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PSEUDOGRAVIMETRIC ANOMALIES OVER PART OF THE GONGOLA ARM OF THE UPPER BENUE TROUGH, NIGERIA

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ABSTRACT

The Gongola arm of the Upper Benue trough in northeastern Nigeria has been extensively studied due to its rich geological history and potential natural resources. However, there has been limited research on the region using pseudogravimetric techniques. Pseudogravimetric transformation is used in converting the total magnetic field intensity (TMI) to pseudogravimetric anomaly by converting at each point of the source distribution the magnetization contrast to density contrast. The pseudogravimetric anomaly has all the usual characteristics of gravity anomaly. This paper presents the results of investigating the pseudogravimetric anomalies over a part of the Upper Benue trough, Nigeria. 2D Forward modelling of some profiles and the derivatives of the Pseudogravimetric anomalies were carried out. The result of the analysis showed the magnetic anomalies to be a result of igneous intrusions, horst/graben structures and magnetic basement topography. The results of the forward modelling show significant variations in the magnetic basement depths across the study area, indicating complex geological structures and potential mineral resources. It also shows the density of the basement rocks to be within the range of 2.64g/cm^3 to 2.77g/cm^3 which is typically within the range of that of granitic rocks, and the Cretaceous sediment to be in the range of 2.45 g/cm^3 to 2.55 g/cm^3. The depths of the Cretaceous sediments vary within the range 300 m to a maximum of about 4 km. These results have contributed to a better understanding of the geological processes and evolution of the trough.

Keywords: Pseudogravimetric anomaly, analytic signal, horizontal derivative, tilt angle, Benue trough
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INTRODUCTION

The Gongola arm of the Upper Benue Trough is a part of the larger Benue Trough, a major linear SW-NE sedimentary basin located in Nigeria and formed during the rifting of the African and South American plates during the Cretaceous period. The rifting induced a complex network of tensional forces, leading to crustal stretching, and fracturing, creating a series of sub-basins and horst structures, with volcanic intrusions, shaping the basin's geological framework (Guiraud et al., 1992; Binks & Fairhead,1992). The trough's sedimentary sequence comprises shale, sandstone, limestone, coal, evaporites, and volcanic deposits, reflecting a range of depositional environments. As an important area for oil and gas prospecting, mining, and agricultural activities, it has been extensively studied using a wide array of geophysical methods. Despite these research efforts, there exist a gap in utilizing pseudogravimetric technique to investigate this region.

The interpretation of magnetic data is theoretically more challenging than the corresponding gravity data. This is due to the dipolar nature of the magnetic field in contrast with the simpler monopolar gravity field, and the latitude dependent nature of the induced magnetization for a given body due to the variability of the ambient field over the Earth's surface (Blakely, 1995). As a result of these factors, the shape of a magnetic anomaly relative to its source is distorted causing a decrease in the amplitude of the anomaly, asymmetry in the anomaly and a shift of the peak of the anomaly to the south in the northern geomagnetic hemisphere and the converse in the southern geomagnetic hemisphere (Verdusco et al. 2004). However, in practice the interpretation of the magnetic data is simpler due to the smaller number of contributory sources which is often one source, the crystalline magnetic basement.

To remove the complexities associated with the measured magnetic anomalies, Baranov (1957), described an application of Poisson's relation in which a grid of the total magnetic field anomaly is converted into a grid of pseudo-gravity anomaly by replacing the common source body the magnetization distribution by an identical density distribution (i.e., $\frac{M}{\rho}$ is a constant throughout the source) and assuming that the remanent magnetization is negligible. He called the resulting quantity Pseudogravimetric anomaly, and the transformation is referred to as Pseudogravimetric transformation (Blakeley, 1995).

Pseudogravity transformation among other things eliminates the asymmetry that characterizes magnetic anomalies concerning their causative bodies and centers them on their perturbing bodies (Baranov, 1957; Tandrigoda, 1982; Ofoegbu, 1985). The transformation may also be carried out to filter out short wavelength anomalies that are due to shallow sources and enhance the long wavelength that are due to deeper sources thereby facilitating the mapping of the deeper magnetic basement (Ofoegbu, 1985; Panepinto et al., 2014; Ahmed et al., 2013). It can also be used to enhance subsurface imaging of areas with complex geological settings (Tandrigoda, 1982). In sedimentary basins, it can be used to map the magnetic basement, thereby exposing hidden basins suitable for resource exploration (Reeves, 2005).

The total horizontal derivative (THD), vertical derivative (VDR), AS derivatives, and the tilt angle of the pseudogravimetric anomaly can be used to map the lateral extent of anomalous density or magnetization of bodies and their edges. The total horizontal derivative is used to map out the edges of sources, the vertical derivative is used to sharpen up the anomalies over their sources, analytic signal is used locate the sources and their lateral extend and the tilt angle is used as an automatic control filter to equalize the amplitude output of the anomalies. It is the aim of this study to investigate the pseudogravimetric anomalies over a part of the Upper Benue trough.

Location of Study Area

The area of study is a part of the Upper Benue Trough, Northeast, Nigeria, bounded by latitude 9°.00N to11.30°N and longitude10°.30°E to 12°.00E (Figure 1.1).

Geology of the Study Area

The African continent is characterized by two major rift systems: the East African Rift System of Tertiary to Recent age and the West and Central African Rift System of Cretaceous to Early Tertiary age. The NE trending Benue Trough is the main component of the West and Central African Rift System. It extends for about 800km in length, 50 km -150 km in width, and is estimated to contain 5,000m of cretaceous sediments and volcanic rocks. It forms an important part of a system of linear sedimentary basins which include rivers Benue, Niger, and the Gongola (Ofoegbu, 1985).

The Benue Trough runs from the northern boundary of the Niger Delta to the Southern boundary of the Chad Basin (Obaje, 2009). The Benue Trough is arbitrarily divided into three basins: Lower Benue, Middle Benue, and Upper Benue Trough. The Trough is filled with Cretaceous rocks whose ages range from Middle Albian to Maastrichtian, of which those predating the mid-Santonian have been compressional, folded, faulted, and uplifted in several places. Compressional folding during the mid-Santonian tectonic episode affected the whole of the Benue Trough producing over 100 anticlines and synclines.

Upper Benue Trough is the northern section of the trough and is made up of three basins: The trending Gongola basin (Gongola arm), the east-trending Yola basin (Yola arm), and the northeast-trending Lau basin (Main arm). The geology consists of crystalline basement, Cretaceous sediments, and volcanics. The Precambrian crystalline basement is made up of scattered remains of well-metamorphosed sedimentary rocks and diverse, mostly granite, plutonic masses that are collectively called older granites.

The earliest Cretaceous sequence is the continental Albian Bima (Figure 1.2) sandstone which rests unconformably on the undulating Precambrian basement. The Bima Sandstone is the most extensive earliest continental sediments deposited on the entire basin, northeast Nigeria as a basal unit of the Cretaceous series soon after crustal rifting. From the field relationships of the beds, it is possible to differentiate the formation into lower Bima, Middle Bima, and Upper Bima.

Overlying the Bima Formation conformably is the Yolde Formation. This formation is of the Cenomanian age and represents the beginning of marine incursion into this part of the trough. It comprises of alternating sandstone and shales. The sandstones are fine to medium-grained and light brown, with shale and limestone intercalations. The base of the Yolde Formation is defined by the first appearance of the marine shales and the top by the disappearance of sandstones and the appearance of limestone-shale deposits.

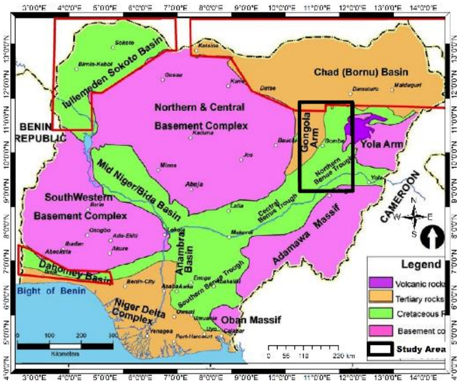

Figure 1.1 to Map of Nigeria Showing a part of the Upper Benue Trough (U)

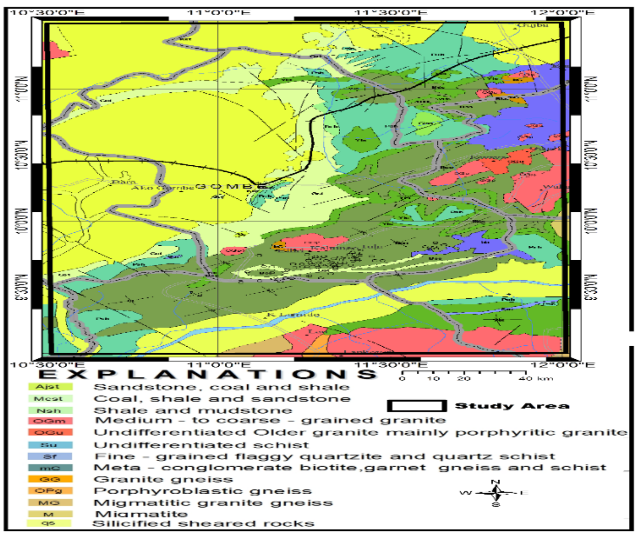

Figure 1.2: Geology of the Study Area.

Pseudogravimetric anomaly

The pseudogravimetric anomaly of a source body is the gravity anomaly obtained from the magnetic anomaly when the magnetization contrast at each point of the body is replaced with an equivalent density contrast. The concept of Pseudogravimetric transformation was first introduced by Baranov (1957), the purpose of which was to transform the total magnetic intensity (TMI) anomalies to pseudogravity anomalies to simplify interpretation. The pseudogravimetric anomalies have the usual characteristics of gravity anomalies. The pseudogravimetric computation is based on Poisson's relation which shows that the magnetic potential (V) and the gravitational potential (U) for a body with the ratio of density to magnetization constant at each point, and the magnetization vector in a constant direction are related by directional derivatives in three-dimensions;

$$\boldsymbol{V_{x,y,z} = \frac{C_m M}{G\rho}\frac{\partial U_{x,y,z}}{\partial m}, \frac{M}{\rho} = constant} \qquad \textbf{(1.1)}$$

Where ρ is the density contrast, M is the intensity of magnetization contrast, **m** is a unit vector in the direction of total magnetization and G is the gravitational constant.

The magnetic field anomaly $T_{x,y,z}$ at an external point due to a body is related to the magnetic potential (V) as (Tandrigoda & Ofoegbu, 1989);

$$\boldsymbol{T_{x,y,z} = \frac{\partial V_{x,y,z}}{\partial f}} \qquad \textbf{(1.2)}$$

Where **f** represents a unit vector in the direction of Earth's total field. Substituting equation 1.1 into equation 1.2, we obtain:

$$T_{x,y,z} = \frac{C_m M}{G\rho}\frac{\partial U_{x,y,z}}{\partial f \partial m} \qquad \textbf{(1.3)}$$

It is possible therefore to compute a theoretical gravity potential U from any given measured magnetic anomaly T (x, y, z) and from this gravitational potential, a pseudogravity anomaly ∇U can be computed. This pseudogravity anomaly is not the true gravity anomaly due to the body, but a fictitious anomaly derived from a true magnetic anomaly assuming the ratio ($\frac{M}{\rho}$) to be constant throughout the source body. From equation 1.3, the pseudogravimetric potential is obtained:

$$\boldsymbol{U = \frac{G\rho}{C_m M}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} T_{x,y,z}\, \partial f \partial m} \qquad (1.4)$$

Taking the fictitious density contrast to be equal to:

$$\rho = \frac{C_m M}{G}$$

The pseudogravimetric anomaly is then given by:

$$g_{x,y,z} = \frac{dU}{dz} = \frac{d}{dz}\int\int_{-\infty}^{\infty} T_{x,y,z}\, df dm \qquad (1.5)$$

Taking Fourier transform of both sides, we obtained:

$$\boldsymbol{F(g_{x,y,z}) = F(H_f) * F(T_{x,y,z})} \qquad (1.6)$$

H_f = Filter that transforms the total-field anomaly $\boldsymbol{T_{x,y,z}}$ measured on the horizontal surface into the Pseudogravity anomaly $\boldsymbol{g_{x,y,z}}$.

The Fourier transform of the pseudogravity transform filter is given (Blakely,1995):

$$F(H_f) = \frac{k}{(|k|f_z + ik_x f_x + ik_y f_y)(|k|m_z + ik_x m_x + ik_y m_y)} \qquad (1.7)$$

k_x,k_y are wavenumbers in the direction of x and y axis respectively, $(m = m_x, m_y, m_z)$ and $f = f_x + f_y + f_z$re unit vectors of ambient magnetic field and magnetization field with respect to x, y, z axis.

RESEARCH METHODOLOGY

Materials

The materials needed for this study are;

1. The data used for the research were TMI sheets: 108 (Akwiam), 109 (Nafada), 110 (Mutwe), 130 (Duku), 131 (Bajoga), 132 (Gulani), 151(Ako), 152 (Gombe), 153 (Wuyo), 172 (Futuk), 173 (Kaltungo), 174 (Guyok) obtained from the Nigerian Geological Survey Agency (NGSA). The aeromagnetic survey had a flight line spacing of 500m, sensor mean terrain clearance of 80m, and tie line spacing of 5000m.
2. Oasis Montaj Software version 8.4 has been used for processing of the data and estimating source parameters.
3. GM-SYS computer software

Pseudogravimetric (PSG) Transformation of the Total Magnetic Field Intensity (TMI) Map

The pseudogravimetric transformation filter in Fourier domain according to Blakely (1995) is given by:

$$(H_f) = \frac{k}{(|k|f_z + ik_x f_x + ik_y f_y)(|k|m_z + ik_x m_x + ik_y m_y)} \qquad (1.8)$$

From equation 1.6, the process consists of three steps; Fourier transformed the magnetic field anomaly $F(|T|_{x,y,z})$ multiplied by the filter $F(|H|_f)$ and then inversed Fourier transformed the product. The process requires a 2D gridded magnetic field map. Pseudogravity transform can also be carried out by the vertical integration of the reduction to the pole aeromagnetic data (Blakely, 1995).

First vertical derivative (FVD)

The effect of this enhancement is to sharpen up the anomalies over their source bodies and to emphasize near-surface features and reduce anomalies complexities (Foss, 1989). The transformation can be noisy since it enhances short wavelength anomalies (Blakely & Simpson, 1986).

$$FVD = \frac{\partial T}{\partial z} \qquad (1.9)$$

T is the magnitude of the total magnetic field intensity (TMI) or the PSG anomaly, and $\frac{\partial T}{\partial z}$ is their first vertical derivative with respect to the z- axis.

Analytical Signal (AnaSig)

The effect of this enhancement is that it generates maxima above discrete bodies as well as the edges. The Analytic Signal Amplitude can be calculated (Debeglia & Cortel, 1997) as:

$$(AS) = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2} \qquad (1.10)$$

T is the magnitude of the PSG anomaly. This transformation is often useful at low magnetic latitudes since it is independent of magnetization direction.

Total Horizontal Derivative (THD) of the Pseudogravimetric (PSG) anomaly

The maxima of the total horizontal gradient of a gravity or Pseudogravimetric Anomaly tends to overlie the edges of the body (Blakely and Simpson 1986). This enhancement is designed to delineate faults and contact features.

The magnitude of the total horizontal gradient of the pseudogravity anomaly is then given by:

$$HDR = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2} \qquad (1.11)$$

T is the magnitude of the PSG anomaly.

Tilt derivative (TiltD) of the Pseudogravimetric anomaly

The effect of this enhancement is to sharpens the edges of anomalies and is used in recognizing the horizontal location and extend of sources. It is the arctangent of the vertical derivative to the total horizontal derivative (Salem et al., 2008).

$$TiltAngle(\theta) = tan^{-1}\left[\frac{\frac{\partial T}{\partial z}}{\sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2}}\right] = tan^{-1}\left[\frac{FVDR}{THDV}\right] \quad (1.12)$$

Due to the nature of the arctan trigonometric function, all amplitudes are restricted between -90 and +90 degrees regardless of the amplitudes of FVDR and THDR. This makes the filter to act like an automatic gain control (AGC) filter. The tilt angle yields a result that gives equal emphasis to both large and smaller anomalies. The tilt angle ranges from -90 to + 90 degrees. The TDR is independent of inclination, just like the analytic signal but is more useful in highlighting subtle features in magnetic data (Foss, 1989).

2D Profile Modelling

Gravity forward modelling involves the computation of the gravitational field intensity generated by a given source mass distribution. The foundation of GFM is the Newton's law of universal gravitation which states that the force of attraction of two-point masses is proportional to the product of their masses, *m, M* and inversely proportional to the square of the distance, r separating them:

$$F = \frac{GmM}{r^2}$$

G = 6.67 x 10^{-11} N m^2 kg^{-2} is the universal gravitational constant. By using the Newton's law of universal gravitation, the gravitational field generated by the mass distribution is computed. An initial model for the source body is constructed based on geologic and geophysical intuition. The model's anomaly is calculated and compared with the observed anomaly, and model parameters are adjusted in order to improve the fit between the two anomalies. The three-step process of body adjustment, anomaly calculation, and anomaly comparison is repeated until calculated and observed anomalies are deemed sufficiently alike. This comparison helps in refining the model to better the match the observed. In most practical applications, of GFM, unit mass is assumed (m = 1) in the computation point, and the second body's mass, ($M = \rho \int dv$) is considered the source of the gravitational field (Blakely, 1996).

RESULTS

Pseudogravimetric (PSG) transformation of the Total Magnetic Field Intensity (TMI)

Figure 1.5 is the Pseudogravimetric Anomaly transformed from the Total Magnetic Field Intensity of Figure 1.4. The Pseudogravimetric transformation filter, is a low- pass filter**,** and has some noticeable effects on the Total field intensity map (Figure 1.4) which includes filtering out the short wavelengths anomalies that are due to shallow features and enhancing the anomalies that are due to deeper sources. Therefore, the resultant effects of the transformation will be of broad-based regional anomalies that are due to magnetic basement. The maximum value of the pseudogravimetric anomaly is 19.7 milliGal, the minimum is -42.4 milliGal. Two broad, positive, regional East-West trending Pseudogravimetric anomalies can be identified in Figure 1.4 which are due to positive magnetizations flanking a pseudogravimetric low. Overall, the structure shown in figure 1.1 is a consequence of the Pseudogravimetric transform filter on the TMI giving rise to a regional structure that is a central graben and two flanking horsts. The central graben is filled with Cretaceous sediments. The existence of block faulting has been suggested in the area by Shemang et al. (2004). Also, the positive magnetic anomalies that occupy the central region in figure 1.1 have been replaced with negative magnetic anomalies, indicating a 90^o phase shift from the magnetic equator to the pole.

First Vertical derivative (FVD) of PSG

Figure (1.6) is the First Vertical Derivative (FVD) of the Pseudogravimetric Anomaly. As a high-pass filter, the FVD tends to be responsive to the high frequency components of the anomalies than to the broad, low frequency regional. It therefore tends to give a sharper picture than the pseudogravimetric (PSG) map. Those shallow magnetic features can be interpreted as igneous intrusions into the Cretaceous sediments in the southern part or intra-sedimentary detrital and diagenetic magnetic minerals in the northern part of the study area. The anomalies are of different shapes and sizes covering almost the entire parts of the study area. The intrusions peaked in Kaltungo, Futuk and Akwaim where there are several shallow magnetic features. Some are elongated, while some are compact. There is an elongated magnetic anomaly striking NE-SW from Futuk to Gombe which may correspond to an emplaced intrusive dyke. Sedimentary sub-basins can also be seen around Ako, Duku, and Gombe. Shemang et al. (2004), referred to one of the graben structures as the Duku sub-basin. From figure 1.7, it can be seen that there is a high correlation between the first vertical derivative (FVD) and the tilt derivative (TiltD). However, the tilt derivative has amplified the subtle features more than the vertical derivative.

Analytic Signal (AnaSig) of the PSG

As can be noticed I figures 1.7 & 1.10, the analytic signal maximizes over structures and edges with high pseudo-density contrasts. The analytic signal is symmetrically located over its source body and does not depend on strike or dip of magnetization (Debeglia & Corpel, 1997). In this context, therefore, figure (1.10) shows the analytic signal maximizing over the boundary of central prominent structure in the study area. The centrally located prominent structure is a sub-basin with high pseudo-density contrasts (see figure 1.10). Also from figure 1.10, it can be seen that the analytic signal has emphasized the edges and boundaries more than the first vertical derivative and the tilt derivative.

Total Horizontal Derivative (THD) of the Pseudogravimetric (PSG) Anomaly

Figure (1.8) shows several maxima of the total horizontal derivative over some areas in the study area which indicates discontinuities within the pseudogravimetric map. Some of the discontinuities are lithology boundaries between basins and basement highs while some are fault lines. Some are trending west-east, while some are trending SW-NE. Some of the trending SW-NE are around Gombe fault and Kaltungo fault and the Burashika fault. The Eastward trending maxima are in Akwaim, Bajoga, Wuyo and Gulani. Among those edges are boundaries between horst and graben structures which are evidences of crustal extension and the subsequent block faulting.

Tilt derivative (TiltD) of the pseudogravimetric (PSG) anomaly

From the figure (1.9), the area is structurally marked by numerous SW-NE linear intrusive igneous features of positive pseudogravimetric with sharp boundaries. Positive values indicate magnetic sources, negative values indicate sedimentary basins and zero indicate boundaries or vertical contacts. The zero values are the vertical contacts between graben rock units and horst rock units. In Kaltungo, Futuk, Guyok, parts of Ako and Wuyo are magnetic sources. There are numerous relatively smaller magnetic sources around Akwaim, Nafada, Mutwe and Gulani. In the middle of the study in parts of Ako, Duku, Gombe, Bajoga and Wuyo are negative values of the tilt angle indicating that they are sedimentary sub-basins or graben depressions. The positive values indicate horst structures, the negative values indicate graben structure while the zero values indicate the vertical contact between the graben and horst. Block faulting has been suggested by Shemang et al. (2004) around Kaltungo, Gombe and Wuyo.

2D Forward modelling of pseudogravimetric anomalies

Modelling of profile 1

This anomaly is characterized by positive pseudogravimetric anomaly that ranges from 1milliGal to 15.5 milliGal. The profile 1 (colored blue in Figure 1.5) is oriented NW-SE with a length of approximately 70 km and azimuth angle of 325°. The anomaly is located around Dadiya, Kaltungo, and Kumo (figure 1.4). As modelled, the magnetic basement of the anomaly has a density of 2.77g/cm^3 while the overburden Cretaceous sediments have a density of 2.55g/cm^3, and a maximum depth of 4 km. The inference from the structural shape of the basement is that it is typically that of a graben and horst structure which is the result of normal fault from rifting and extension of the crust.

Modelling of profile 2

The profile 2 (colored black in figure 1.5) is oriented NE-SW with an approximate length of 30 km. The anomaly of this profile is characterized by positive pseudogravimetric values that ranges in from 4 milliGal to 14 milliGal. The anomaly is located around Sabon gari (figure 1.4). The basement of the anomaly also has a density of 2.77g/cm^3 and the cretaceous sediment of 2.55g/cm^3. The maximum thickness of the sediment is about 3 km. The inference is that the anomaly is due to a magnetic basement of variable topography.

Modelling of profile 3

This pseudogravimetric anomaly ranges from about 5milliGal to 12 MilliGal. The profile is oriented NE-SE, with a length of approximately 39 km. It is located around Nafada, Kuka and Fika Ningi (figure 1.4). The magnetic basement of variable topography and depths ranging from 300 m to 2.5 km. A steep gradient of magnetic basement within a short distance is evidence of normal fault. The magnetic basement pseudo-density is also 2.77g/cm^3, and the overburden sediment 2.53 g/cm^3.

Modelling of profile 4

This anomaly is located around Buni-Yadi, Kokuwa and Mutwe, and is a positive pseudogravimetric of value ranging from 0.5 milliGal to 5 milliGal, and of length 59 km. The pseudo-density-density of the magnetic basement is 2.68g/cm^3, while that of the Cretaceous sediment is 2.45g/cm^3. The anomaly which is around Kokuwa maybe caused by magmatic intrusion into the sedimentary rock as a result of faulting. Transcurrent and normal faulting has been suggested to have taken place in the region at the end of the Cretaceous by Benkhelil (1989). The thickness of the sediment ranges from about 900 m to 1.4 km. A vertical contact of such magnitude within a short distance is evidence of normal fault and intrusion.

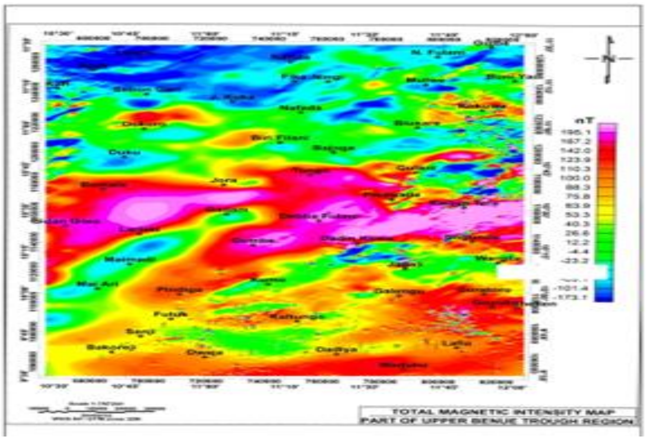

Figure 1.4: Total Magnetic Intensity (TMI) Map of a part of the Upper Benue Trough Region, Nigeria.

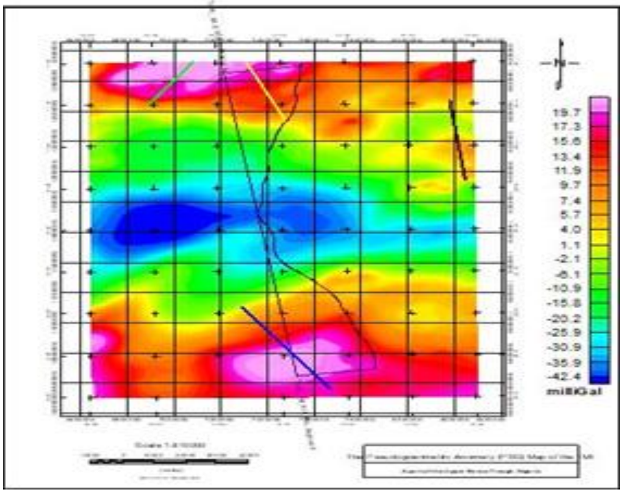

Figure 1.5: Pseudogravimetric (PSG) Anomaly Map transformed from the Total Magnetic Intensity (TMI) Map Figure (1.4) with the modelled profiles.

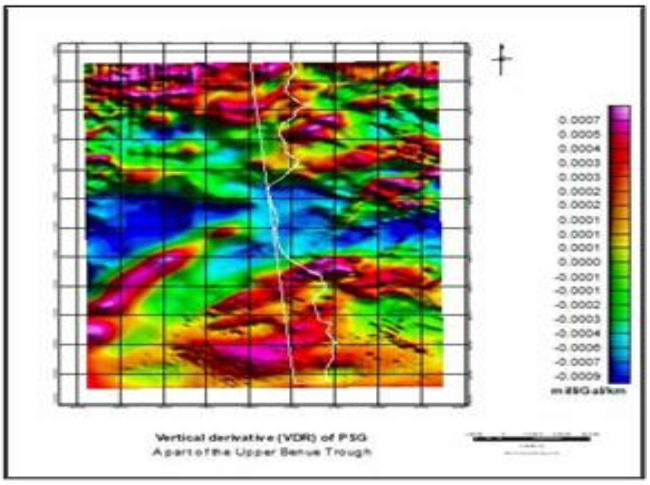

Figure 1.6: The first vertical derivative (FVD) of the PSG anomaly of figure 1.5 with a profile.

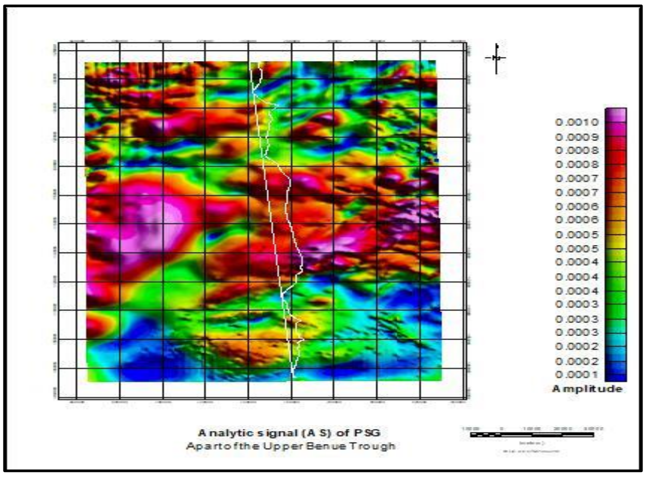

Figure 1.7: The analytic signal (AnaSig) of the PSG anomaly of figure 1.5 with a profile.

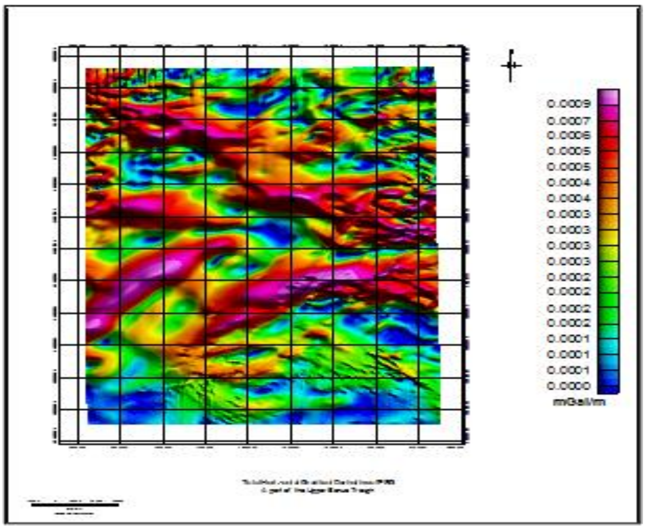

Figure (1.8): The total Horizontal Derivative (THD) of the PSG Anomaly Figure 1.5

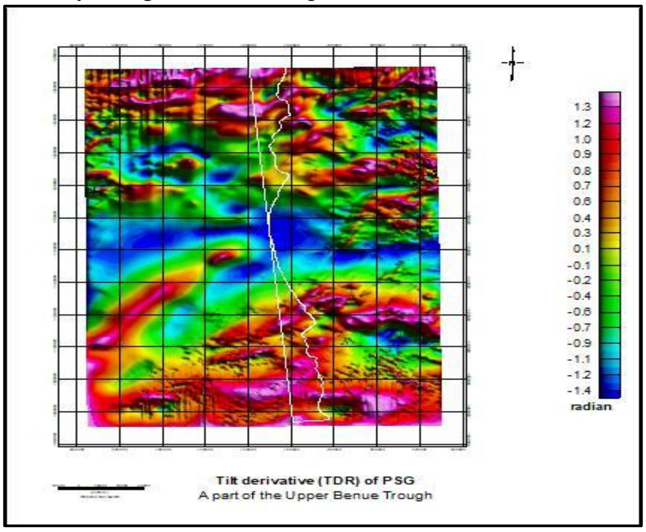

Figure (1.9): The Tilt Angle (TiltD) of the Pseudogravimetric (PSG) Anomaly.

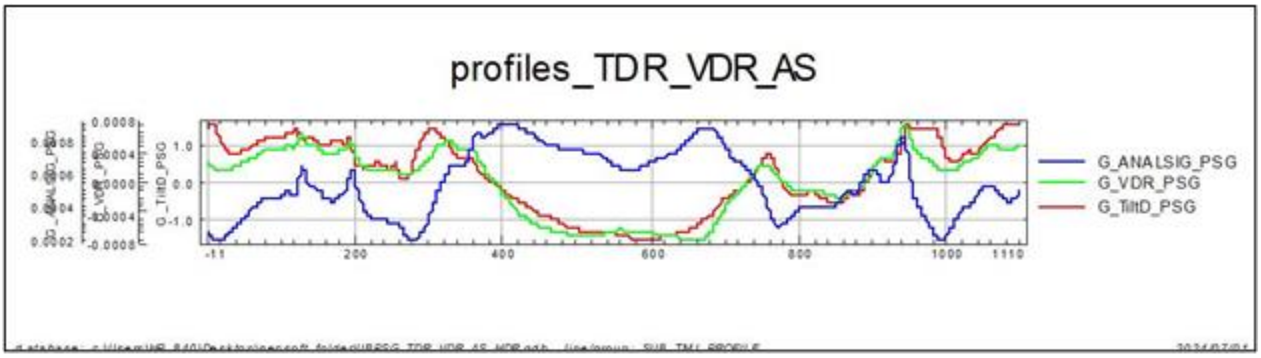

Figure 1.10: Comparison between the responses of the vertical derivative (green), analytic signal (blue) and the Tilt derivative (red) of the PSG anomaly along the same profile.

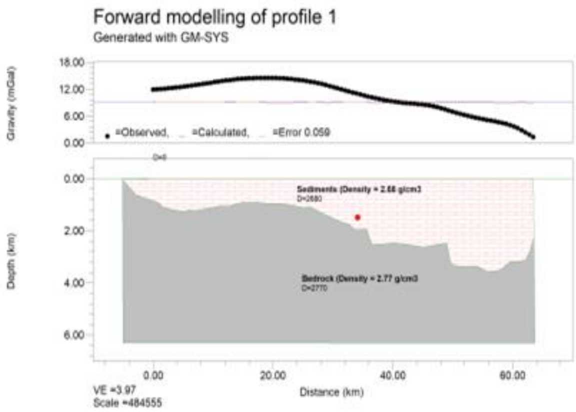

Figure 1.11: Forward modelling of profile 1 (blue in Figure 1.5) with azimuth angle of 325° (NW-SE)

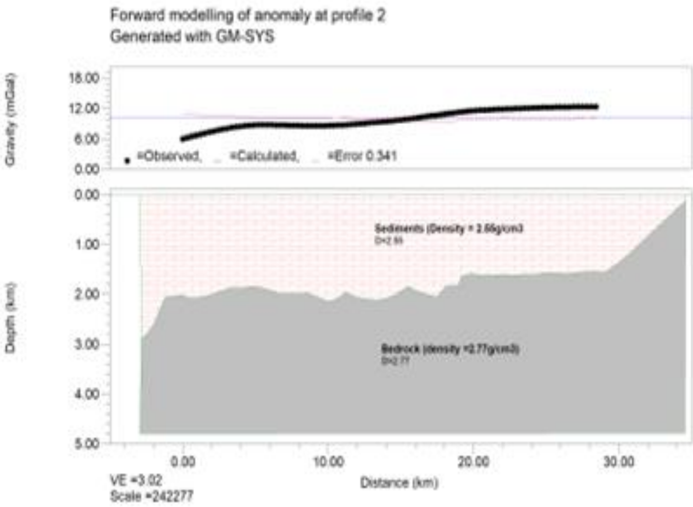

Figure 1.12: Forward modelling of profile 2 (green in Figure 1.5) with azimuth angle of 23° (NE-SW).

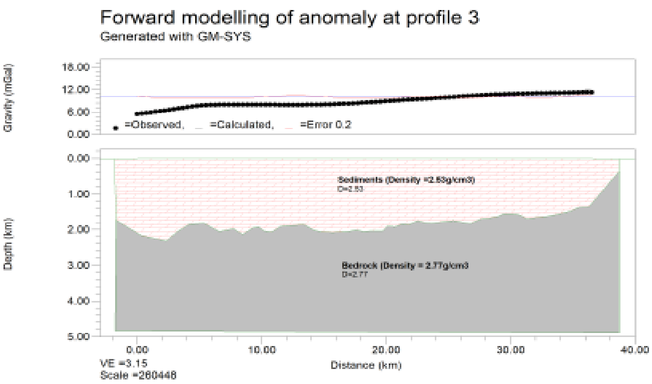

Figure 1.13: Forward modelling of profile 3 (yellow in Figure 1.5) with azimuth angle of 342° (NNW-SSE).

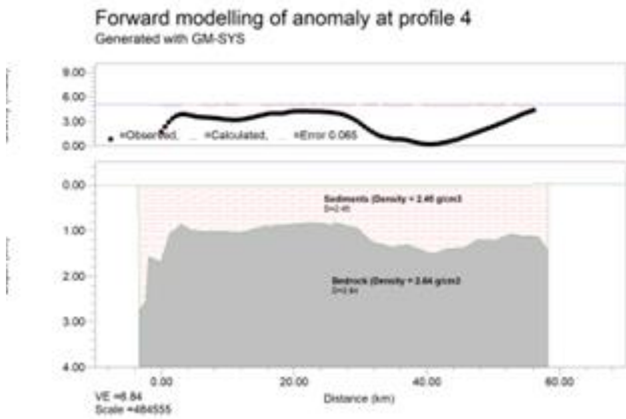

Figure 1.14: Forward modelling of profile 4 (black in Figure 1.5) with azimuth angle of 353° (NNW-SSE).

DISCUSSIONS

Summary of findings

The area studied is a part of the Gongola arm of the Upper Benue trough located in northeast Nigeria which is an important geological region that is linked with the West and Central African rift system and known for its huge potential for hydrocarbon and solid mineral. Because of that, the area has attracted extensive geophysical investigations from a vast array of geophysical methods. In spite of these research efforts, there exist a gap in utilizing pseudogravimetric technique in investigating the region. This study seems to address this gap by using the pseudogravimetric transformation of Aeromagnetic data to study the medium to deep magnetic sources and their implications for resource exploration. The total magnetic field intensity (TMI) data of the region was subjected to pseudogravimetric (PSG) transformation. A grid of the PSG anomaly was further subjected to various derivatives (first vertical derivative, analytic signal, total horizontal derivative and the tilt angle) to highlight for the anomalies, their shapes, boundaries, edges, locations, intrusions, and any other disruptive feature.

The Enhancement of the Pseudogravimetric (PSG) has revealed the magnetic anomalies to be due to a combination of igneous intra-sedimentary intrusions, intra-basement magnetic bodies, fault system, horst and graben structure and diagenetic (chemical remanent) magnetic sources. A West-East trending negative Pseudogravimetric anomalies (Figure 1.6) including Dukku and Gombe are associated with low density Cretaceous sedimentary sub-basins. Shemang (2005) referred to the former as the Dukku sub-basin. There is also a positive prominent pseudogravimetric anomaly in Kaltungo located in the southern part of the study area (Figure 1.6) which can be associated with the Kaltungo basement horst.

The pseudogravimetric anomalies has been modelled using the 2D Profile modelling algorithm. The maximum depth to the top of the magnetic basement as determined by the 2D Forward modelling technique reveals depths from 0.3km to 4 km which is indicative of lateral and vertical variations in the composition of the crust and depths to the magnetized lower crust. The density of the basement rock as modelled is within the range of 2.64 g/cm3 and 2.77 g/cm3 which is within the range of the densities of granitic rocks, and that of the Cretaceous sediments to be within the range of 2.45 g/cm^3 and 2.55 g/cm^3.

The results obtained from this study is in agreement with the interpretation of aeromagnetic anomalies over a part of the Upper Benue trough by Ofoegbu (1988) in terms of igneous intrusion and basement of variable topography. It also agrees with those of Nur (2001); Nur et al. (2003) and Salako (2014). The result is also in agreement with the interpretation of gravity anomalies over the region in terms of graben and horst structures with the associated igneous intrusions (Shemang et al. 2005).

Overall, the study uncovered the presence of sub-basins, igneous intrusions, and horst structures within the study area, underscoring the potential for hydrocarbon and mineral resources. The sub-basins create favourable conditions for the accumulation of organic-rich sediments, which are necessary for the formation of hydrocarbons. The faults and fractures create pathways for the migration of hydrocarbons, allowing them to accumulate in reservoir rocks such as limestone and sandstone. Additionally, the subsidence and faulting can create traps for the accumulation of mineral resources such as lead, tin, and other rare earth minerals. These findings underscore the significance of the upper Benue trough as a promising target for resource exploration.

The Benue trough has undergone several geological processes including sedimentation, block faulting, volcanism and emplacement of igneous materials within the basin. The sources of the pseudogravimetric anomalies as modelled in this study are related to the regions geological processes: according to Benkhelil (1988), the tectonic evolution of the Benue trough was linked with the rifting of the West and Central African region. The rifting induced a complex network of local compressional and tensional forces with the former resulting into folding and the latter into sub-basins, crustal thinning, faults, horst and graben structures along the restraining and releasing points (Guiraud et al., 1992; Binks & Fairhead,1992).

Limitations

The pseudogravimetric transformation requires assumptions concerning the direction of magnetization within the rocks of the mapped area, as well as a scaling factor given by the ratio of density to magnetization of the rocks. The following assumptions may introduce errors: the assumption that the ratio of magnetization to density $\left(\frac{M}{\rho}\right)$ has a constant value throughout the source and the assumption also that the total magnetization of source body is entirely due to induce magnetization with remanence been negligible and therefore in the direction of the ambient field.

Conclusion

The use of pseudogravimetric transformation has proven to be a good tool for studying the magnetic basement of the Upper Benue trough. The analysis of the pseudogravimetric anomaly by using various derivatives such as analytic signal, horizontal derivative, tilt angle and vertical derivative has provided valuable insights into the geological structure of the magnetic bodies underneath the study area. The findings of the study which include the identification of igneous intrusions, graben and horst structures, topography of the basement has contributed to the understanding of the regions geological processes and evolution. The most common explanation advanced to explain the origin and evolution of the Benue trough is that it is an aulacogen (R-R-R triple junction), a passive branch of a triple rift system that existed at the site of the present-day Niger Delta that formed during the breakup of Gondwana, as South America separated from Africa. The three arms are the Gulf of Guinea (R), the South Atlantic (R), and the Abakaliki- Benue arm (R) (Ofoegbu, 1984). According to Ofoegbu (1984), the tectonic evolution of the Benue trough involved the rise of a mantle plume, where heat results in melting the of the Upper mantle. Thinning and stretching the crust, followed by rifting of the weakened crust. This is repeated several times, with the trough deformed between the rifting episodes. Both models provide satisfactory explanation for the formation of graben and horst structures, volcanic intrusions, and faults in the Benue trough. The choice between these models depends on the specific geological and geophysical evidences available for the region.

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