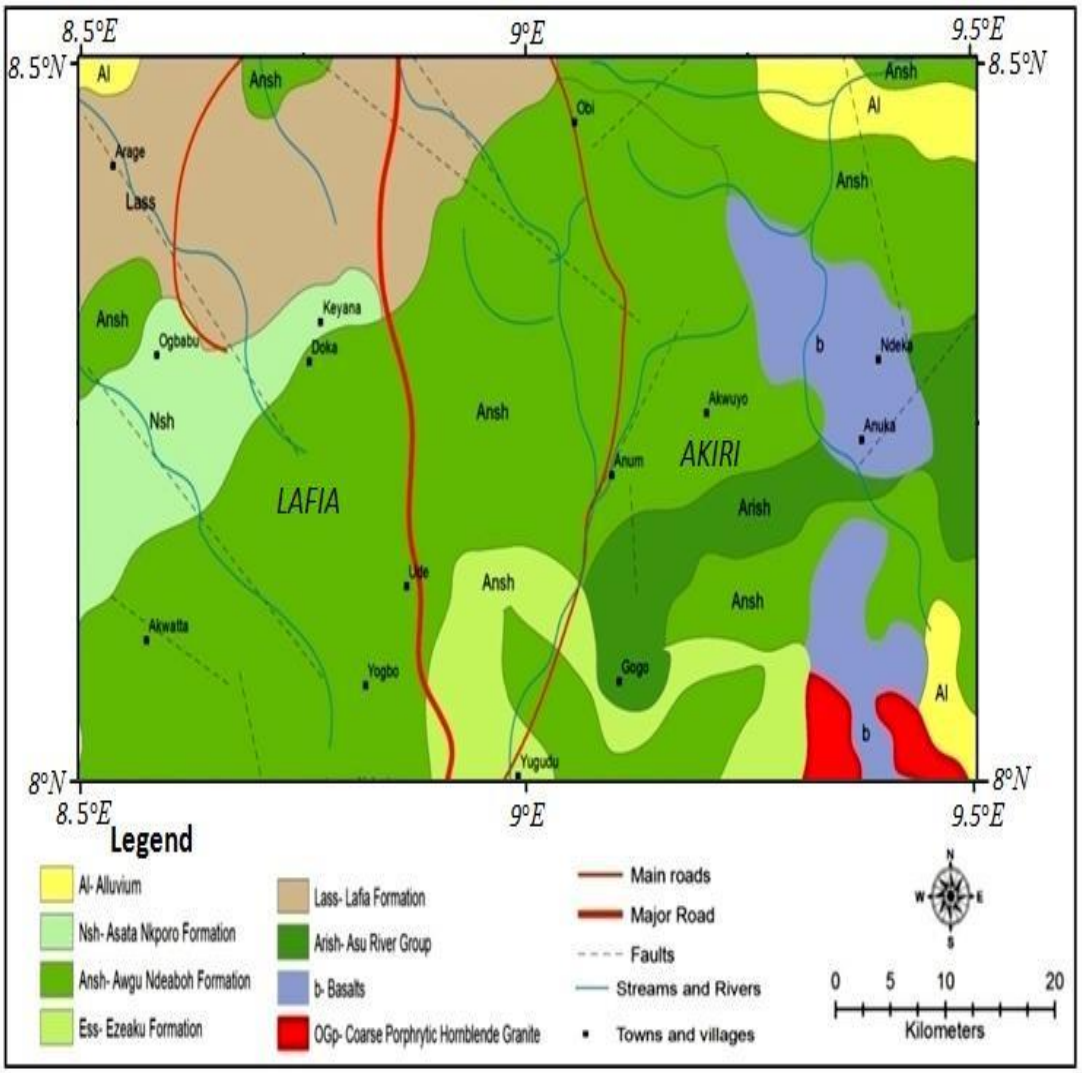

Figure 1a: Geologic map of the study area

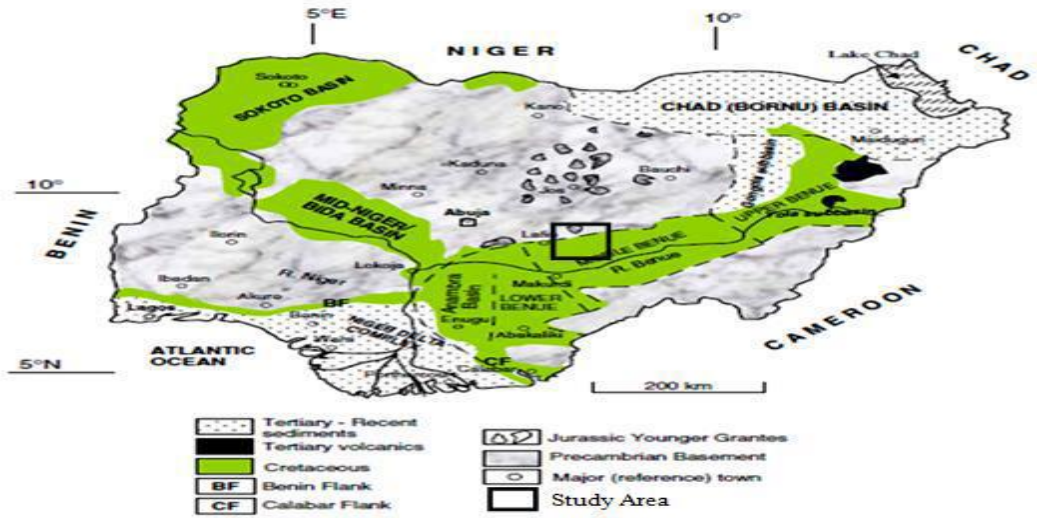

Figure 1b: The map of Nigeria showing the location of Middle Benue Trough (Obaje, 2009).

The older granites, also known as Pan-African granitoids, are mostly granites, diorites, and dolerites and are Pan-African in age, ranging from Neoproterozoic to Early Palaeozoic (600 ± 200 Ma). During the 600 ± 200 Ma Pan-African tectonic events, the older granites, also known as Pan-African granitoids, distorted and invaded the Migmatite-Gneiss Complex. The younger, high-level, anorogenic granites of the Mada and Afu ring complexes (210–145 Ma, or Triassic–Jurassic in age) are found at the trough's edge in the northwest of the research region. They are mostly composed of microgranites and biotite granites. The majority of the research region is composed of Cretaceous sedimentary rocks, which include the Asu River Group, Awe Formation, Keana Formation, Markudi Formation, Ezeaku Formation, Awgu Formation, and Lafia Formation. During the Santonian tectonic event (c. 86 Ma), sedimentary rocks from the Cretaceous epoch, which were older than the Santonian, underwent deformation that resulted in several uplifts, faults, and folds. These features generally followed a NE–SW trend, parallel to the trough boundary.

3. Materials And Methods

The Nigerian Geological Survey Agency provided the high-resolution aircraft gravity data used in this investigation (NGSA). Two Lafia (sheet 231) and Akiri (sheet 232) gravity sheets are the materials used. The German Aerospace Center and the National Aeronautics and Space Administration (NASA) used the GRACE GRAVITY MODEL Sensor onboard 2 satellites in 2013 to collect the airborne gravity data. To prepare them for interpretation, these data underwent a number of processing steps, including gridding, mathematical filtration, and depth estimation. There were two approaches of interpretation used: qualitative and quantitative.

In qualitative interpretation, surface and subsurface structures, such as intrusive formations that gave rise to the obvious anomalies, are mapped in order to extract geologic information from maps and grids (Revees, 2005). This entails creating gravity maps or grids, which are used to plot data from various stations and generate contours at appropriate intervals. The computer program Oasis Montaj uses interpolation to create the contours. Colored maps and grids are used to display contours. Additionally, the depth and size of the anomaly sources were numerically estimated by the quantitative interpretation process (Revees, 2005). Forward and inverse modeling approaches were used for this.

3.1 Data reduction

The least curvature method, which fits a minimum curvature surface to data points, was used to convert the data to an evenly spaced two-dimensional (2D) grid at the initial stage of the qualitative interpretation analysis (Reid, 1980; Li and Gotze, 1999). The Oasis Montaj program was used for this analysis. The Bouguer gravity map of the research area is created by gridding the data. The gridded sheets were digitally combined into a composite aerogravity map while maintaining the integrity of the original maps. The residual anomaly (Figure 3) was then obtained by mathematical filtering, which removed the regional anomalies (Figure 4) from the overall Bouguer gravity map (Figure 2). The first step in interpreting quantitative data is mathematical filtration. On our data, the first order polynomial fitting method was used. According to the study, additional data filters used are the first vertical derivative (FVD), second vertical derivative (SVD), and horizontal derivative (HD) (Biswas et al., 2017). The aerogravity data was then interpreted qualitatively and quantitatively.

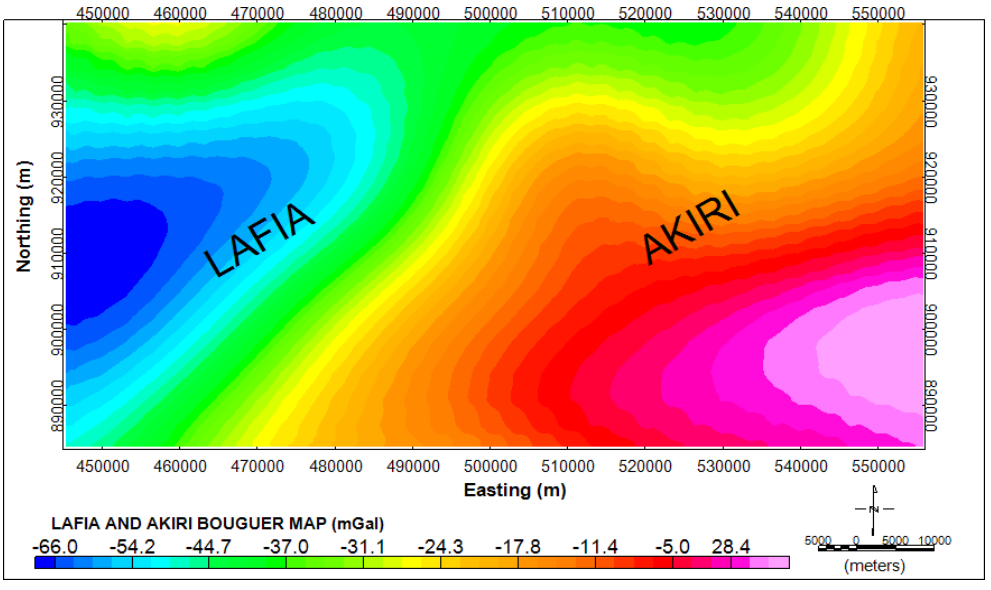

Figure 2: Bouguer gravity map of the study area.

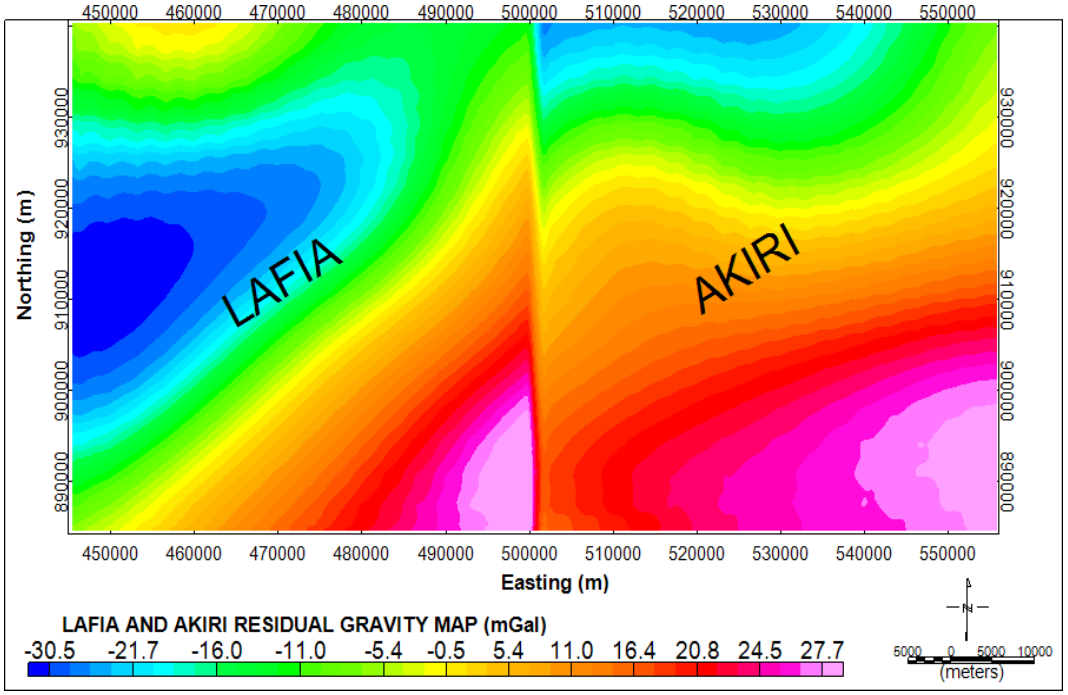

Figure 3: Residual gravity map of the study area

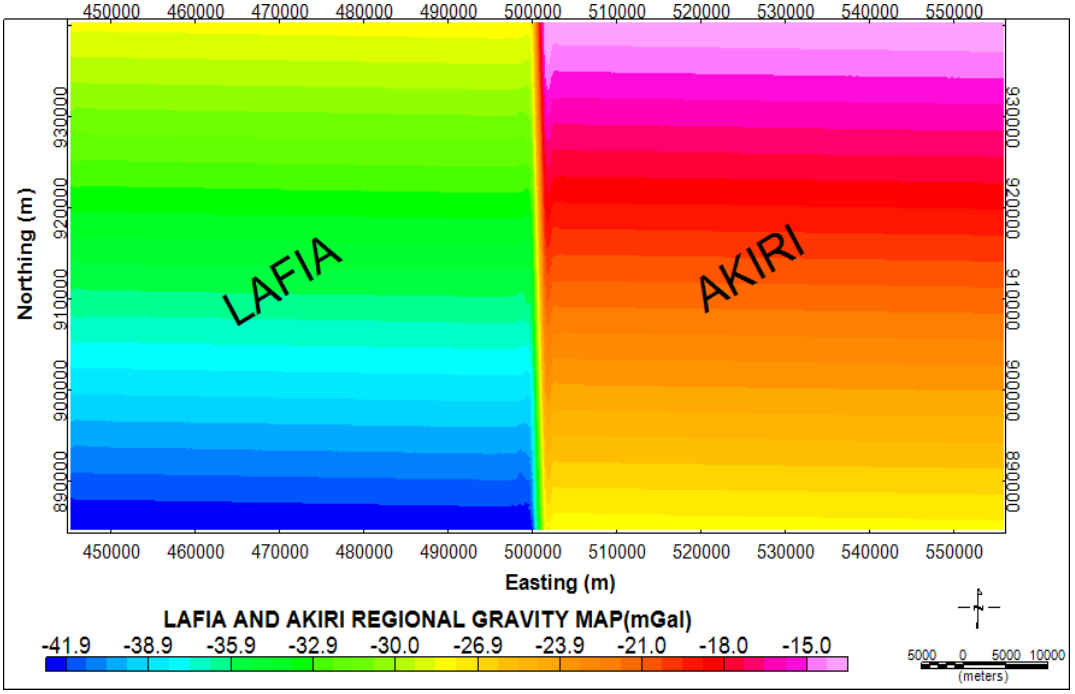

Figure 4: Regional Gravity Map of the study area

3.2 Forward and Inverse Modelling

Following thorough data reduction, forward and inverse modeling approaches were used to quantitatively analyze the collected data. The forward modeling technique involves numerically estimating the causes of anomalies' depth and dimensions. This is often accomplished by modeling source bodies, which theoretically have the ability to reproduce the anomalies observed in the survey (Reeves, 2005; Biswas et al., 2017; Biswas, 2016). Position and susceptibility were adjusted in the model until the computed curve matched the observed curve as closely as possible. The forward modeling which is a trial and error technique; involves the adjustment of position, shape and physical properties of the models in order to get a good fit between the observed and the calculated field data. Furthermore, the inverse modeling technique is a mathematical process that adjusts automatically the model parameters to improve the fit between the observed and the calculated field. This technique uses the PotentQ 3D tool of the Oasis montaj software. Three profiles (P1, P2 and P3) were taken at different portions of the residual map (Figure 8); each produced the best fitted model for the given type of body at the end of the modeling session with the modeling parameters being displayed in Figure 9(a-c).

4. Results

The aerogravity data interpretation was first carried out qualitatively through the production of the Bouguer gravity map of the area (Figure 2) using Oasis Montaj software. The interpreted data result showed that Bouguer anomaly of the area ranges from -66.0 mGal (minimum) to 28.4mGal (maximum) indicating that the area is characterized with high and low gravity signatures; these variations in gravity may be attributed to differences in density or density contrasts beneath the sub-surface of the area. Furthermore, the residual Bouguer anomaly (Figure 3) of the area ranges from -30.5 mGal (minimum) to 27.7mGal (maximum) showing that the area is made up of low (blue colour) and high (red and pink colour) gravity signatures. The regional Bouguer anomaly map (Figure 4) ranging from -41.9 mGal to -15.0 mGal was removed from the bouguer gravity map to get the residual map using the first order polynomial fitting. Figure 5 to 7 after the data reduction techniques showed the FVD, SVD and the HD map respectively. The FVD and SVD enhanced shallow sources through the suppression of deeper ones and thereby giving better resolutions to closely spaced sources while HD map showed more exact locations of faults.

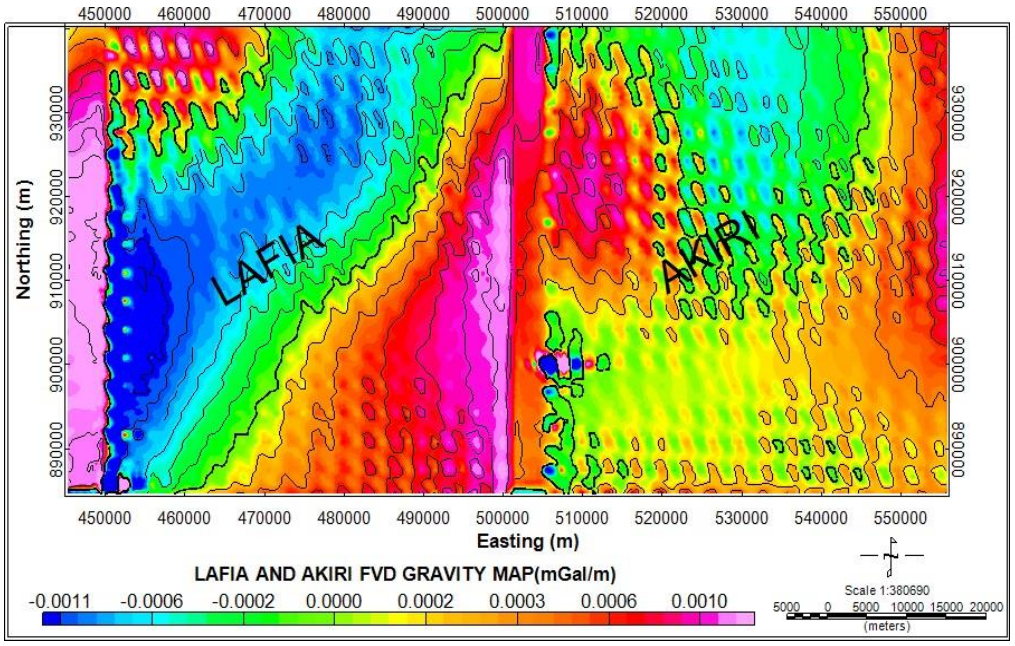

Figure 5: Aerogravity First Vertical Derivative (FVD)

Forward and inverse modeling was carried out with PotentQ 3D software. Figure 8 is the residual map showing number of profiles modelled with their locations used for the interpretation, while Figure 9(a -c) showed the subsets of the modeled portions. From the modeled profiles P1, P2 and P3, the modeled areas were shown as: Lafia and Akiri, respectively, whereas the red curves depict the calculated fields while the blue curves seen depict the observed fields. To get a good correlation between both fields, the model parameters like susceptibility and position were adjusted continuously until the calculated field curve best fits the observed field curve. Finally, the forward and inverse modeling results were summarized in Table 1.

5. Discussion

The Bouguer gravity map of the area (Figure 2) showed ranges of gravity anomaly which vary from -66.0 mGal to 28.4 mGal , whereas the residual Bouguer anomaly (Figure 3) is from -30.5 mGal to 27.7mGal. Areas of high and low gravity values were shown by the colour legend bar. The areas with high gravity values correspond to areas with high density contrasts below the surface while low gravity values correspond to areas of low density contrasts. The sign of these density contrasts determine the sign of the gravity anomalies while the variations due to the Earth's gravity are caused by variations in the sub-surface geology of the area. From the colour legend bar, the high gravity anomaly was observed in the south-eastern and north-eastern parts of the area, whereas the low gravity anomaly was seen in the south-western and north-western part of the area. The southern part of the area show more high density contrasts below the subsurface which declines towards the northern part. Areas of high gravity (red and pink) were identified more around Akiri area while intermediate (green and yellow) and low gravity (blue colour) areas were identified more in Lafia area.

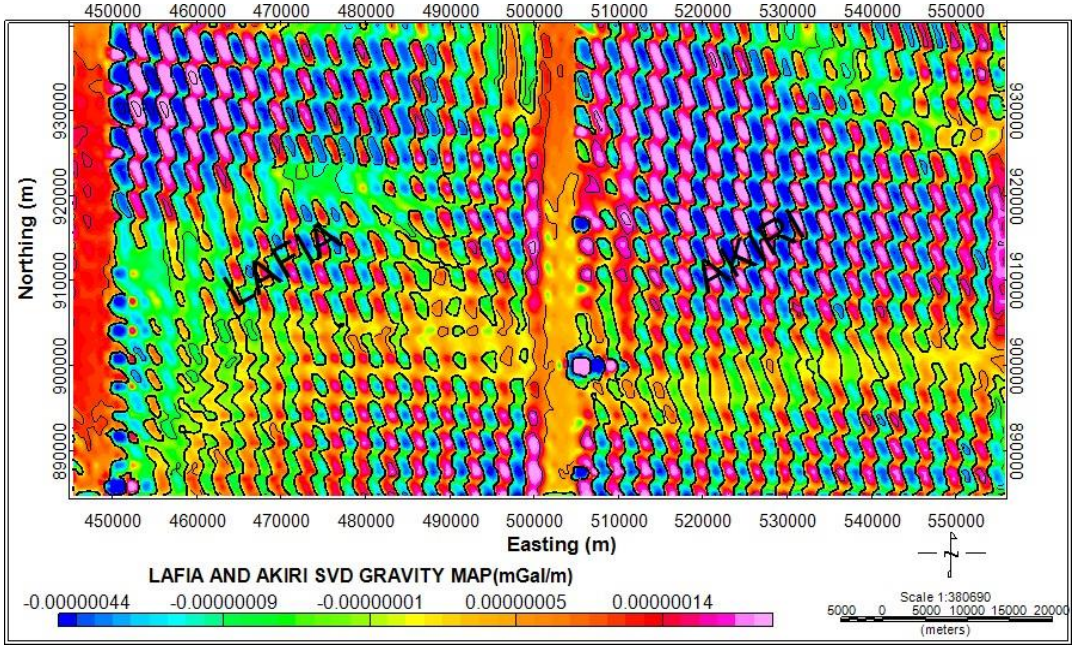

Figure 6: Aerogravity Second Vertical Derivative (SVD)

The Akiri areas are dominated more by bodies with high gravity anomaly in the north-eastern and south-eastern part which trends central wards while the north-western and south-western part of Akiri are marked with low gravity anomaly. The Lafia areas are dominated with bodies of high gravity anomaly in the south-eastern part with low gravity anomalies in the north-western and north-central parts, trending towards the north-eastern part of Lafia area. The regional Bouguer anomaly map (Figure 4) ranges from -41.9 mGal to -15.0 mGal. The removal of regional anomaly from the Bouguer gravity map gave a better resolution of the residual map. The FVD (Figure 5) computed on the residual data of the area helped to enhance the shallow sources through the suppression of the effect of the deeper ones thereby revealing near surface intrusions. The SVD (Figure 6) sharpened the effect of the first vertical derivatives and helped in determining the edges of the anomalous bodies while the HD (Figure 7) map helped in bringing out more the exact locations of faults.

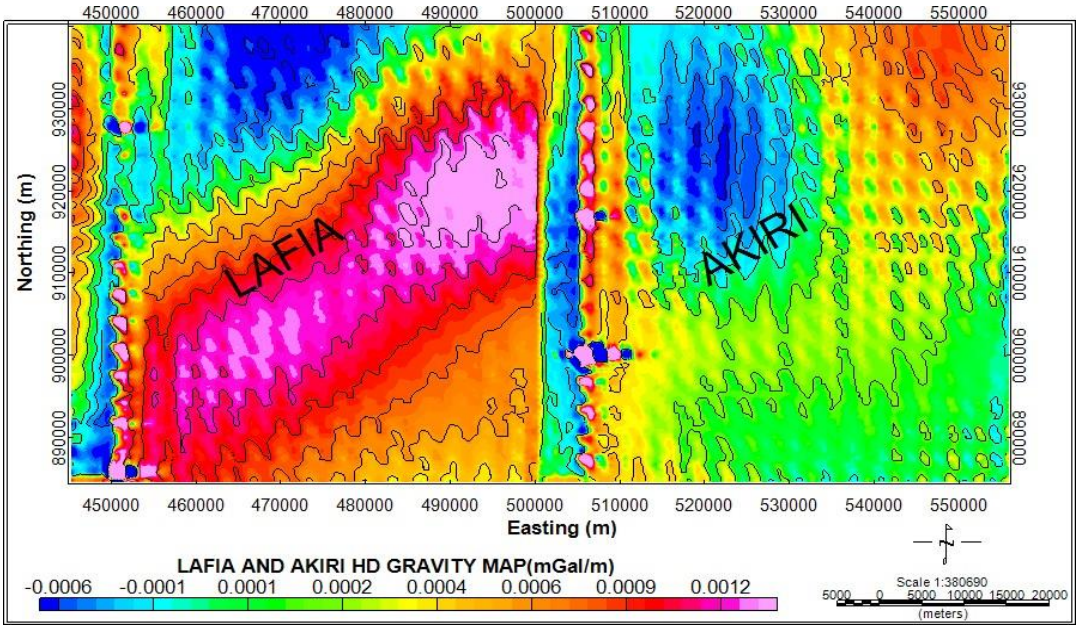

Figure 7: Aerogravity horizontal derivative (HD)

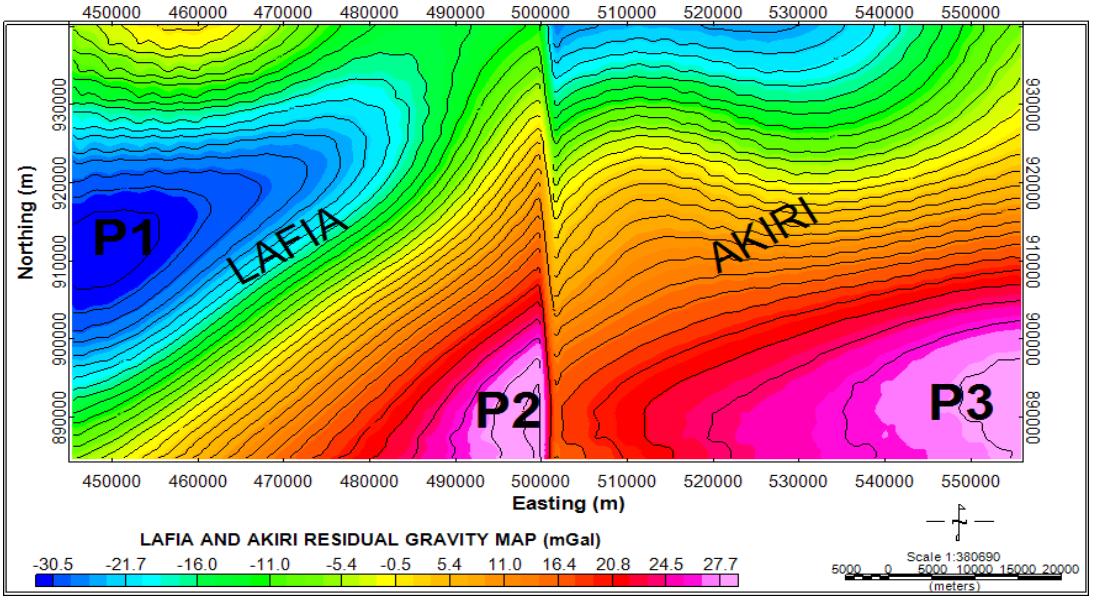

Figure 8: Residual map showing number of profiles modelled with the locations

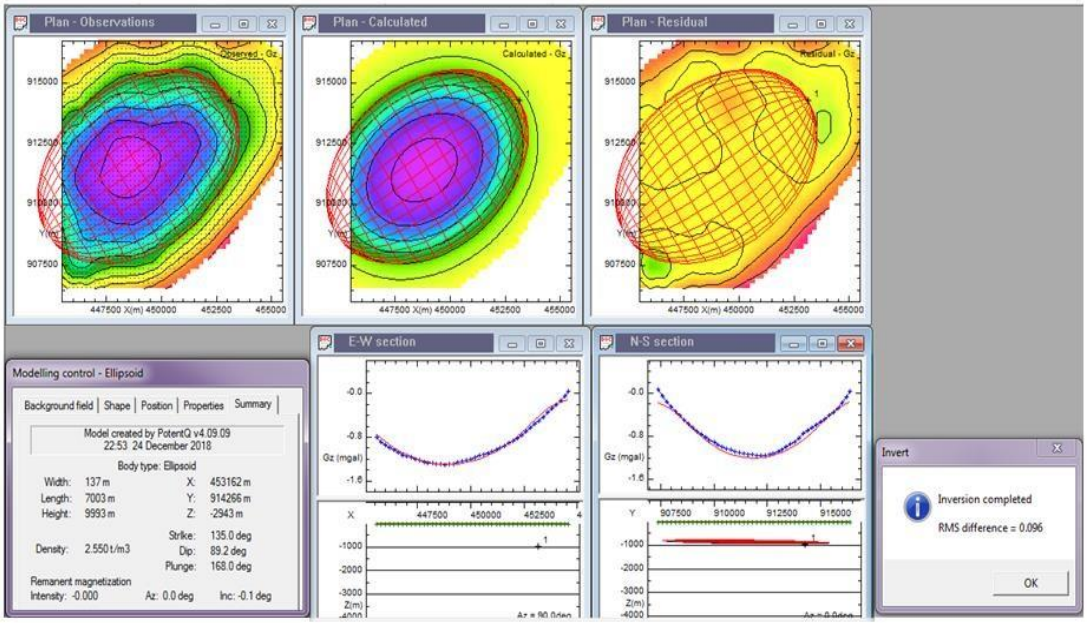

Figure 9a: Profile 1 (P1) modeled

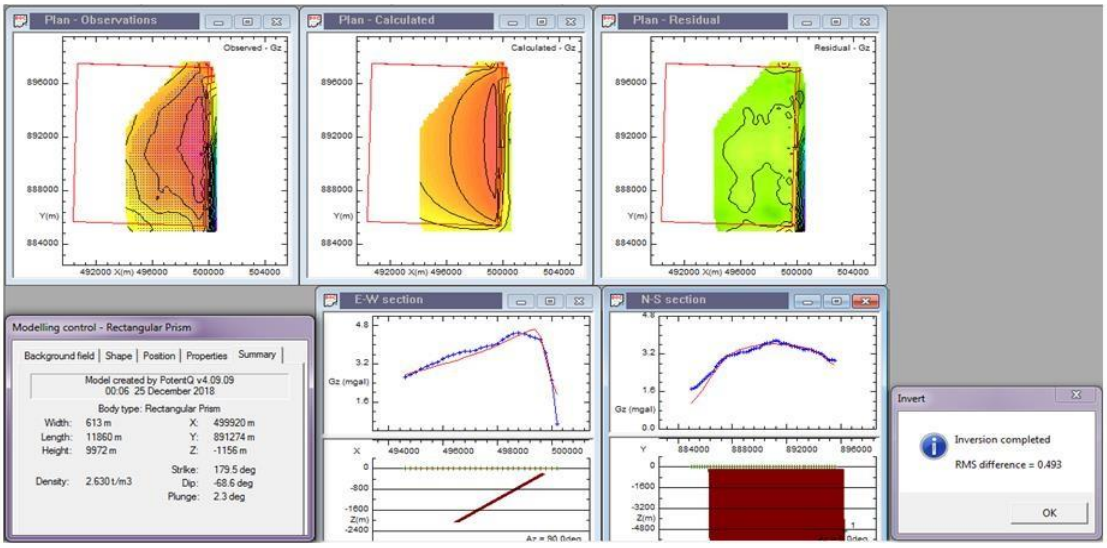

Figure 9b: Profile 2 (P2) modelled

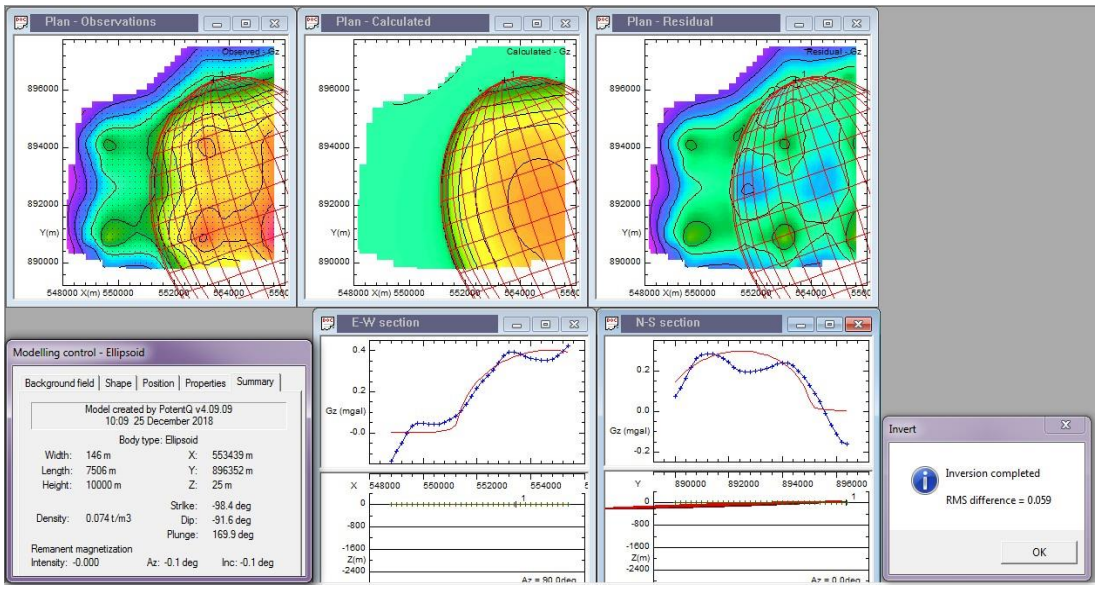

Figure 9c: Profile 3 (P3) modeled

Three profiles were taken from the aerogravity residual map (Figure 8) at different portions of the map within the study area. Profile 1 and 2 were modeled while profile 3 (Figure 9a-c) could not model, may be due to no enclosed contour. This is done to show the distribution of bodies causing the anomalies in the selected area. Each of the profiles produced a degree of dip, strike and plunge where the calculated values and the observed values matched well thereby producing the best model fit with the model parameters being displayed for the given type of bodies. From the summary of aerogravity forward and inverse modeling results (Table 1), profiles 1 and 3 were modeled by ellipsoid bodies at depth of -2943 m and 25 m with density values of 2.550 g/cm^3 and 0.074 g/cm^3 respectively. Profile 2 was modeled by rectangular prisms at depths of -1156m with density value of 2.550 g/cm^3. Other parameters obtained such as Inclination, Azimuth and Remnant magnetization are as shown on the model results. The shallow depth is due to sources from igneous intrusions in the sediment whereas the deep depth is associated with sources from the basement.

Model	Model shape	X(m)	Y(m)	Depth to anomalous body (m)	Plunge (deg)	Dip(deg)	Strike(deg)	Density value (g/cm^3)
P1	Ellipsoid	453162	914266	-2943	168.0	89.2	135.0	2.550
P2	Rectangular Prism	499920	891274	-1156	2.3	-68.6	179.5	2.630
P3	Ellipsoid	553439	896352	25	169.9	-91.6	-98.4	0.074

The observed density of these bodies suggested that they are likely metamorphic or igneous intrusions of basic to intermediate compositions, typically of mineral bearing rocks like limestone, pyrite, copper ore, zinc, lead, granite, marble, silica, clay etc (Telford et al., 1976). This result is found to be in agreement with Soluap Technologies Ltd that found solid minerals such as heliodor, aquamarine, emerald, topaz, amethyst, mica, quartz, granite in Nasarawa Eggon local government area of which Akiri town is a part of and clay, silica sand, topaz in Lafia area. Also, the NGSA found copper, zinc and lead around Akiri area. This agrees with the works of other researchers within the middle Benue trough (Ahmed et al., 1994; Nwosu, 2014). Furthermore, a depth ranging from 2000 m to 6291.5 m within the middle Benue trough was obtained using source parameter imaging (SPI) method (Nwosu, 2014).

Consequently, a group of researchers used spectral analysis to show that the deep depths to basement sources within the middle Benue trough varies from 1600 to 5000 m while the shallow depths varies from 60 to 1200 m (Ahmed et al., 1994). In other study, researchers used forward and inverse modelling technique to obtain minerals such as graphite and pyrite and rocks such as limestone, marble, granite, gnesis and schist around

Akiri area with deep depths to basement recorded within the area (Onyishi et al., 2019). They also found that hydrocarbon accumulation is higher within the Akiri area. Therefore, the deep depth of -2943 m recorded at the south-eastern part of our study area (around Akiri) show thick sediments able to hold higher concentrations of solid minerals than Lafia area with less sedimentation. The area also has higher prospect for hydrocarbon potential if all the other conditions for hydrocarbon accumulations are favorable.

6. Conclusion

The forward and inverse modelling techniques was employed in the quantitative interpretation of the aerogravity data of some parts of middle benue trough of Nigeria to determine the depth of the density contrasts, sedimentary basin and types of mineralization prevalent within the area. The Bouguer anomaly map identified region with high gravity which correspond to region with high density contrasts around Akiri area and low gravity which corresponds to region of low density contrasts around Lafia area. The densities of the modelled body suggests the presence of rock bearing minerals such as limestone, pyrite, copper ore, zinc, lead, granite, marble, silica, clay etc. These rock bearing minerals are more dominant around Akiri area. The south-eastern part of the study area with highest sediment depth of -2943 m holds more solid mineral accumulation prospects than the Lafia area with minimum depth. Copper and its alloy are well known for their near excellent and perfect electrical and thermal conductivities, ease of fabrication and resistance to corrosion: hence the use for electrical wire production.

Therefore Copper being a strategic mineral, its mineralization, occurrence and exploration will assist greatly in understanding the geological structures. These minerals can be exploited in order to diversify the economy of Nigeria. It is recommended that more works should be carried out in this area with integrated geophysical methods covering the whole middle Benue trough. This will help the government to have a detailed documented data of the area for future researchers. Finally, this research will guide investors greatly in the decision makings thereby expanding further the solid mineral resources of the country : since the most primary factors that affect the establishments of an industry in a place are the availability and nearness of the raw materials which is needed by the industry in that location.

References

Ahmed, N., Onuoha, M.O., and Ofoegbu, C.O., 1994. Spectral Analysis of Aeromagnetic Data over the Middle Benue Trough Nigeria. J. Min. Geol., 30 (2), Pp. 211-217.

Ajayi, C.O., and Ajakaiye, D.E., 1986. Structures deduced from gravity data in the middle Benue Nigeria. Jounal of African Earth Sciences, 5, Pp. 359-369.

Akande, S.O., Egenhoff, S.O., Obaje, N.G., and Erdtmann, B.D., 2011. Stratigraphic evolution and petroleum potential of middle cretaceous sediments in the lower and middle Benue Trough, Nigeria: Insights from New Source Rock Facies Evaluation. Petroleum Technology Development Journal, ISSN 1595 – 9104.

Bako A.S.J., 2010. Geothermal energy potential in the part of benue trough located in Nasarawa state. A thesis submitted to the postgraduate school Ahmadu Bello University, Zaria, Nigeria.

Biswas, A., and Sharma, S.P., 2016. Integrated geophysical studies to elicit the structure associated with Uranium mineralization around South Purulia Shear Zone, India: A Review. Ore Geology Reviews, 72, Pp. 307-1326.

Biswas, A., Mandal, A., Sharma, S.P., and Mohanty, W.K., 2014a. Delineation of subsurface structure using self-potential, gravity and resistivity surveys from South Purulia Shear Zone, India: Implication to uranium mineralization. Interpretation, 2 (2), Pp. T103-T110.

Biswas, A., Mandal, A., Sharma, S.P., and Mohanty, W.K., 2014b. Integrating apparent conductance in resistivity sounding to constrain 2D Gravity modeling for subsurface structure associated with uranium mineralization across South Purulia Shear Zone. International Journal of Geophysics, Article ID 691521, Pp. 1-8.

Biswas, A., Parija, M.P., and Kumar, S., 2017. Global nonlinear optimization for the interpretation of source parameters from total gradient of gravity and magnetic anomalies caused by thin dyke. Ann. Geophys., 60 (2), Pp. 1-17.

Ekpa, M.M.M., Okeke, F.N., Ibuot, J.C., Obiora, D.N., and Abangwu, U.J., 2018. Investigation of gravity anomalies in parts of Niger Delta Region in Nigeria using aerogravity data. International Journal of Physical Sciences, 13 (4), Pp. 54-65, 28.

Kasidi, S., and Nur, A., 2012. Curie depth isotherm deduced from spectral analysis of Magnetic data over sarti and environs of North-Eastern Nigeria. Scholarly Journal of Biotechnology, 1 (3), Pp. 49-56.

Li, X., and Gotze, H., 1999. Comparison of some gridding methods. Leading Edge, 18, Pp. 898-900.

Lowrie, W., 2007. Fundamentals of Geophysics. Cambridge University press, United Kingdom, Pp. 354.

Mandal, A., Biswas, A., Mittal, S., Mohanty, W.K., Sharma, S.P., Sengupta, D., Sen, J., and Bhatt, A.K., 2013. Geophysical anomalies associated with uranium mineralization from Beldih mine, South Purulia Shear Zone. India. J. Geol. Soc. India, 82 (6), Pp. 601-606.

Mandal, A., Mohanty, W.K., Sharma, S.P., Biswas, A., Sen, J., and Bhatt, A.K., 2015. Geophysical signatures of uranium mineralization and its subsurface validation at Beldih, Purulia District, West Bengal, India: A case study. Geophysical Prospecting, 63, Pp. 713-726.

Nwosu, O.B., 2014. Determination of Magnetic Basement Depth over Parts of Middle Benue Trough by Source Parameter Imaging (SPI) Techniques using HRAM. Int. J. Sci. Tech. Res., 3 (1), Pp. 262-271.

Offodile, M.E., 1976. The Geology of the Middle Benue Nigeria. Cretaceous Research, Paleontological Institute: University of Uppsala. Special Publication, 4, Pp. 1-166.

Ofoegbu, C.O., 1985. A review of the geology of the Benue trough, Nigeria. Journal African Earth Sciences, 283-291.

Okwesili, N.A., Abangwu, J.U., and Awucha, I.E., 2019. Spectral analysis and source parameter imaging of aeromagnetic data of Lafia and Akiri Areas, Middle Benue Trough, Nigeria. International Journal of Physical Sciences, 14 (1), Pp. 1-14, 16. DOI: 10.5897/IJPS2018.4752

Okwesili, N.A., Okeke, F.N., and Orji, P.O., 2020. Geophysical survey of aerogravity anomalies over Lafia and Akiri regions of middle Benue trough, Nigeria, employing Power Spectrum and Source Parameter Imaging technique. IOSR Journal Of Applied Physics (IOSR-JAP), 12 (5), Ser. I, Pp. 58-68

Onuoha, K.M., Ofoegbu, C.O., and Ahmed, M.N., 1994. Spectral Analysis of Aeromagnetic Data over the Middle Benue Trough, Nigeria. Journal of Mining and Geology, 30 (2), Pp. 211-217.

Onyishi, G.E., Ugwu G.Z., and Okonkwo, A., 2019. Forward and Inverse Modelling of Aeromagnetic Anomalies over Parts of Middle Benue Trough, Nigeria. American Journal of Geophysics, Geochemistry and Geosystems, 5 (1), Pp. 16-23. http://www.aiscience.org/journal/aj3g

Reeves, C., 2005. Aeromagnetic Surveys; Principles. Practice and Interpretation, GEOSOFT.

Reid, A.B., 1980. Aeromagnetic survey design. Geophysic, 45, Pp. 973-976.

Salako, K.A., Adetona, A.A., Rafiu, A.A., Alahassan, U.D., Aliyu, A., and Adewumi, T., 2020. Assessment of Geothermal Potential of Parts of Middle Benue Trough, North-East Nigeria. Journal of the Earth and Space Physics, 45 (4), Pp. 27-42. DOI: 10.22059/jesphys.2019.260257.1007017

Telford, W.M., Geldart, L.E., Sheriff, R.E., and Keys, D.A., 1976. Applied Geophysics, Cambridge University Press, Cambridge

Telford, W.M., Geldart, L.P., and Sheriff, R.E., 1990. Applied geophysics (2nd edition). Cambridge University Press, Cambridge.