Applied Journal of Physical Science
Volume 2(3), pages 80-88, August 2020
Article Number: D0864A7F4
ISSN: 2756-6684
https://doi.org/10.31248/AJPS2020.031
https://integrityresjournals.org/journal/AJPS

Full Length Research

Determination of sediments thickness in part of Lower Benue Trough, Nigeria, from the residualization of aeromagnetic data: Implication for diversification of the Nigerian economy

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Received 11th August, 2020; Accepted 26th August, 2020

ABSTRACT: Aeromagnetic data were used in the study to determine the sediment thickness in the Lower Benue Trough. To achieve the objectives of the study, geophysical techniques were employed to analyze four aeromagnetic maps on a scale of 1:100,000, covering parts of the Lower Benue Trough. These include map merging, polynomial fitting, directional derivatives and forward modeling. Nine (9) profiles were modeled to determine sediment thickness, presence of possible intrusives and the subtle structural features and their trend within the study area. Results from this study revealed the existence of many intrusives which were majorly granite and basalt rocks which suggests complex tectonic events which accompanied the evolution of the Benue Trough. Lineament orientation revealed is majorly NE-SW direction and other directions were NW-SE, E-W and N-S. A sedimentary thickness ranging from 7 to 10 km were suggested by a 3D forward modeling, and this estimated depth did not coincide with an average of 5 km suggested by earlier researchers. Huge variations within the basement complex are however induced by the presence of horst structures as well as graben and this is profound within the depocenters where sedimentary pile is thicker. Magnetic sources within the sediment in Abakiliki, Udi and Nkalagu areas have potentials for hydrocarbon accumulation due to the thickness of the sediments in these parts of the study area. However, Bansara area reveals the presence of lots of intrusives, indicating high geothermal regimes that may not be favourable for hydrocarbon accumulation but have high potentials for solid mineral resources. Therefore, the Bansara area is recommended for organised and formal solid mineral exploration, which can apparently diversified the economy of Nigeria.

Keywords: Depocenters, diversification, economy, forward modelling.

INTRODUCTION

The fluctuating price of crude oil, massive exploration of alternative energy due to global warming occasioned by the used of crude oil products as energy source has rendered crude oil dependent economy unstable. Every unstable economy has attendant effects on national planning. Therefore, it becomes imperative for mono-economic nations to diversify their economy. The challenge the Nigeria economy is currently facing compounded by the mono-cultural product economy and heavy reliance on importation of goods and services. To generate a stronger and stable growth rate, the Government is promoting the increased production in the non-oil sector of the economy by creating a level-playing field for private-sector led activity. This essentially pivots around the framework for the development in area of agriculture and agro-business, solid minerals develop-ment, manufacturing, information and communications technology (ICT) and tourism (FGN, 2016). The knowledge of sediments thickness in the Benue Trough could provide useful information in the area of solid minerals development

Sedimentary basins are regions of earth with long-term subsidence creating accommodation space for infilling by sediments. The subsidence results from the thinning of underlying crust, sedimentary, volcanic, and tectonic loading, and changes in the thickness or density and magnetic susceptibility of adjacent lithosphere. Subsidence area can create favourable environments for agricultural activities and mining of solid minerals besides hydrocarbons exploitation.

The Benue Trough is one of the most important rift features in Africa. It is believed to be formed by the rifting of the central West African basement during the Cretaceous. Studies have shown that depth determination according to earlier researchers in the Lower Benue Trough using aeromagnetic data and gravity data has maximum value in the neighbourhood of 1200 to 5000 m (Ofoegbu and Onuoha, 1990; Adighije, 1981; Shemang Jr et al., 1998). They concluded that this part of the Lower Benue Trough may not hold promise in terms of hydrocarbon accumulation. Other investigations in the study area includes; geological investigation for minerals deposit (Asielue et al., 2019; Uzuakpunwa, 1774; Olade, 1975; Hoque, 1984,). Structural features which control the anomalous mineralization have also been delineated by many researchers (Olade, 1976; Ofoegbu, 1984).

On the contrary, not much detailed geophysical investigations have been carried out in this part of Benue Trough with the aim of determining the economic value of sediment accumulation. It is in the light of effective diversification of the economy from mono-cultural (crude oil based) to multi-cultural product that the study of the basin's thickness (depth to basement) is necessary to determine if the sediments' accumulations are of commercial value, that the aeromagnetic data of the area was considered.

Sedimentary development of the Benue Trough

The trough with its southern limits (bounded by the Northern Niger Delta) is superimposed by tertiary and sediments of more recent age. The trough has three division namely; the lower, middle and upper troughs which extends about 150 km wide to Chad Basin direction (Figure 1). However, in the west of lower region, the Anambra Basin which came into existence at the time of compression is a recent formation of the trough (George and Obaje, 2009).

The development of the trough is believed to be caused by major horizontal movements in the NE-SW inclined fractures accompanied by basement fragmentation, subsidence and rifting at the Mesozoic era (Grant, 1971; Akande et al., 1997). Deposition in the Benue Trough started with the marine Albian Asu River Group. However, Spector and Grant (1970) reported the presence of some pyroclastics deposits which were traced to the early Aptian age. The Asu River Group in the Lower Benue Trough comprises shales, limestones, sandstone lenses and Mfamosing limestone. The Asu River Group is overlain by the marine Cenomanian-Turonian Nkalagu Formation (black shales, limestones, and siltsones) and the interfingering regressive sandstones of the Agala and Agbani Formations. The Mid-Santonian deformation in the Benue Trough displaced the major depositional axis westward and led to the formation of Anambra Basin, whose sedimentation is that of the Campanian-Maastrichtian marine and paralic shales of the Enugu and Nkporo Formations (Kogbe and Buriollet, 1990; Abbass and Mallam, 2013).

The Lower Benue Trough has earth's field inclination of approximately $\pm$ 2°, this makes spontaneous interpretation of magnetic data difficult and reduction to the pole very unstable. The Benue Trough is generally known to contain numerous mafic and felsic intrusives, sub-basinal structures together with a bright prospect for hydrocarbon accumulation. According to Shemang et al. (2005) and Obiora et al. (2018), the Benue rift can be compared with some well-known rift systems such as the East African, the Rhine Graben, the Baikal rift and the Rio Grande rift.

Basement faults and fractured zones are some structural features that are not obvious in geophysical interpretation. These subtle structural features can be mapped with magnetic imaging. The problem in mapping these features with seismic method is due to the limitation of this geophysical technique in imaging shallow vertically oriented structure (Fairhead, 2012). The advantage of magnetic method is that it can be used in imaging near vertical structures by depicting changes in magnetization across a bounding fault and the difference in magnetization within sediment and basement. In a situation with thick sedimentary section, the magnetic signatures from subtle structures within the basement were suppressed though they may be ignored. These structural features are however very important in the magnetic field data because they play a huge role in understanding sedimentation in Lower Benue rift and the basin framework. These subtle structural features can however be delineated using aeromagnetic data, particularly when several attributes of magnetic maps are deployed. In general, potential geophysical methods have proved very effective for providing useful information known to guide various exploration campaigns, be it regional hydrogeological studies (Batista- Rodriguez et al., 2017), economic mineral or oil and gas exploration (Mohamed et al., 2016; Di Massa et al., 2018, Olawale and Temitayo, 2020). Results of aeromagnetic modeling of the subsurface in parts of the Lower Benue by Obi et al. (2010) revealed the presence of subsurface intrusives (mostly rhyolites and basalts). However, this study evaluates sediments thickness using residualization of aeromagnetic data. This is because it is believed that, the magnetic anomaly character can provide useful information on rock type producing the anomaly. Also, well interpreted magnetic anomalies can help in identifying the general rock type based on observed magnetic anomalies character. The knowledge of the current thickness of the Lower Benue Trough could be a good encouragement to

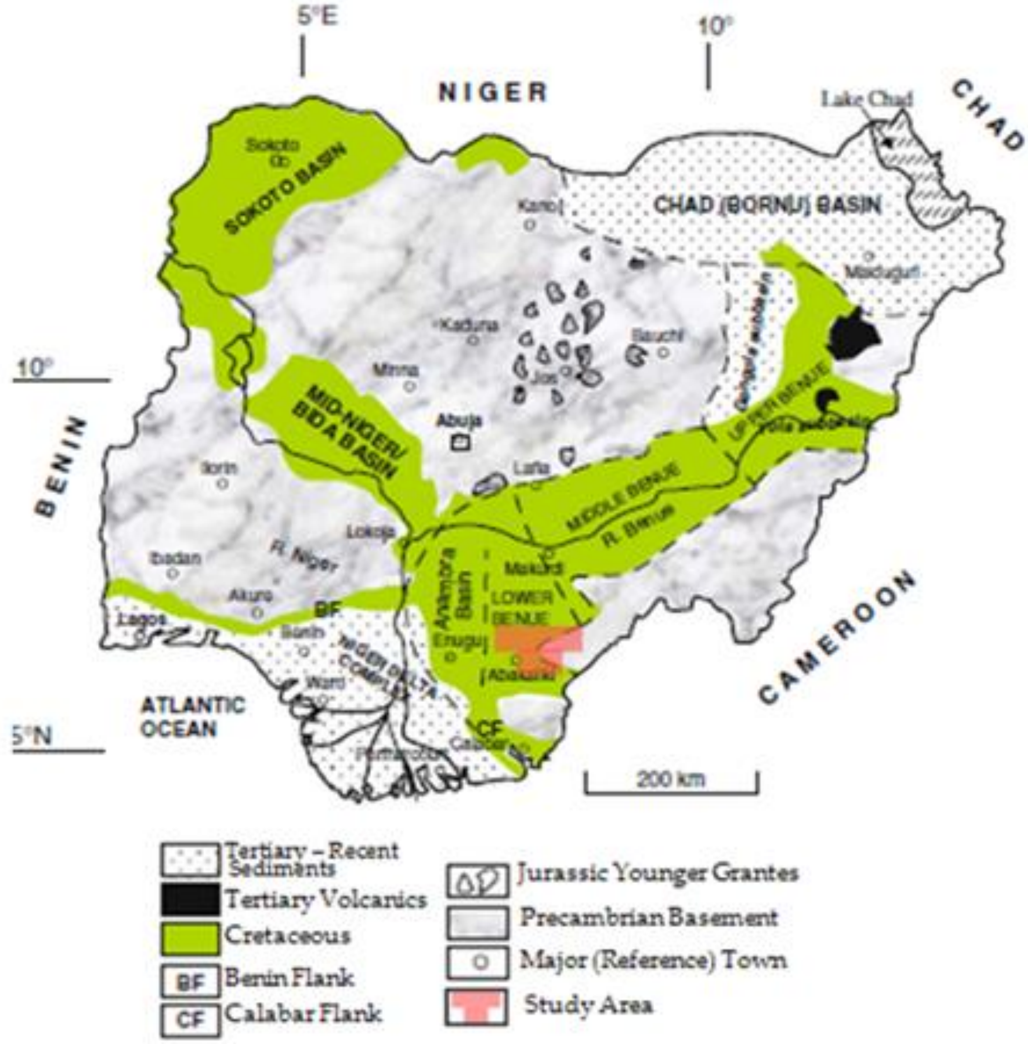

Figure 1. A simplified geology map of Nigeria showing the study area (After George and Obaje, 2009).

the diversification of the economy from hydrocarbon based to mining and agriculture based.

The sediments of the Lower Benue Trough are composed of sandstones, shale and limestone. It is sitting on Precambrian basement. A brief descriptive summary of the main stratigraphic units within the study area is shown in Figure 2.

MATERIALS AND METHODS

The study uses secondary data, which comprises four sheets (301, 302,303 and 304) of aeromagnetic map scaled to 1:100,000 obtained from the Geological Survey Agency of Nigeria, Kaduna. The data was obtained by Hairey Survey's limited in 1975 at Flight height: 500 ft (152 m) above the sea level, Flight lines: 150°/330° Azimuth (NE-SW), Interval: 2 km, Tie lines direction: 60°/240° Azimuth with 20 km interval. International Geomagnetic Reference Field (IGRF) of 1974 was used to perform the regional correction. An International Model of the Earth's Core for spherical harmonic was used for the mathematical model. The 3-D magnetic data modeling was used to determine the depth to basement while data residualization was done using polynomial fitting. Polynomial fitting method use the least square regression analysis in fitting a line of best fit in separating an array of data given g(x , y) at discrete points over a plain x , y as (x^1y^1), (x^2,y^2)……. …..$x^1{}_m,y^1{}_m$).

The above can be represented as a polynomial given as;

$$\mathrm{G}\,(\mathrm{x},\mathrm{y}) = \sum_{k=1}^{m} \mathrm{a}^k G^k\,(x,y)$$

Where: G_1, G_2…..G_m are chosen functions of x and y and a_1, a_2….a_m are empirical constants.

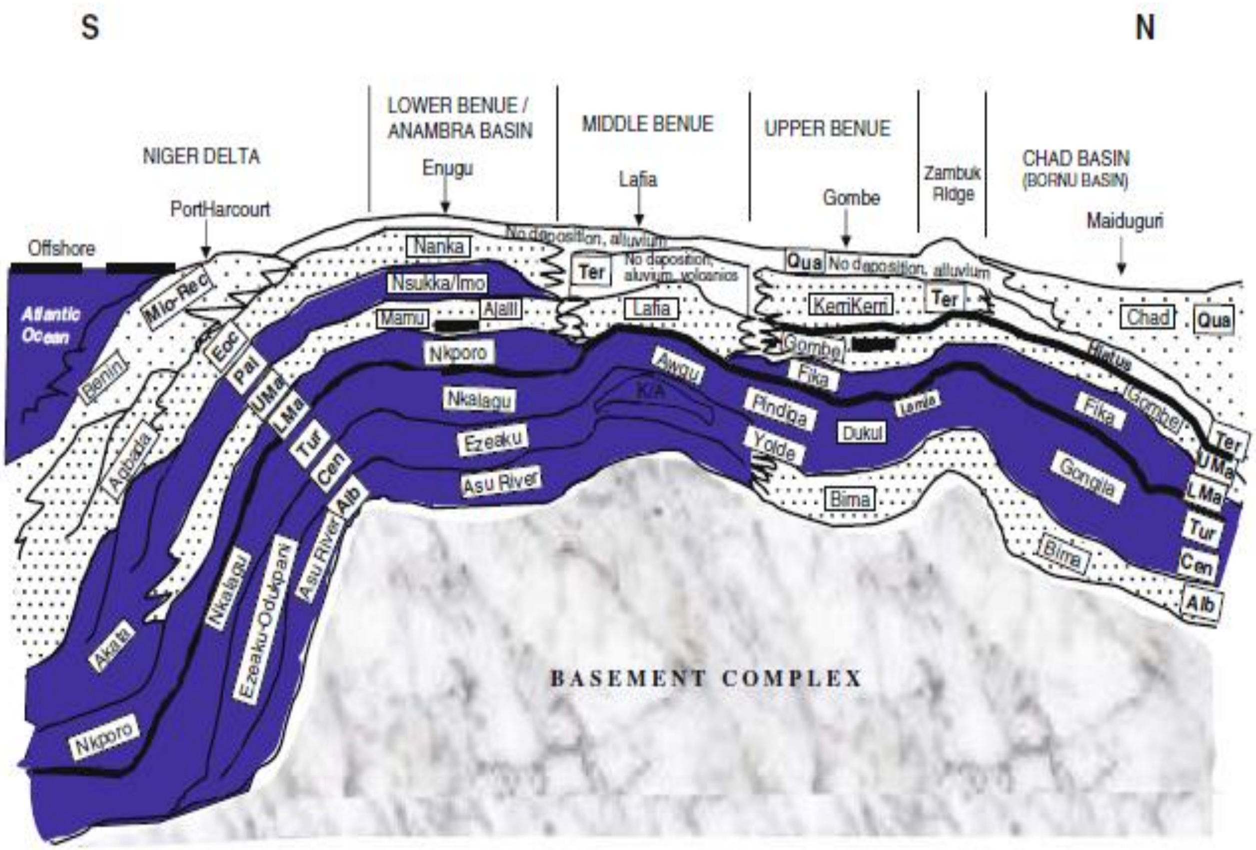

Figure 2. Stratigraphic cross section of Niger Delta, Benue Trough and Chad Basin (Okiwelu et al., 2014).

The polynomial fitting function according to Okiwelu and Ude (2012) can further be expressed as,

$M(x, y) = a^1 + a^2 x + a^2 y + a + x^2 + a^5 xy + a^6 y^2 + \ldots\ldots\ldots\ldots\ldots\ldots$

This can be simplify as,

$T (x, y) = Ax + By + C$

Where A, B and C are the coefficients and are computed so as to minimize the variation of the residual. The regional field was subtracted from the total magnetic field to obtain the residual field data.

The first and second degree polynomial surfaces were determined for the study. However, the first polynomial was considered very adequate in unraveling deep seated structure and sediment thickness based on the geology of the study area. Therefore, this study made use of the first degree polynomial in determining the residual field. This was achieved by the removal of the first degree polynomial data obtained from the total magnetic intensity field (Figure 3). The 3-D computer modeling using POTENT 365 software was performed on the residual magnetic field. This was the basis for quantitative interpretation of the geomagnetic anomalies. According to Bird (1997), the anomalies of higher amplitudes are caused by the availability of igneous rocks within the sedimentary section or the variation of lithology in magnetic basement. The sedimentary thickness, magnetic susceptibilities as well as anomalies orientation was determined from the 3-D interpretation of residual data. The derivatives computed include first vertical derivative (dz) and directional derivatives (dx, dy). These derivatives give a clearer image of the edges of major magnetic anomalies and the lineaments trend that were absent in the total magnetic field intensity map.

RESULTS AND DISCUSSION

The qualitative interpretation (Figure 4) was guided by the analysis of linear trends. This identifying trends on the residual maps that match with edges of geologic structures, faults and lithological contacts. It also entails division of data into magnetic domains/subdomains. The derivatives computed (Figures 5 to 7) gave better images of the edges of the major anomalies. The derivatives include; first derivative (dz) and directional derivatives (dx,

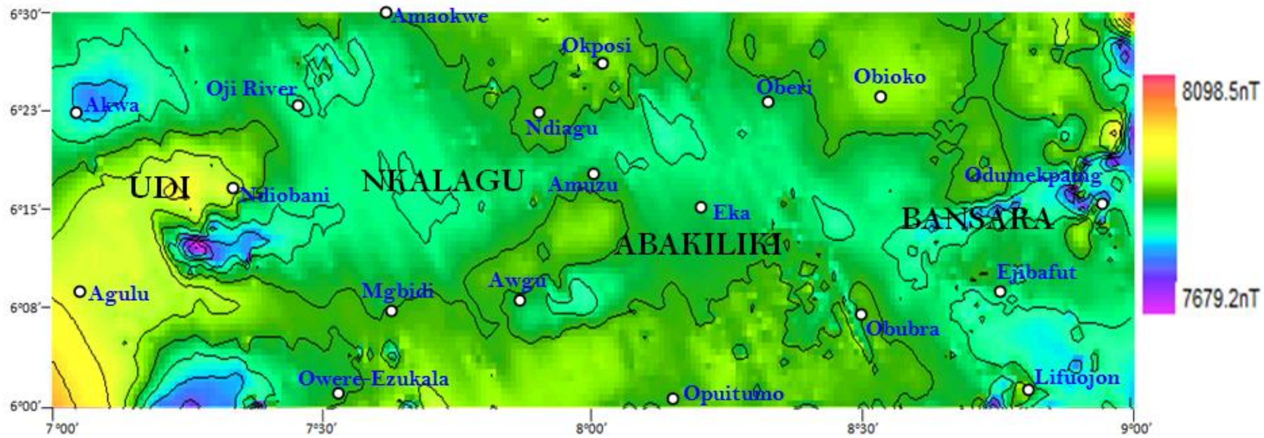

Figure 3. Total magnetic intensity (TMI) of the study area.

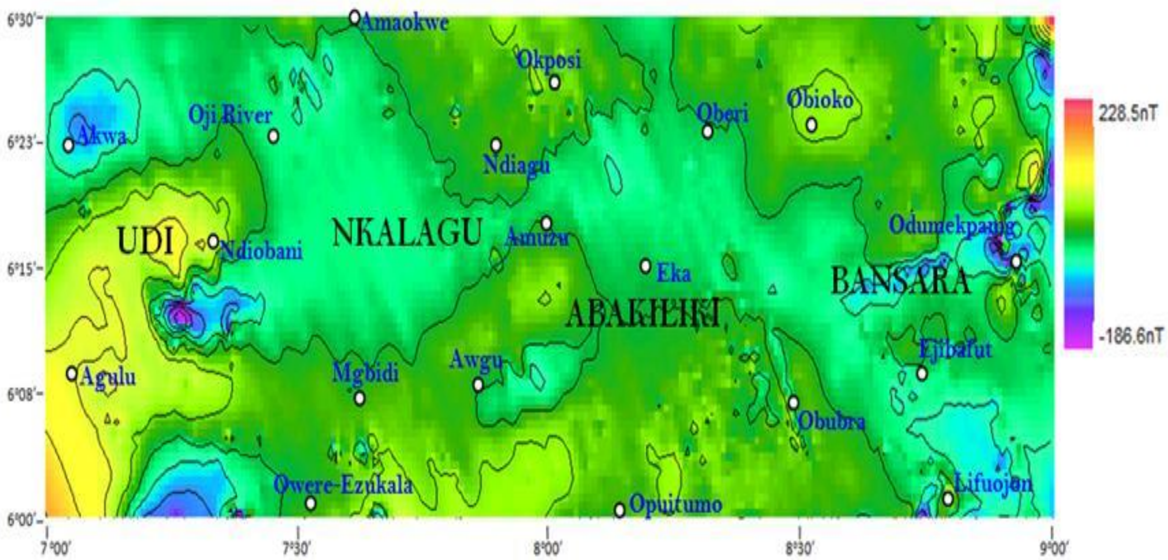

Figure 4. Residual field from TMI1 (1st degree polynomial).

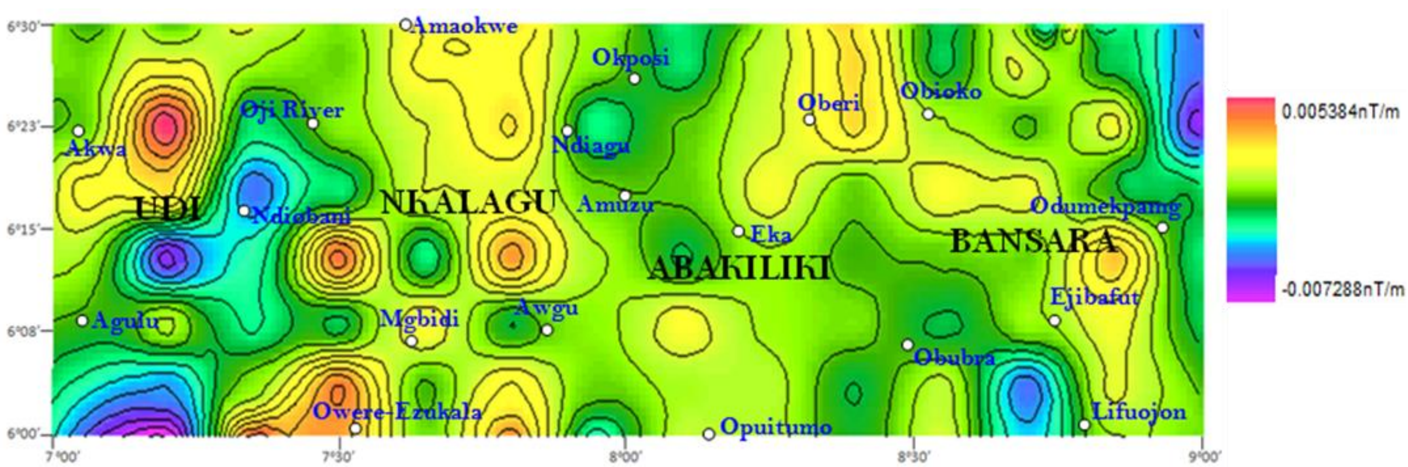

Figure 5. First derivative along x-direction (dx).

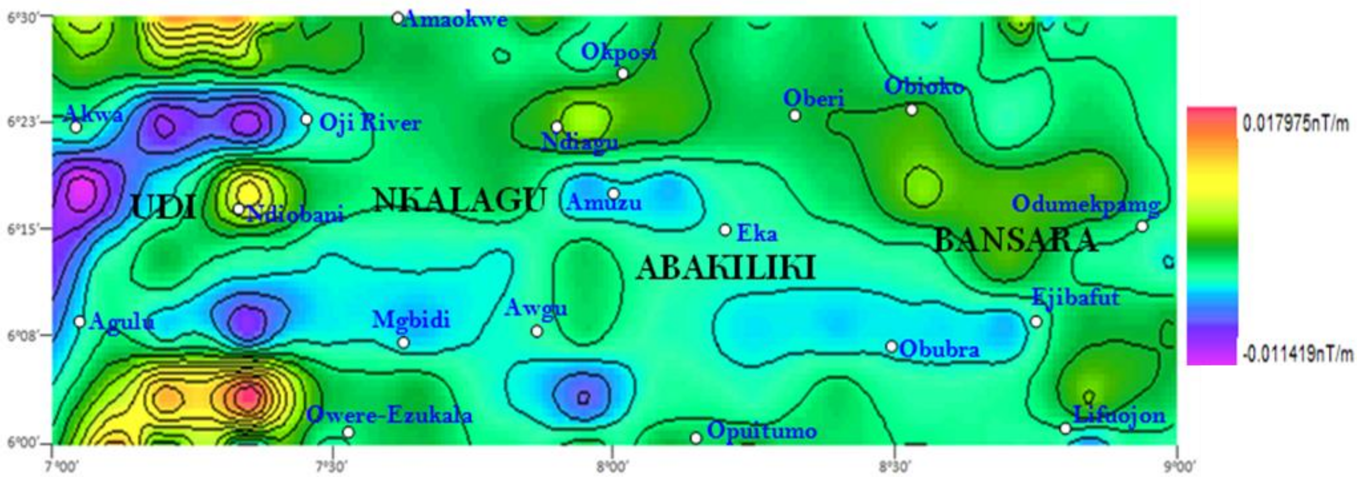

Figure 6. First derivative along y-direction (dy).

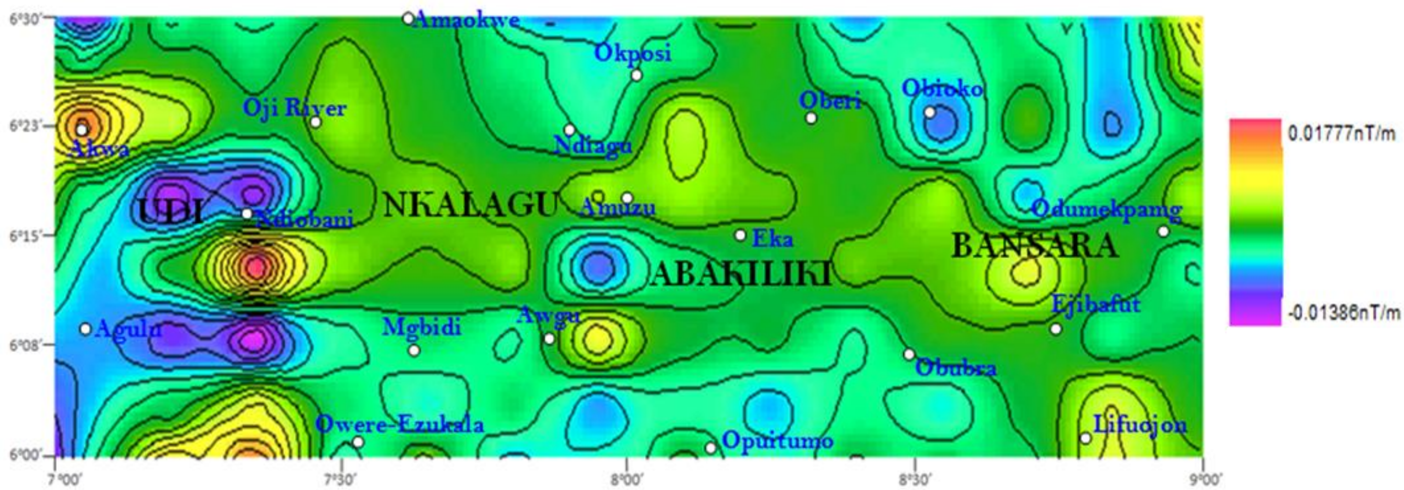

Figure 7. First vertical derivative (dz).

dy). These represents significant geologic structural information which is pre-existing weakness in the crust such as rift zone and deep seated faults that may have been reactivated by stress. The result of the study area from directional derivatives maps (Figures 5 and 6), revealed most of the magnetic lineaments trend NE-SW direction while minor ones trends NW-SE, E-W and N-S directions. These results suggest that the trend of the major lineament coincide with the trend of the Benue Trough and most of the inliers within the trough. The trend also coincides with the main direction of the shear (mylonite) zone in the upper part of the Benue Trough which are characterized by large magnetic anomalies (Ajakaiye et al., 1986, Chinwuko et al., 2013, Benkhelil et al., 1989). The magnetic highs found in the dx and dz maps (Figures 5 and 7) are caused by deformed magnetite-bearing metamorphic basement and prevalent magnetic lows in dy map (Figure 6) are interpreted as zones of low magnetite content (deformed granite plutons). Fairhead and Okereke (1987) using gravity data opined that the magnetic anomalies in the Lower Benue Trough are caused by the topographic relief and diversity magnetic character of the metamorphosed basement beneath the Cretaceous trough. The colour bar shows the variation of the magnetic intensity in the area. The visual inspection of the shape and trend of the major anomalies on the residual maps shows that the colour lines at the East-West part of the study area possesses high magnetic intensities with higher gradients, compare to contours of the North-South which shows more consistency, hence, depths of anomaly. The residual map has also exposed some structural features of the basement which was not prominent in the

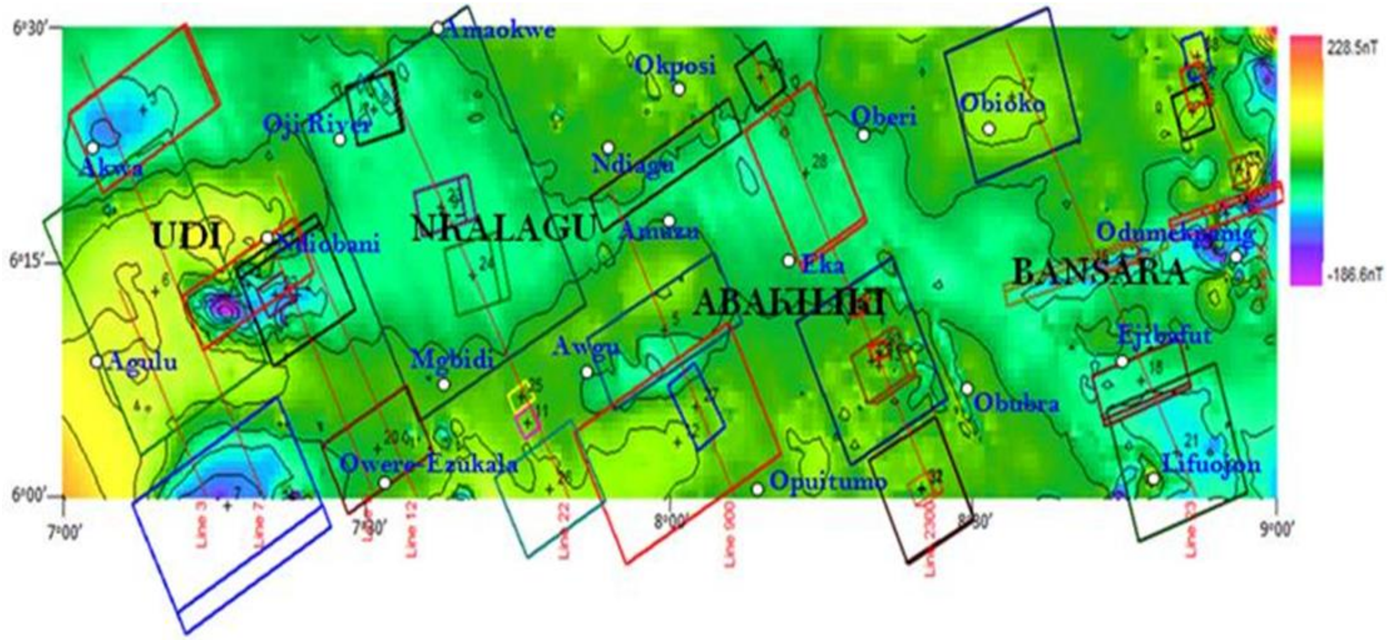

Figure 8. Modeled profiles and inferred geologic structures represented in rectangular wireframes of residual map.

total magnetic intensity by sharpening the contrast between highs and low features. The residual anomaly map of the study area ranges from -184.1 to 182.7 nT (Figure 4).

Quantitative interpretation was accomplished by the use of a 3-D forward modeling. The forward modeling was done using residual map (Figure 4). To accomplish these, profile model of the geologic structures was constructed (Figure 8). Nine (9) profile lines were extracted to observed magnetic anomalies. The extraction was done by using POTENT 365 Software. These were profile lines 3, 7, 9, 12, 22, 900, 2300, 23 and profile line 36. The modeling parameters include; magnetic susceptibility, sediment thickness and body orientation (Table 1). The result shows that, the general geometry of the modeled geologic sources is of the grabens, half grabens, high angle faults and fractures. The value of the mean magnetic susceptibility over the entire profile was reduced to be 6.2 x 10^{-3} SI with anisotropic susceptibility in the range: Ka = 0.00800 SI (maximum susceptibility), Kb = 0.02500 SI (intermediate susceptibility) and Kc = -0.02300 SI (minimum susceptibility) respectively. These orthogonal magnetic susceptibilities were not part of the findings of earlier researchers in the study area (Nwobodo et al., 2018; Onyishi et al., 2019; Okpoli, 2019).

Sedimentary thickness

The 3D forward modeling technique over the Lower Benue Trough was used to determine sedimentary thickness (magnetic source depth). The result shows a thick pile of sediments with maximum thickness of 7 to 10 km. This is in contrast to the average value of 5 km suggested by earlier researchers in the study area (Ofoegbu and Onuoha, 1990; Adighije, 1981; Shemang Jr. et al., 1998).

Magnetic sources within the sediment in Abakiliki, Udi and Nkalagu areas have potentials for hydrocarbon accumulation due to the thickness of the sediments in these parts of the study area. However, Bansara area revealed the presence of lots of intrusives, indicating high geothermal regimes that may not be favourable for hydrocarbon accumulation but have potentials for economic mineral exploitation.

The basement surface plot (Figure 9) has suggested that the crystalline basement block distribution in the study area is not homogenous, hence, step-like structures/block depressions which depict graben and horst structures induced the conspicuous incoherency in the depth to basement, alongside plutonic structures which intercalated through most of the basement structures may be identified as one of the major sources of the blocks height variation in the study area. The basement surface plot also revealed that the study area consists of sedimentary piles, basement ridges and deep troughs that the shape of the basement is undulating and associated with deep faults which results from fractures. The north of Bansara, Obioko and Odumekpang recorded the thinnest sedimentary accumulation in the study map, which reveal low depth to basement or shallow depth to basement. However, the sedimentary thickness increases from Bansara to Abakiliki and down to Nkalagu and north of Udi and Orji River. These high sediment deposited areas revealed high basement depth (depocenters) in the study area.

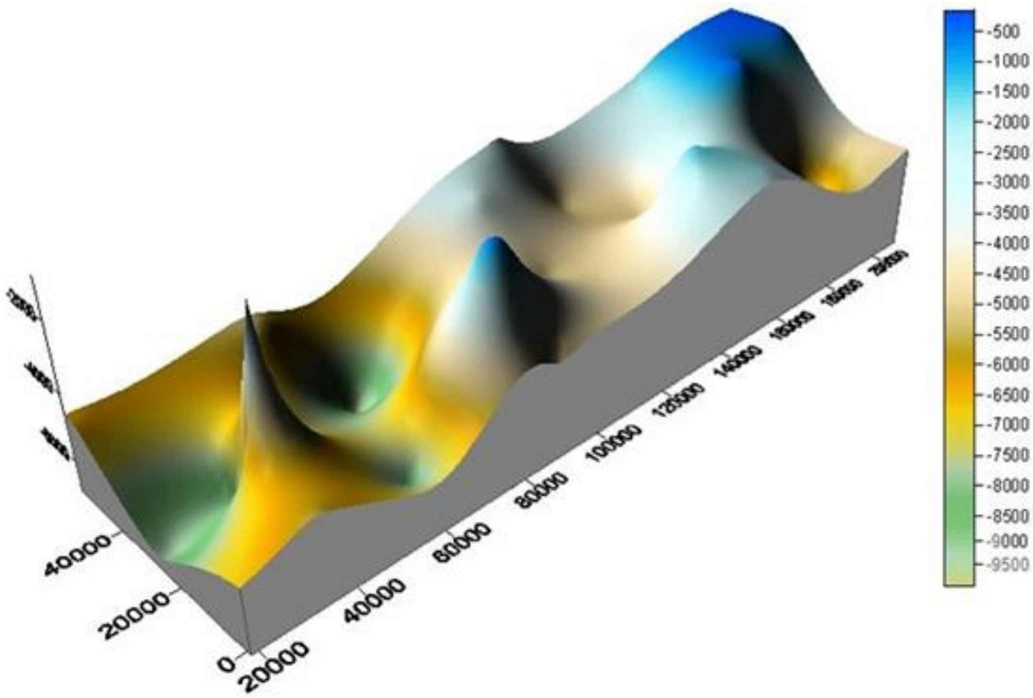

Figure 9. Basement surface plot of residual map in UTM.

Conclusion

Aeromagnetic studies have been successfully used in determining depth to magnetic basement and by implication the sediments thickness in a sedimentary basin. The results revealed maximum sedimentary thickness ranging from 7 to 10km. Lineament orientation is majorly NE-SW direction and other directions are NW-SE, E-W, and N-S. Significant variations within the basement complex are however induced by the presence of horst structures as well as graben. From this study, Abakaliki, Udi and Nkalagu are recommended for hydrocarbon exploration based on their sediment thickness and the presence of fewer intrusives. However, Bansara areas revealed the presence of lots of intrusives indicating high geothermal potential that may not be favourable for hydrocarbon accumulation but have potentials for economic mineral exploitation. Therefore, the Bansara area is recommended for organized and formal solid mineral exploration, which can apparently diversified the economy of Nigeria.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. U. F. Evans for his useful suggestions and advise.

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