Supported by tetfund

GEO-MAGNETIC MODELING AND POTENTIAL HYDROCARBON TRAPS FROM HIGH RESOLUTION AEROMAGNETIC DATA OVER THE GONGOLA BASIN UPPER BENUE TROUGH NORTHEASTERN NIGERIA.

Bello Rasaq [1] Mohammed Ali Garba [2] Musa Hayatudeen [1] and Kuforiji, Hakeem Iyiola[3].
[1](Geophysics Research Group), Physics Dept. Federal University of Kashere Gombe, Gombe state Nigeria.
[2]Dept. of Geology Gombe state University, Gombe, Nigeria.
[3]Department of Physics, Federal University of Agriculture Abeokuta, Ogun State, Nigeria.
Corresponding email: hayatudeenmusa@fukashere.edu.ng

Received: February 11, 2023 **Accepted:** April 15, 2023

Abstract:

Geo-magnetic modeling and potential hydrocarbon traps over the Gongola basin was carried out using the high-resolution aeromagnetic data utilizing the Oasis Montaj^{TM} software, total magnetic intensity map was done and potential hydrocarbon traps as well as modeling were carried out from the residual map. GM-SYS module of the Oasis montaj was used for this study, depocentres (grabens) that may serve as hydrocarbon traps were delineated, as well as basement configuration were determined. The models reveal the horst and graben architecture of the basement and the various faults that segmented the area into block patterns as well as the rifting nature of the Benue trough. The results showed that the models have sediment thickness in the range of 5 km and above which is in agreement with the results obtained by current oil exploration in the area. The points A, B, C, D, E, F, G, H and I are considered as areas of magnetic low' or weak anomalies, and are recognized as potential hydrocarbon traps or a local relief on the basement surface.

Keywords: Geo-magnetic modelling; Hydrocarbon; Gongola Basin; Northeastern Nigeria

Introduction

Geo-magnetic modeling and potential hydrocarbon traps over the Gongola basin was carried out via the high-resolution aeromagnetic data, by exploiting the Oasis Montaj^{TM} software. Total magnetic intensity map was done and prospective hydrocarbon traps as well as modeling were carried out from the residual map. The study area lies between longitude 11:00^0 -12:00^0 E and latitude 10:00^0- 11: 00^0 part of the Gongola basin upper Benue trough, the Benue trough is an intracontinental linear shape sedimentary basin that runs from the south to the north east of Nigeria, which is well over 1000 km long and 100-700 km wide. Its shape suggests a linear structural control on its formation of which numerous models base on rift origin were proposed. A number of authors have put forward distinct models for the origin and evolution of the Benue trough in the perspective of Plate tectonic theory. Some considered it as an Aulacogen and part of a three arm rift system comprising the South Atlantic Ocean, others consider it to be a true rift and compared it to the Afar region of north east Africa, [1] and [2] however construed the Cretaceous Benue trough as a set of pull apart sub-basin generated by sinistral displacement along pre-existing NE-SW transcurrent faults. However, [3] put his own model for the evolution of the Benue trough to be as a consequence of rise of mantle plume, and to upwelling, thinning to some degree and the development of early line of weakness marginal to the plume, emplacement of rigorous igneous material in the crust, more widespread stretching and thinning and consequently rifting.

Geology of the area

The lithostratigraphic unit of this sub basin comprises the Bima sandstones, the Yolde formation, Pindiga formation, Gombe sandstones and the Kerri – Kerri formation, respectively. The Bima sandstone formation: is the most significant of all sedimentary formations of this region it forms at the base of the Cretaceous sequences and extents widely, outlining the contemporaneous shape of the basin. Its thickness was estimate at 1700 m on the northern edges of the Lamurde anticline, on the basis of micro fauna and micro flora, [4] and [5] attribute an Aptian - Albain age to these formation. Yolde formation: It corresponds to the passage between the continental Bima sandstones and the upper marine levels, according to [6] the thickness of this formation varies from 100-400 m , it was dated Cenomanian. The Pindiga formation comprises dominantly of shales with minor silt and limestone and deposited in estuarine – open marine. The Gombe sandstone, composed of grey shale, sandstone and coal deposited in a settings ranging from coastal plain - estuarine is dated Maastrichtian – Campanian. The Kerri-Kerri formation incorporating well sorted coarse - medium grained sandstones is deposited in a coastal plain setting and dated late Maastrichtian in age.

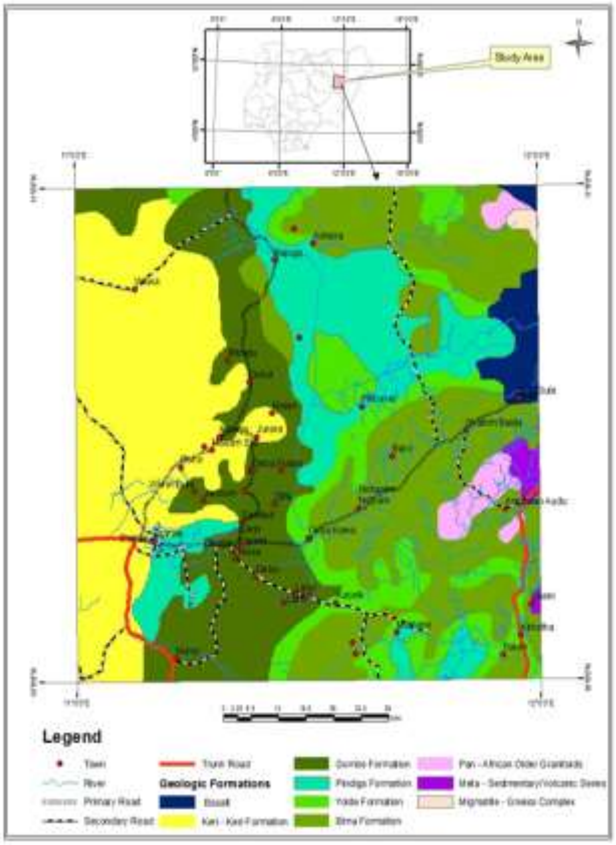

Fig. 1 Geologic map of the study area.

Previous studies

In 2004, [7] studied the Nasara-I well, Gongola basin upper Benue trough, Nigeria on source-rock assessment, their discoveries showed that some oils generated from a probably deeper-seated or laterally-located (and yet to be identified) lacustrine source rock must have migrated and been adsorbed into the coaly facies, which were later sporadically exposed to anoxic to suboxic biodegradation processes.

Working on the Radioactivity and hydrocarbon generation potential of sediments, in the Gongola basin, Nigeria, [8] conclude that the radiogenic heat generated by the sediments contributed considerably to the whole surface heat flux, and the possible influence of radiogenic heat on hydrocarbon generation potential of the sediments.

Values from the basement depth and sedimentary velocity structure in Gongola basin, [9] postulates that the grabens, half grabens, faults and deep sedimentation construed from the seismic reflection data are hydrocarbon related structural features.

Palynostratigraphic studies and age of the sequence penetrated by the Kolmani river 1 well in the Gongola basin, northern Benue trough, Nigeria, [10] propose that the palynofloral assemblages recognized in this well, closely relate to those previously pronounced in Nigeria, Ghana, Senegal, Ivory Coast, Egypt, Malaysia and from other low latitude settings around the World.

Studies on hydrocarbon prospect of Nigeria's Gongola basin based on gravity data interpretation [11] presents an investigative approach to gravity data of the western sector of the Gongola rift. Their results disclose a horst – graben basement configuration with depth to basement computations in excess of 4 km.

Interpretation of aeromagnetic data from upper Benue basin, Nigeria via automated techniques carried out by [12] offered a three depth source, the deeper sources ranges from 6.5 to 10.5 km, the intermediate sources ranging from 3.5 to 5.5 km and a shallow source of 0.01 to 2.5 km.

Similarly on the interpretation of aeromagnetic anomalies over part of upper Benue trough and southern Chad basin, Nigeria, [13] presented a two source depth model, depth to deeper magnetic source bodies ranges from 1.5 to 2.5 km and the shallow magnetic source bodies ranges from 0.5 to 1.4 km.

Working on the magnetic modeling and potential hydrocarbon trap over Yola and environs upper Benue trough northeastern Nigeria, [14] conclude that the models reveal the horst and graben architecture of the basement with the grabens serving as depocentres, hydrocarbon potentials of the area were highlighted via magnetic aureoles mapping.

Materials and Method

The data for this research was acquired for Nigeria Geological Survey Agency (NGSA) in 2010 as part of a country wide geological survey by Fugro international of Netherlands. The data has the following provisions, terrain clearance of 80 m, flight line spacing of 500 m and a tie line spacing of 5000 m. The following sheets with the index numbers 131,132, 152 and 153 were used for this exercise, data was treated to generate the total magnetic intensity map (TMI) and residual map, on these map potential areas for hydrocarbon prospects were demarcated, and modeling of magnetic data was prepared with the use of GM-SYS module of the Oasis Montaj™ software. The broad objective of modeling a magnetic data is to appraise the geometry and physical character of the cause to an investigated anomaly, (e.g a low magnetic linear feature). Modeling of magnetic data are not expected to establish precise and very accurate detail rock models, but the objective is to support the deformation zone with indication largely concerning the dip and width of low magnetic zones. In this study the initial modeling parameters used are the contact/basement boundary blocks, depth to the bottom of the magnetic source and existing geologic information, each distinct part of the model (blocks) was assigned a susceptibility value. The anomaly along the entire profile is the sum of the contributions of each separate blocks, the modeling involve four pieces of information top surface, bottom surface, susceptibility and anomaly. If any three of the above is identified or presumed the fourth item can be calculated. By and large black points are magnetic data, blue lines are theoretical while red lines are errors, the red line must have a best fit with the blue line in order to get a good model. Magnetic susceptibility is essentially the important parameter of magnetic surveying used for hydrocarbon exploration, as it reveals changes in the subsurface geologic structures and this property of rocks fluctuate from place to place below the earth's surface. This distinction in the magnetic susceptibility can cause small magnetic difference in the magnetic fields of rocks measured on the surface. According to [15] sedimentary magnetization contrasts have been discovered to be related to anomalies with amplitude of 1 nT. Similarly [16] concluded that many of these small amplitude anomalies were sourced in the sedimentary section. The trend of these low amplitude anomalies was in certain places roughly comparable to major mapped fractures and faults. Equally [17] indicate that intrusives may offer suitable hydrocarbon traps or reservoir rocks in some cases. Based on the perceived amplitude (<10 nT), spatial scale, orientation, correlation across flight lines, the low-level magnetic anomalies seem to be of natural origin. Since hydrocarbon exploration has much depend on the mostly expensive seismic method with the magnetic method limited to the traditional and conventional role of exploration of potential sedimentary basins in terms of overall basin architecture (size and shape), depth to basement and basement configuration. Less frequently has magnetic data been used for "pin pointing" hydrocarbon concentration and determining the genetic association of basement fault configuration with the sedimentary structural pattern. However, [14] postulate that the efficacy of high resolution aeromagnetic data for the direct discovery of hydrocarbon had been severally documented. Observations by [18], [19] discovered that the short wavelength, low amplitude magnetic anomalies found over some oil fields are as a result of micro seepage of hydrocarbon into iron rich sedimentary rocks which precipitates digenetic magnetic minerals such as magnetite, pyrrotite close to water table. The reduction plumes thus formed above the hydrocarbon deposit is well known from the perceived geochemical alteration of the overlying sediment. In his view [18], states that if the magnetic minerals were deposited in adequate quantities, they would yield a characteristic high frequency, low amplitude magnetic anomalies which will be a direct indicator of the existence of hydrocarbon at depth and which can be discovered by aeromagnetic surveys. This was described by [20] as modern magnetic survey. Whereas conventional aeromagnetic anomalies provide information about the basement structure, sediment thickness and distribution of faults and volcanics, the modern magnetics detect the weak signature that may be technologically advanced along areas of hydrocarbon seepages due to authigenic mineralization. Hence the modern magnetics is a form that captures and exploits the full spectrum of the earth's magnetic field, all frequencies of anomalies sourced all over the geologic section, near surface to magnetic basement [21].

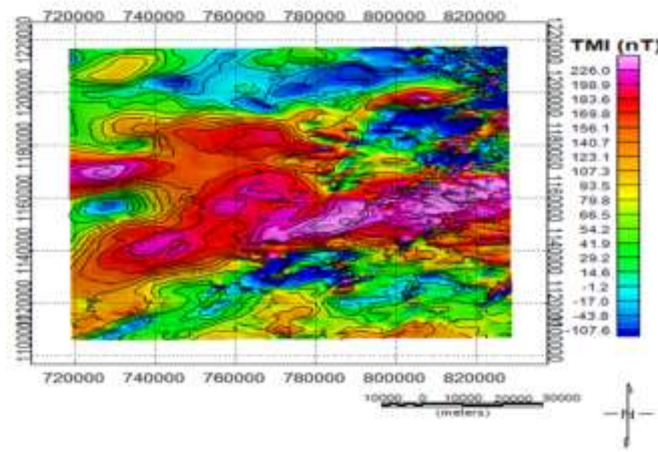

Fig. 2. Total magnetic intensity map of the study area.

Results and Discussion

Results

The total magnetic intensity map of the region (TMI) fig. 2 demonstrates the anomalies of high and low magnetic intensity values of 226 to- 107.6 nT with dominant NE-SW inclinations, the dominant long wavelength anomalies with spatial scales of numerous kilometers are absolutely due to deep seated basement under the basin. The map demonstrates that the area is composed of different magnetic province. The provinces are distinguished on the basis of the difference of the intensity of magnetic response. The northeastern side is characterized by low magnetic anomalies, however the central part is characterized by highs. The residual anomaly map fig. 3 exhibits magnetic anomalies of 132.4 to -138.2 nT as a sequence of areas of magnetic highs and lows. The principal trend is in the NE-SW direction, which is associated with the Pan Africa events. The long wavelength features are absolutely due to very deep basement source and are referred to as regional. Small amplitude short wavelengths anomalies are superimposed on these large features.

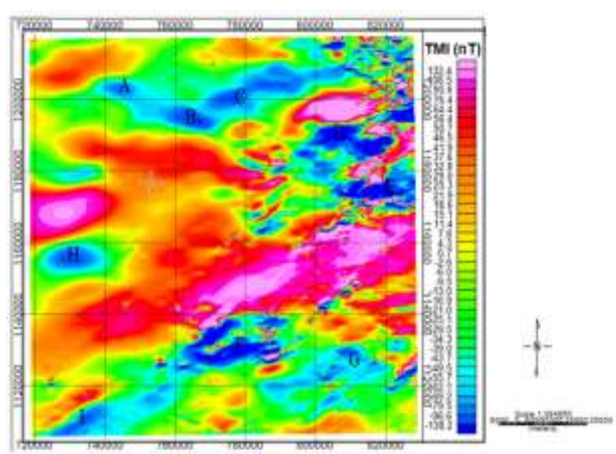

Fig.(3). Residual anomaly map of the study area with point A-I.

Modeling

The result of the modeling work will be used as supportive information for determining geological models of deformed zones and rock units of the region. Since the computation of earth models is grounded on the observed field data and the starting model, a poor starting model will result in unreasonable solution. Four profiles were drawn on the residual magnetic anomaly map over the area across prominent anomalies as shown in figure 4, so as to appraise the geometry and physical character of the cause to an explored anomaly. The anomalies were modeled based on the contextual information of the geology of the area, and the depths to basement were interactively altered to reduce error and achieved the best fit. All the magnetic field responses computed from the models used total field strength of 34132 nT, declination of -0.065 degrees and inclination of -3.5 degrees.

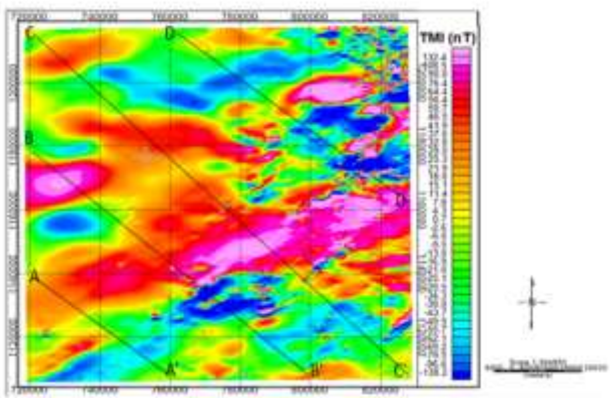

Fig. 4. Residual map of the study area with profiles A-A', B-B', C-C' and D-D' used in modeling.

NW
SE

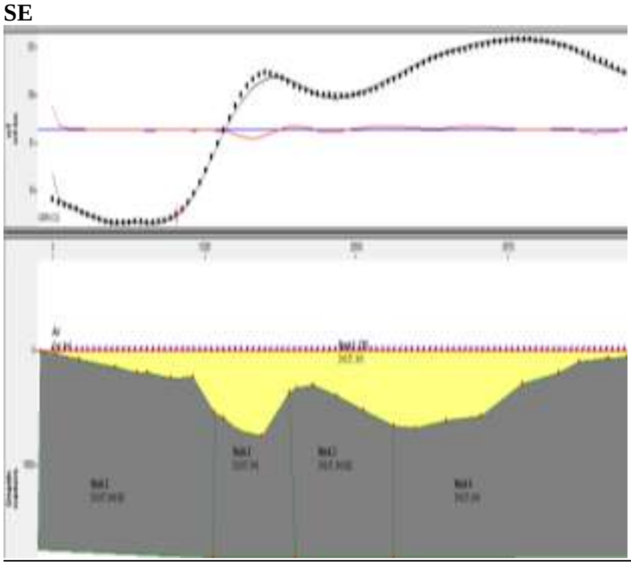

Fig. (5). Modeled magnetic profile A-A'.
NW
SE

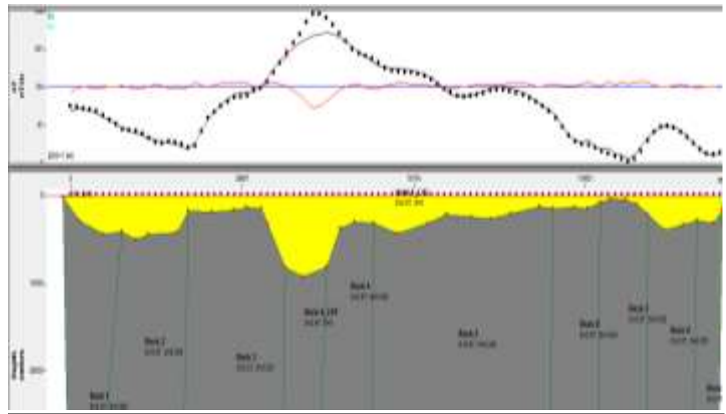

Fig. (6). Modeled magnetic profile B-B.
NW
SE

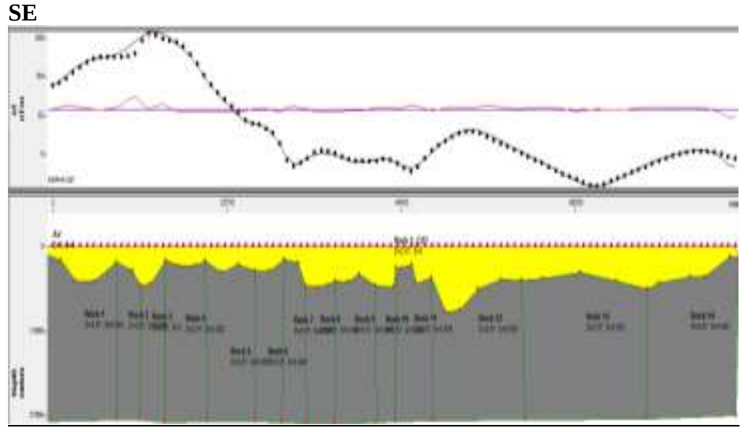

Fig (7). Modeled magnetic profile C-C'.

NW
SE

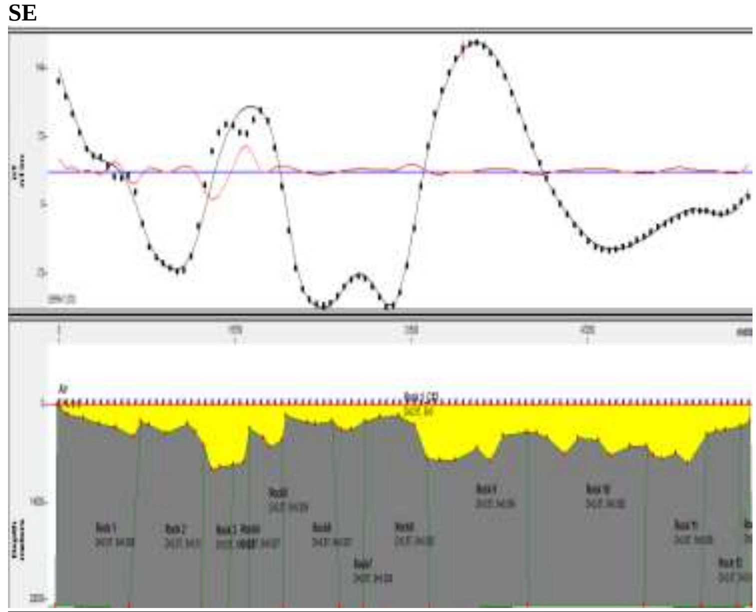

Fig. (8). Modeled magnetic profile D-D'.

Discussion

From the Residual anomaly map, fig. 3, points A-I, shows weak anomalies or low magnetic readings that may reflect the occurrence of a local relief on the basement surface which were investigated quantitatively, or it can also indicate the existence of oil traps in some cases. Modifications in the subsurface geologic structures are typically reflected by magnetic susceptibility and this property of rocks fluctuates from place to place below the earth's surface. This difference in the magnetic susceptibility can cause small magnetic variation in the magnetic fields of rocks measured on the surface. The occurrence of a local relief on the basement surface or the presence of oil traps in some cases can be investigated quantitatively, as they are reflected on the residual map as weak or low magnetic anomalies. In the search for hydrocarbons, residual maps plays key role in detecting the presence of intrusives, lava flows and igneous plugs, which are areas to be avoided in the course of an exploratory exercise, in this case the Kaltungo inlier, Tangale and Kufai plugs and other volcanic plugs that doted the area may serve as a case in point. The geothermal energy required for the maturation of petroleum source rocks may be provided by the intrusives, as they are not entirely disadvantageous to the hydrocarbons per se, problem will only arise as their existence in large quantity may possibly lead to over maturation of source rocks where more geothermal energy will be released, it is at this point that the temperature window for hydrocarbon generation could be surpassed, thus, affecting the quantity to be generated. The points A, B, C, D, E, F, G, H and I in fig. 3, are considered as areas of magnetic low' or weak anomalies, and are recognized as potential hydrocarbon traps or a local relief on the basement surface.

Modeled magnetic profile A-A'

This model passes across the study area in the NW-SE direction fig. 5. It displays a good fit between the perceived and computed magnetic profile with an error of roughly 2.00%. The profile was displayed as four (4) basement blocks i.e. rocks 1-4. Movement along these blocks may be liable for the uplifted blocks (horst) and down faulted blocks (graben) given rise to undulation of the basement topography. Blocks 2 and 4 are graben while 1 and 3 are horst. The green line that distinct rocks 1-4 are lithologies or structural contacts. Abroad graben blocks was perceived in block 2 and 4 which are inferred to be lithologic contact or joints or faults which have marginally moved relative to the neighboring blocks. The entire profile has an average depth of 18 km with sediment thickness of less than 10 km.

Modeled magnetic profile B-B'

This model passes across the study area in the NW-SE direction fig 6. It displays a good fit between the perceived and computed magnetic profile with an error of roughly 7.55%. The profile was displayed as ten (10) basement blocks i.e. rocks 1-10. Movement along these blocks may be liable for the uplifted blocks (horst) and down faulted blocks (graben) given rise to undulation of the basement topography. Blocks 1,2,4 ,9 and 10 are graben while 3,5,6,7 and 8 are horst. The green line that distinct rocks 1-10 are lithologies or structural contacts. A deep graben was perceived in block 1,2 and 4 which are inferred to be lithologic contact or joints or faults which have marginally moved relative to the neighboring blocks. The entire profile has an average depth of 30 km with sediment thickness of less than 12 km.

Modeled magnetic profile C-C'

This model passes across the study area in the NW-SE direction fig 7. It displays a good fit between the perceived and computed magnetic profile with an error of roughly 5.10%. The profile was displayed as fourteen (14) basement blocks i.e. rocks 1-14. Movement along these blocks may be liable for the uplifted blocks (horst) and down faulted blocks (graben) given rise to undulation of the basement topography. Blocks 2,4,7 and 10 are horst, while the rest are graben. The green line that distinct rocks 1-14 are lithologies or structural contacts. A broad graben was perceived throughout the model which is inferred to be lithologic contact or joints or faults which have marginally moved relative to the neighboring blocks. The entire profile has an average depth of 28 km with sediment thickness of less than 10 km.

Modeled magnetic profile D-D'

This model passes across the study area in the NW-SE direction fig. 8 . It displays a good fit between the perceived and computed magnetic profile with an error of roughly 7.10%. The profile was displayed as thirteen (13) basement blocks i.e. rocks 1-13. Movement along these blocks may be liable for the uplifted blocks (horst) and down faulted blocks (graben) given rise to undulation of the basement topography. Blocks 3,4,9,10 and 11 are graben, while the rest are horst. The green line that distinct rocks 1-13 are lithologies or structural contacts. Abroad graben blocks was perceived in block 9-13 which are inferred to be lithologic contact or joints or faults which have marginally moved relative to the neighboring blocks.The entire profile has an average depth of 28 km with sediment thickness of less than 10 km. The depocentres (grabens) identified in this study from modeling are generally in covenant with earlier workers such as, [22] who studied the northern sector of the Benue trough and some section of Borno Basin, N.E. Nigeria exploiting source parameter imaging and acquired sediment thickness of 5.0 kilometers in the region. Studies on the Gongola trough a division of the upper Benue trough [11] posits that the sediment thickness (depth to basement) in the region from spectral analysis of gravity data is in excess of 4 km. Also [23] got sediment thickness in the region of 5 km, using first horizontal and first vertical derivatives from high resolution aeromagnetic data over the Gongola basin upper Benue trough northeastern Nigeria.

Conclusion

This research was carried out to delineate depocentres which may serve as possible hydrocarbon traps as well as modeling exercise for basement configuration, which were carried out from the residual map, points A, B, C, D, E, F, G, H and I are considered as areas of magnetic low' or weak anomalies, and are recognized as potential hydrocarbon traps or a local relief on the basement surface. The models reveal the horst and graben architecture of the basement and the numerous faults that segmented the basement into block patterns. The results further indicated that the models have sediment thickness in the range of 5 km and beyond which is in concurrence with the outcome gotten by current oil exploration in the area and other researchers.

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