International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 13, Issue 10 [October. 2024] PP: 07-20

Mapping the Magnetic Basement of part of the Upper Benue Trough, Nigeria from the Pseudogravimetric data and its derivatives

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ABSTRACT
Pseudogravimetric transformation is used in converting the total magnetic field intensity (TMI) to produce gravity-like data called pseudogravimetric data. The transformation is particularly useful in removing the characteristic skewness of magnetic anomalies relative to their perturbing sources, enhancing the low spatial frequency components of the anomalies and attenuating the high frequency components. This paper presents the results of investigating the magnetic basement of part of the Upper Benue trough, Nigeria from the Pseudogravimetric data. Various derivatives of the Pseudogravimetric data, such as the horizontal derivatives, analytical signal, and tilt angle, were also used to enhance the understanding the magnetic basement of the study area. The result of the analysis showed the magnetic anomalies to be a result of igneous intrusions, horst/graben structures, magnetic basement topography and susceptibility variations. The results show significant variations in the magnetic basement depths across the study area, indicating complex geological structures and potential mineral resources. The Source parameter imaging (SPI^{TM}) was employed for quantitative interpretation, revealing an average depth ranging from a minimum of 447.7 m to a maximum of 7.51 km. These results align closely with those of other scholars, contributing to a better understanding of the geological processes and evolution of the trough. The findings offer valuable insights for resource exploration and management in the region.
***Keywords**: Pseudogravimetric transformation, analytic signal, horizontal derivative, tilt angle, Benue trough.*

Date of Submission: 03-10-2024 Date of acceptance: 15-10-2024

I. INTRODUCTION

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 Benue trough is thought to be an active rift system and a failed arm of a triple junction at the Gulf of Guinea formed from lithospheric stretching during the early Cretaceous when the south Atlantic first formed (Min & Hou, 2019). According to Ofoegbu (1984), a mantle plume in the Gulf of Guinea may have played a role in the triple junction forming the Mesozoic West and Central African Rift system. This breakup led to the opening of the Atlantic Ocean and the separation of the African and South American continents. The region has experienced complex tectonic movement, including crustal extension and thinning leading to the formation of faults, folding, grabens and horsts which have significantly influenced the basin's geological structure and hydrocarbon and mineral deposits potential.

The advent of aeromagnetic survey came with the knowledge that virtually all of the variations in the earth's magnetic field intensity result from topographical or lithological changes associated with the basement or the underlying igneous intrusive (Gunn, 1997). It has also been recognized that there is a proportionate relationship between the wavelengths of the magnetic anomalies and the depth of their sources: high wavenumber components (short wavelengths) of the anomalies are associated with shallow magnetic sources, while the low wavenumber components (long wavelengths) are attributable to deeper magnetic sources (David & Leigh, 2013).

The interpretation of magnetic anomaly is relatively more complex than the corresponding gravity anomaly. Firstly, is the dipolar nature of the magnetic field in contrast to the simpler monopolar gravity field. Secondly, the inclined magnetization of the source body is dependent upon the latitude and longitude 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). Furthermore, if shallow magnetic sources do exist, these are usually of short wavelengths and discrete and can mask the identification of the medium and longer wavelengths, thereby complicating their interpretation (Hinze et al., 2010).

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 aim of this research is to map the deeper magnetic basement of a part of the Upper Benue trough, Nigeria from the pseudogravimetric data and its derivatives.

The total horizontal derivative (THD), vertical derivative (VDR), AS derivatives, and the tilt angle of the Bouguer gravity and reduced-to-pole (RTP) magnetic fields have traditionally been used to map the lateral extent of anomalous density or magnetization bodies and their edges when interpreting gravity and magnetic data in terms of their geological structures. 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 map the magnetic basement of part of the Upper Benue trough using the derivatives of the pseudogravimetric data.

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).

According to Ofoegbu (1984), the evolution of the Benue trough is thought to have involved the rise of a mantle plume giving rise to updoming and development of initial lines of weaknesses marginal to the plume. Continued updoming is believed to have been accompanied by more pronounced zones of weakness and possibly a slight amount of wedge subsidence. Renewed mantle plume activity and updoming gave rise to the emplacement of intrusive bodies along the lines of weakness and consequently block faulting. The continued emplacement of intrusive materials enhanced the breakup of the crust and block faulting, giving rise to the rather irregular topography of the basement. It is thought that post-depositional erosion and subsequent deposition of sediments might have obliterated the fault lines hence making their recognition on gravity and magnetic maps rather difficult (Ofoegbu, 1988)

The Benue Trough has for long been recognized as one of the main structures associated with the breakup of Gondwanaland, the separation of Africa from South America and the opening of the South Atlantic Ocean. It 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 The Bima sandstone is dominantly a quartz arenite derived from juxtaposed basement suites of the granites and gneisses which were subjected to humid conditions that accelerated the weathering process. 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.

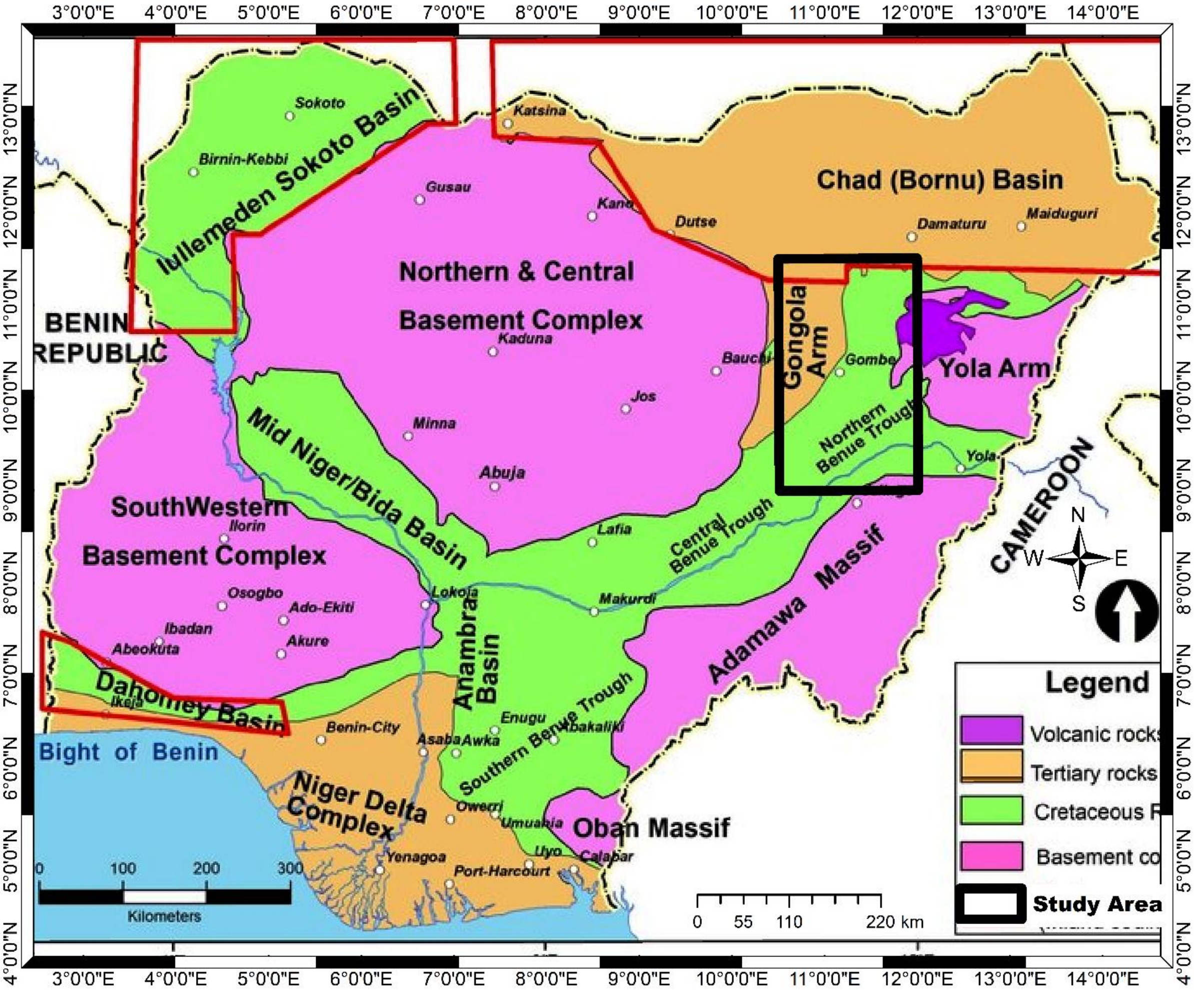

Figure 1.1 Geological Map of Nigeria Showing a part of the Upper Benue Trough (U)

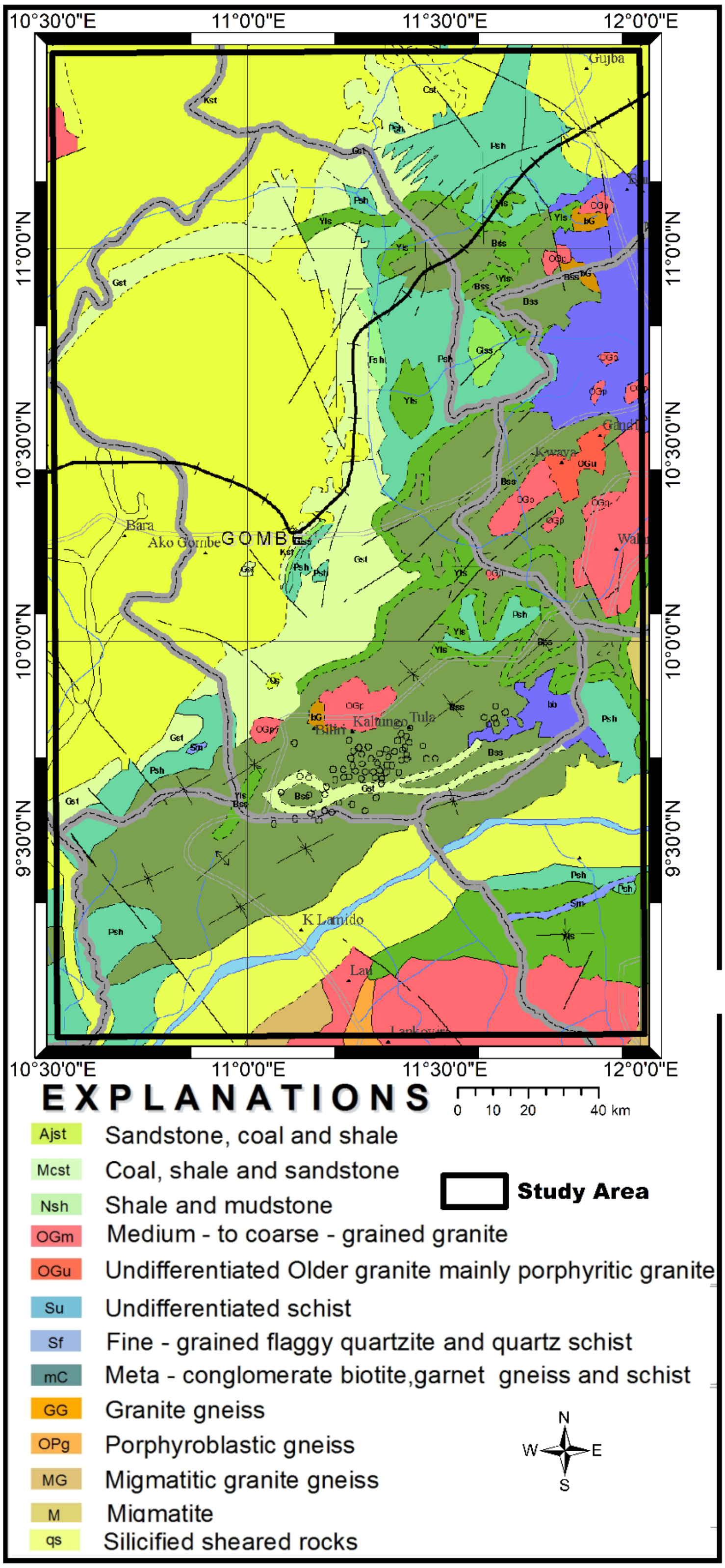

Figure 1.2: Geology of the Study Area.

Magnetic Basement

A basement means the lowest part of a tectonic unit such as a sedimentary section. The term is usually synonymous with crystalline basement. A magnetic basement is the upper surface of extensive igneous or metamorphic rocks having susceptibilities which is much higher than the sedimentary rocks above it (Gunn, 1997). The Sedimentary formations which can be Cenozoic or Mesozoic are places where oil and gas are generated and preserved and are usually covered by thick sediments. The basement is usually magnetic. If the magnetic units in the basement occur at the basement surface, then depth determination for those units will map the basin floor morphology. This approach has been used with remarkable success to locate and delineate the sedimentary basins (David & Leigh, 2013). If it contains numerous magnetic rock units such as igneous intrusions or extrusions, magnetic sediments, or metamorphic magnetic rock units, these can provide information on the morphology of the sedimentary basin and its structure (David & Leigh, 2013). For magnetic exploration, the magnetic basement is the dominant regional subsurface structure that contributes to the total magnetic field intensity (TMI) after applying the IGRF correction.

Pseudogravimetric Transformation

The concept of Pseudogravimetric transformation was first introduced by Baranov (1957), the purpose of which was to simplify the interpretation of aeromagnetic data. The pseudogravity 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.

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).

II. 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.

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

Pseudogravimetric transformation uses Poisson's theorem to transform a magnetic anomaly into a gravity-like effects called pseudogravimetric anomaly. The transformation is used to investigate a source's magnetic effects for possible gravity effects assuming that the source has correlative magnetization and density variations. Pseudogravity maps appear as gravity maps and are thus free from the distortion in magnetic anomaly maps that are cause by inclined magnetic polarization and fields. The transformation is particularly useful in enhancing the low frequency spatial components of the anomalies that are due to deeper sources, and attenuating the high frequency anomalies that are due to shallow sources. It is therefore a useful strategy in mapping the magnetic basement. Pseudogravimetric anomaly maps may appear as gravity maps, they only reflect the magnetic properties of the rocks in the study area and not the density. The pseudogravimetric transformation filter in Fourier domain according to Blakely (1995) is given by:

$$\left(H_f\right) = \frac{k}{(|k|f_z+ik_xf_x+ik_yf_y)(|k|m_z+ik_xm_x+ik_ym_y)} \qquad (1.8)$$

First vertical derivative (FVD)

The first vertical derivative represents the difference between the magnetic response measured at two different heights above the Earth surface. It is the most robust and reliable high pass filter for potential field applications. The effect is to sharpen the edges of the anomalies and to emphasize near-surface features where the difference between the responses calculated at two different heights will be largest (Foss, 1989). This enhancement will highlight edges of magnetic sources and appear over the top of magnetic source. The transformation can be noisy since it enhances short wavelength anomalies (Blakely & Simpson, 1986).

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

The transformation delineates the high frequency components of the anomaly and can therefore be useful in identifying the short wavelength intrusions into the Cretaceous sediments. The major drawback is that it can be noisy since it will amplify short wavelength noise.

Analytical Signal (AnaSig)

The analytic signal is formed through the combination of the horizontal and vertical derivatives of a magnetic anomaly. It has the property that it generates maxima above narrow bodies as well as the edges of larger geological features that are in magnetic or density contrast with their surroundings. The application of analytical signal to magnetic interpretation was pioneered by Nabighian (1984) for the two-dimensional case primarily as a tool to estimate depth and position of magnetic sources. More recently, the method has been expanded to three dimensional problems (Nabighian et al., 1998). The Analytic Signal Amplitude can now be calculated (Debeglia & Cortel, 1997) as:

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

This transformation is often useful where magnetic remanence is suspected and at low magnetic latitudes since it is not affected by magnetization direction.

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

The steepest horizontal gradient of a gravity or Pseudogravimetric Anomaly caused by a tabular body tends to overlie the edges of the body (Blakely and Simpson 1986). The steepest gradient will be located directly over the edge of the body if the edge is vertical. This is used to map or locate abrupt changes in density or magnetization

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

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

The horizontal gradient applied to a 2D grid of gravity or Pseudogravimetric Anomaly maximizes over the steepest gradients can be used to locate discontinuities which can include faults, the edges of tabular bodies, or lateral compositional changes.

Tilt derivative (TiltD) of the Pseudogravimetric anomaly

The tilt angle of a magnetic anomaly *T* has the property of being positive over a source, zero over a contact and negative outside the source. It sharpens the edges of anomalies and is used in recognizing the horizontal location and extend of sources. It normalizes the first vertical derivative (FVDR) by the total horizontal derivative (THDR) so it responds well to both shallow and deep sources. It is the arctangent of the vertical derivative to the total horizontal derivative (Salem et al., 2008).

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

The tilt angle yields a result that gives equal emphasis to both shallow and deep sources. The tilt angle ranges from -90 to + 90 degrees (Verdusco et al., 2004).

The Source Parameter Imaging (SPI^{TM}) Method

The Source parameter imaging (SPI^{TM}) or wavenumber method (Thurston & Smith, 1997; Fairhead et al., 2004) is a profile or grid-based method for estimating magnetic source depths and other source parameters like dip, contacts and susceptibility contrasts. The method is based on the relationship between source depths and the local wave number (k) of the total magnetic field anomaly. For any point within the grid or profile, the local wavenumber (k) is calculated by using second derivatives of the vertical and horizontal gradients of the total field anomaly.

The 2D local wavenumber k for a magnetic field **T** is defined as the rate of change of the phase of the analytical signal (Bracewell, 1965).

$$k_x = \frac{\partial \theta}{\partial x} \qquad (1.13)$$

Where the phase is given by:

$$\theta = tan^{-1}\{\left(\frac{\partial T}{\partial z}\right)/\left(\frac{\partial T}{\partial x}\right)\}$$

$$k_x = \frac{\partial}{\partial x} tan^{-1}\left[\frac{\partial T}{\partial z}/\frac{\partial T}{\partial x}\right] \qquad (1.14)$$

Carrying out the differentiation of equation (1.14) gives (Thurston & Smith, 1997):

$$k_x = \frac{1}{|A(x)|^2}\left\{\frac{\partial^2 T}{\partial x \partial z}\frac{\partial T}{\partial x} - \frac{\partial^2 T}{\partial^2 z}\frac{\partial T}{\partial x}\right\} \qquad (1.15)$$

In 3D it can be written as

$$k_{x,y} = \frac{1}{|A(x)|^2}\left\{\frac{\partial^2 T}{\partial x \partial z}\frac{\partial T}{\partial x} - \frac{\partial^2 T}{\partial y \partial z}\frac{\partial T}{\partial y} - \frac{\partial^2 T}{\partial^2 z}\frac{\partial T}{\partial x}\right\} \qquad (1.16)$$

Where (Nabighian et al., 2005)

$$A(x) = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2} \qquad (1.17)$$

And A(x) is the analytical signal in 3D.

The local wavenumber over simple bodies such as contacts, thin dykes and horizontal cylinders with horizontal locations xo and zo is given by:

$$k_x = \frac{[(\eta+1)(z_o-z)]}{(x-x_o)^2+(z-z_o)^2}, \qquad (1.18)$$

Where η is a parameter characterizing the source geometry depends on the assumed source geometry (analogous to the structural index in Euler deconvolution: for example, η = 0 for a contact, $\eta = 1$ for a dyke and $\eta = 2$ for horizontal cylinders). The SPI method (the local wavenumber approach) depends on equation 3.18.

The Advantage of the SPI^{TM} method over other methods such as the Euler deconvolution, Werner deconvolution and the spectral method is that no moving window is involved, and the computation time is relatively short (Keary et al., 2002). The limitation of this method is that it is model-dependent and as a result the depth can only be estimated if the structural index η is known. As a result, the accuracy of the result depends upon how closely the structural index (the assumed model) approximates the real structure.

At peaks in the local wavenumber grid, the source depth is given by:

$$s = \frac{N}{k} \qquad (1.19)$$

Where N depends on the assumed source geometry (analogous to the structural index in Euler deconvolution: for example, N= 1 for a contact, N=2 for a dyke and N= 3 for horizontal cylinders). Peaks in the wavenumber grid are identified using a peak tracking algorithm and the depth estimates are isolated.

III. RESULTS

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

Figure 1.2 is the Pseudogravimetric Anomaly transformed from the Total Magnetic Field Intensity of Figure 1.1. The Pseudogravimetric transformation filter, is a low- pass filter**,** and has some noticeable effects on the Total field intensity map (Figure 1.1) 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 (1.3) 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

The purpose of Analytic Signal amplitude is to remove the skewness of the magnetic anomaly with respect to the causative body so that the anomaly and the causative body will be directly correlated. It is an effective tool for marking geological boundaries with appreciable pseudo-density contrast and is also a function of gradients which makes it an efficient tool for edge detection of source bodies. As can be noticed I figures 1.4 &1.7, 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 (1.4) 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 1.7). Also from figure 1.7, 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

The total Horizontal Derivative usually shows maxima over regions of discontinuity within the pseudogravimetric data (e.g. lithology boundaries, faults or dykes). In this context, therefore, the figure (1.5) 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

The Tilt angle mathematically normalizes the vertical derivative and maximizes over the PSG anomalies irrespective of the depth of their sources. This makes the Tilt angle function like an Automatic Gain Control (AGC) Filter. From the figure (1.6), 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.

The Source Parameter Image (SPI^{TM})

The Source Parameter Imaging of the Pseudogravimetric anomaly is shown in Figure (1.6). The basement underneath the trough as modelled by the source parameter imaging has minimum depth value to the magnetic basement as 447.7 meters, the maximum depth value as 7.51 km. Comparing the Source Parameter Imaging (SPI) with the Pseudogravimetric (PSG) anomaly, it will be noticed that areas with the largest depths correspond with areas with low Pseudogravimetric values (areas with thick sediments). Similarly, areas with low depths values to the magnetic basement correspond with areas with high Pseudogravimetric values. Areas with the highest depth values are Akko, Duku and Gombe and Bajoga. Areas with the lowest depth values are found in Akwaim, Nafada, Mutwe, Gulani, Kaltungo, Wuyo, Guyok and Gulani. The result of this interpretation is in close agreement with the interpretation of aeromagnetic studies over the trough (Ofoegbu, 1988; Salako and Udensi (2013) and the interpretation of gravity profiles over the Gongola arm of the basin by Shemang et al. 2013.

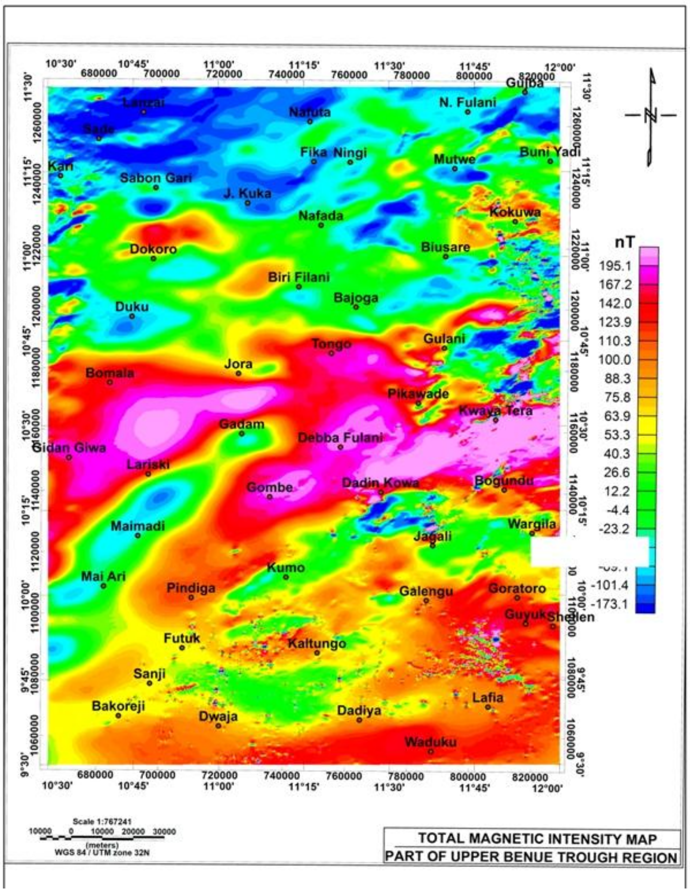

Figure 1.1: Total Magnetic Intensity (TMI) Map of a part of the Upper Benue Trough Region, Nigeria.

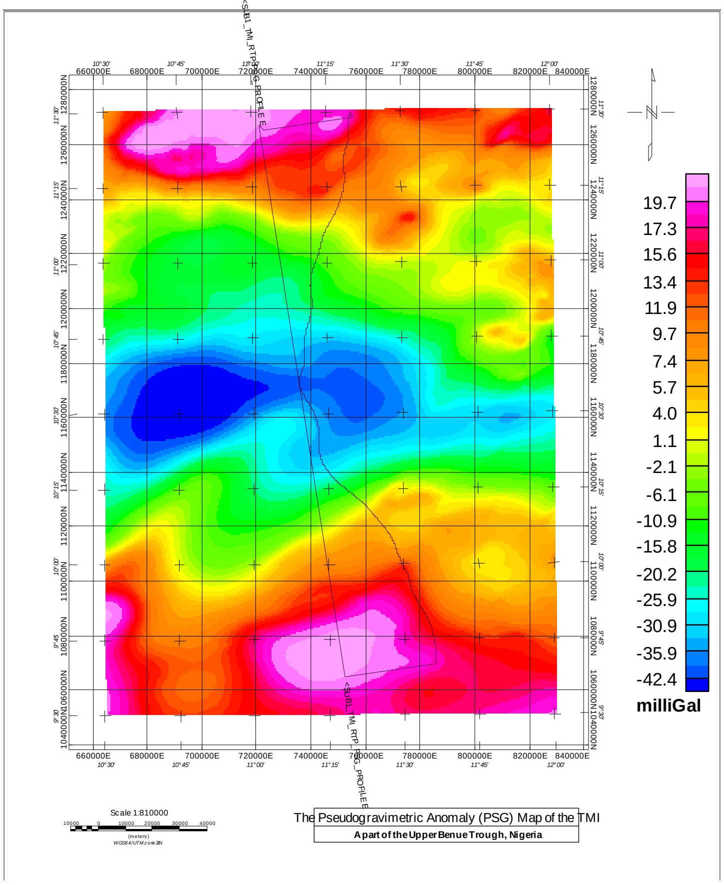

Figure 1.2: Pseudogravimetric (PSG) Anomaly Map transformed from the Total Magnetic Intensity (TMI) Map Figure (1.1)

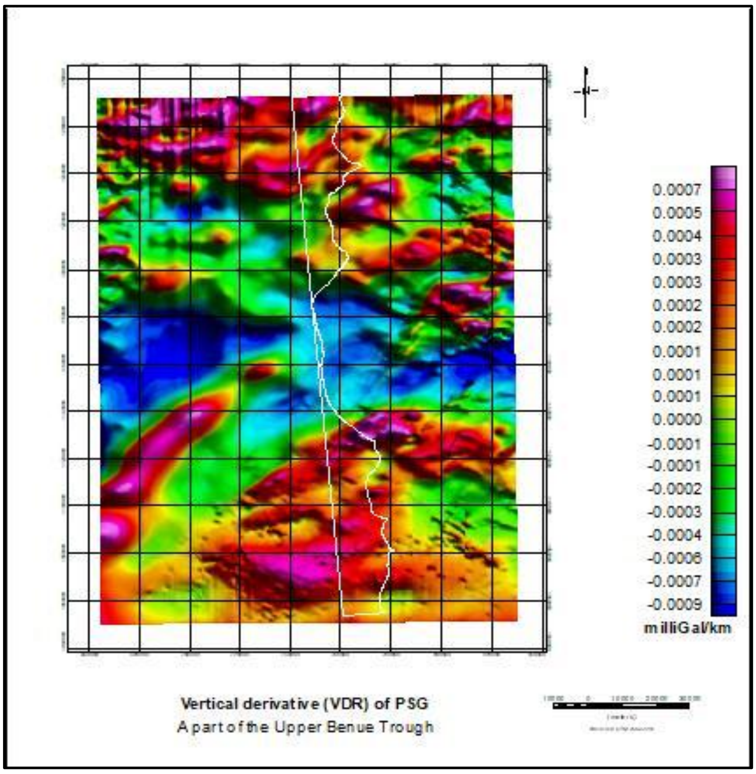

Figure 1.3: The first vertical derivative (FVD) of the PSG anomaly of figure 1.2 with a profile.

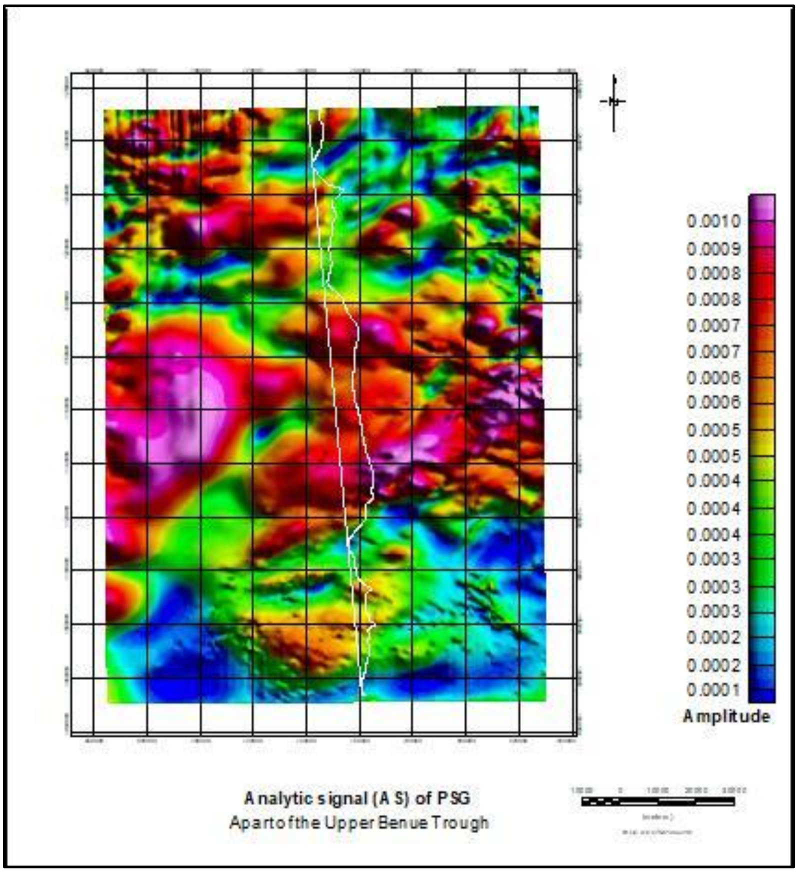

Figure 1.4: The analytic signal (AnaSig) of the PSG anomaly of figure 1.2 with a profile.

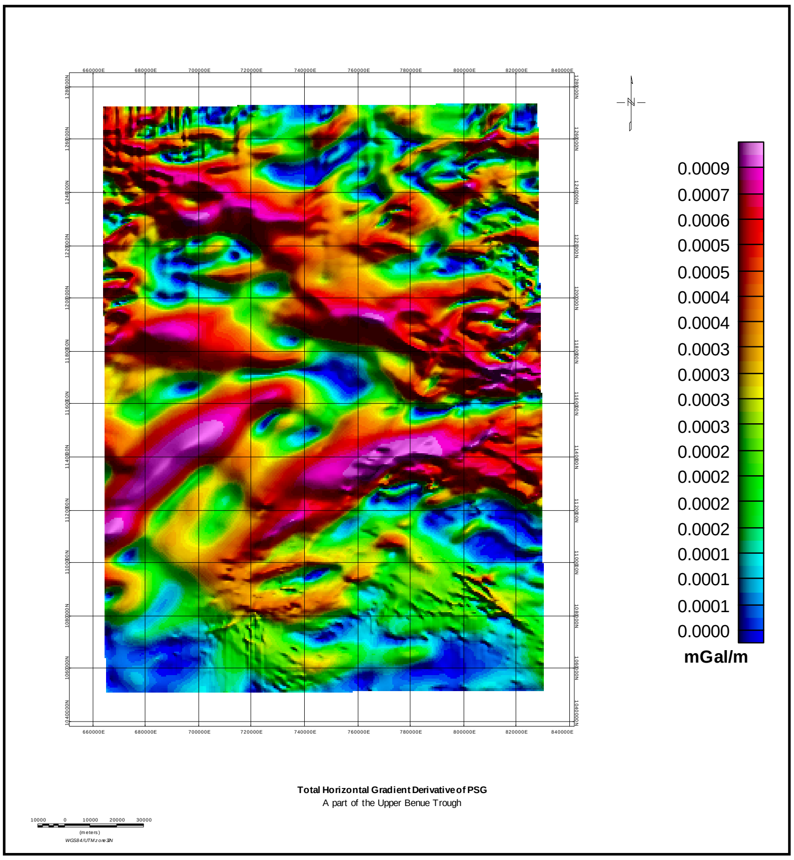

Figure (1.5): The total Horizontal Derivative (THD) of the PSG Anomaly Figure 1.2

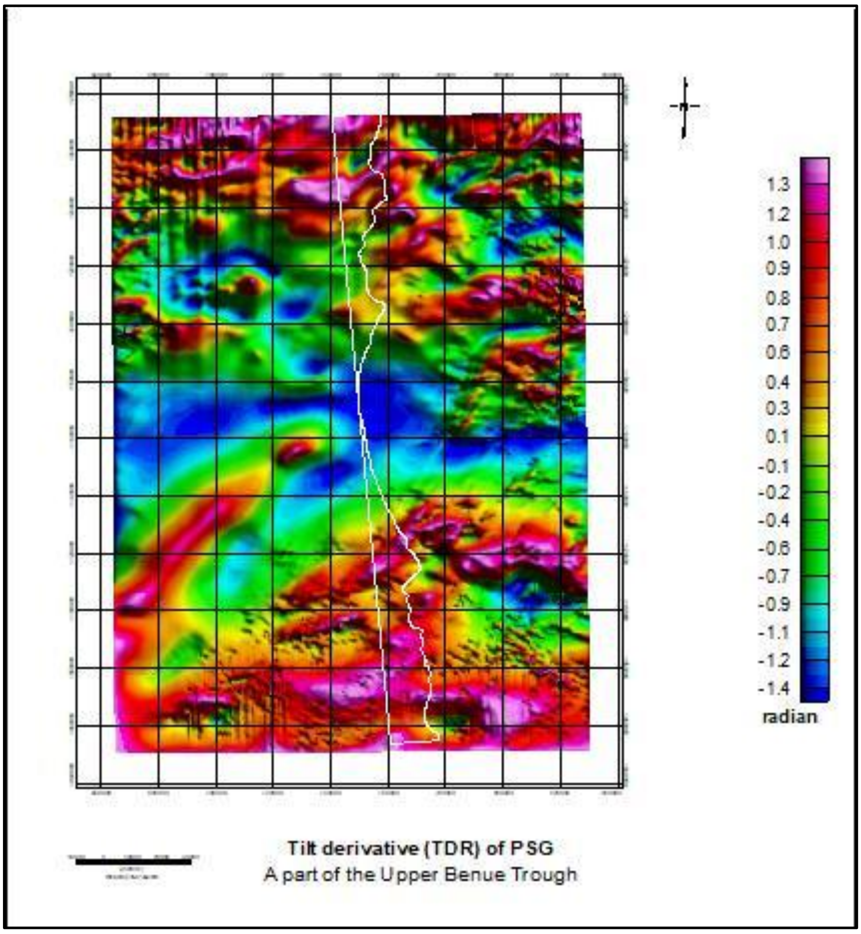

Figure (1.6): The Tilt Angle (TiltA) of the Pseudogravimetric (PSG) Anomaly.

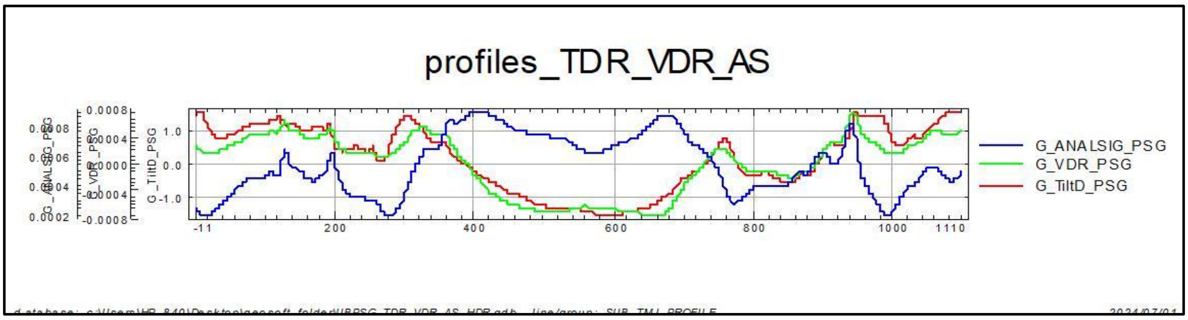

Figure 1.7: Comparison between the responses of the vertical derivative (green), analytic signal (blue) and the Tilt derivative (red) of the PSG anomaly along the same profile.

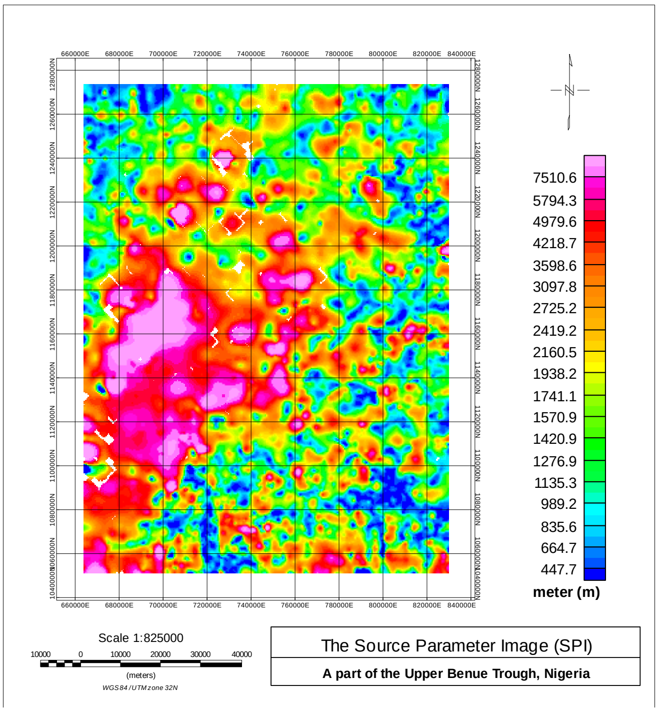

Figure 1.6: Source Parameter imaging of the pseudogravimetric anomaly map.

IV. DISCUSSIONS

Summary of findings

A Pseudogravimetric study of a part of the Upper Benue Trough, Nigeria has been carried out. The total field Intensity (TMI) has been transformed into a gravity anomaly called the Pseudogravimetric Anomaly. The overall effect of the transformation has been to reduce to pole the field intensity, to attenuate the short wavelength anomalies that are due to shallow sources and to enhance the anomalies that are due to deeper magnetic basement.

The Enhancement of the Pseudogravimetric (PSG) by various derivatives; first vertical derivative, analytical signal, total horizontal derivative, and the tilt angle has revealed the magnetic anomalies to be due to a combination of igneous intra-sedimentary intrusions, intra-basement magnetic bodies, horst/graben faults (figure 1.7). Negative Pseudogravimetric anomalies are associated with low density sedimentary basins. The crystalline basement depth has been determined using the Source Parameter Imaging. The minimum and the maximum depth as modelled by the (SPI^{TM}) method are 443 m and 7.51 km. The ranges also agree well with that of other scholars. From figure 1.7, it is clear that the analytic signal has emphasized the boundaries and the edges of the anomalies more than the first vertical derivative and the tilt derivative.

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.

V. 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, intra-basement sources, topography of the basement and variable magnetic susceptibility has contributed to the understanding of the regions geological processes and evolution. The evolution of the Benue trough is thought to have involved tensional forces that led to the stretching and thinning of the Earth's crust resulting in the formation of the rift system. The tensional forces are believed to be driven by the mantle plume activity. The mantle plume theory suggests that hot, buoyant upwellings of magma from the Earth's mantle can create stretching and thinning of the Earth's crust, resulting in the formation of the rift system.

Continued stretching and thinning is believed to have been accompanied by more pronounced zones of weakness and possibly subsidence. Continuous mantle plume activity and updoming gave rise to the emplacement of intrusive bodies along the lines of weakness and consequently block faulting. The continued emplacement of intrusive materials enhanced the breakup of the crust and block faulting, giving rise to the formation of graben (down-dropped blocks) and horst (uplifted blocks) structural features which gives the magnetic basement a rather irregular topography. Future research including integrating additional geophysical methods, detailed petrological and geochemical analysis of rock samples and Long-term monitoring of the magnetic field variations through time-lapse analysis can assist in understanding the geological structure and resource potential of the area.

AKNOWLEDGEMENTS

I would like to extend my appreciation to Tertiary Education Trust fund (TEDFund) for providing the funding for the data and software used in this research. Many thanks to the staff of the department of physics, Nasarawa state university for their support and professional guidance.

References

[1]. Ahmed, s., Chris, O., Samuel, C., Derek, F., & Essan, A. (2013). Mapping the depth to magnetic basement using inversion of pseudogravity; application to the bishop model and the stored basin, northern North Sea. Geophysics, 2(2). 69-78. http://DOI:10.1190/INT-2013-0105.1.
[2]. Baranov, V. (1957). A new method for interpretation of aeromagnetic maps pseudo-gravimetric anomalies; Geophysics. (22), 359-383.
[3]. Blakely, R.J. (1995). Potential Theory in Gravity and Magnetic Applications. Cambridge University Press.
[4]. Blakely, R. J., & Simpson, R. W. (1986). Approximating edges of source bodies from magnetic or gravity anomalies. Geophysics. 51(7), 1494-1498.
[5]. Bracewell, R. N., (1965). The Fourier Transform and its Applications (3rd edn). McGraw-Hill Book Co.
[6]. David, A. P. & Zhiqum, S. (2004). An improved pseudogravity magnetic transform technique for investigation of deep magnetic source rocks, ASEC Extended Abstracts, 2004:1, 1-4. http://DOI.10.1071/ASEC2004ab116.
[7]. David, J. & Leigh, R. (2013). Geological Interpretation of Aeromagnetic Data. CSIRO Publishing.
[8]. Fairhead, J.D., Williams, S.E. And Flanagan, G., (2004). Testing Magnetic Local Wavenumber Depth Estimation Methods using a Complex 3D Test Model. SEG Annual Meeting, Denver, Extended Abstract.
[9]. Gunn, P. J. (1997). Application of aeromagnetic surveys to sedimentary basin studies. Journal of Australian Geology & Geophysics, (17(2), 133-144.
[10]. Hinze, W.J., Von Frese, R.R.B., Saad, A.H. (2012). Gravity and Magnetic Exploration; Principles, Practices and Applications. Cambridge University Press.
[11]. Ge, M & Guiting, H. (2019). Mechanism of the Mesozoic African rift system: Paleostress field Modelling. Journal of Geodynamics, Vol. 132.
[12]. https://doi.org/10.1016/j.jog.2019.101655
[13]. Getech. (2008). Advance processing and Interpretation of gravity and magnetic data. Getech.
[14]. Obaje, N.H. (2009). Geology and Mineral Resources of Nigeria. Springer.
[15]. Ofoegbu, C.O. (1985). A review of the Geology of the Benue Trough, Nigeria. Journal of African Earth Sciences, 3(3) 283-291.
[16]. Ofoegbu, C.O. (1985). Preliminary result from a pseudogravity study of the Benue-Trough Nigeria. Journal of African Earth Sciences, (5) 187-192.
[17]. Ofoegbu, C, O. (1988). An aeromagnetic study of part of the Upper Benue Trough, Nigeria. Journal of African Earth Science, 7(1) 77-90.
[18]. Ofoegbu, C, O. (1984). Interpretation of aeromagnetic anomalies over the lower and middle Benue Trough of Nigeria. Geophysics, 79(3), 813-823.
[19]. Panepinto, S., luca, L.D., Mantovani, M., & Sfolciaghi, M. (2014) Using Pseudogravity functional transform to enhance deep magnetic sources and enrich regional gravity data. [Conference presentation]. Denver, 1275-1279
[20]. Pratt, D.A. & Zhiqun, S. (2004). An improved pseudo-gravity magnetic transform technique for investigation of deep magnetic source rocks. [Conference presentation] ASEG 17th Geophysical Exploration and Exhibition, 1-4, DOI; 10.1071/ASEG2004ab116.
[21]. Reeves, C. (2005). Aeromagnetic Surveys: Principles, Practice and Interpretation. Geosoft E-book. http://www.geosoft.com/media/uploads/resources/technicalpapers/Aeromagnetic.
[22]. Salako, A. K. (2014). Depth to basement determination using Source Parameter Imaging (SPI) of aeromagnetic data: an application to Upper Benue Trough and Borno Basin., Northeast, Nigeria. Academic Research International, 5(3).
[23]. Salem, A., Williams, S., Fairhead, D., Smith, R. Ravat, D. (2008). Interpretation of Magnetic data using Tilt Angle Derivative. Geophysics, 73(1) 1-10.
[24]. Shemang, E.M., Jacoby, W.R., Ajayi, C.O. (2004). Gravity Anomalies over the Gongola arm, Upper Benue Trough, Nigeria. Global Journal of Geological Sciences 3(1). 61-69.
[25]. Tandrigoda, D.A, & Ofoegbu, C.O. (1989). A Routine for the Rapid Computation of the Pseudogravity field. Inverse modelling in Exploration Geophysics. Friedr, Vieweg and Sohn, Wiesbaden, 93-109.
[26]. Tandrigoda, D.A. (1982). Interpretation of magnetic anomalies using Pseudogravimetric transformation and other methods with applications to tertiary volcanic centers in NW Scotland. [Unpublished doctoral dissertation]. University of Durban, Durhan, UK.
[27]. Thurston, J. B. & Smith, R. S. (1997). Automatic conversion of magnetic data to depth, dip, and susceptibility contrast using SPI™ method, Geophysics, 62(3), 807-813.
[28]. Verduzco, B., Fairhead, J.D., Green, C.M., and Mackenzie, C., (2004) New insights into magnetic derivatives for structural mapping: The Leading Edge, v. 23, p. 116- 119
[29]. Zhou, W. (2018). Aeromagnetic Survey. In Encyclopedia of Engineering geology. Encyclopedia of Earth Sciences Series. Bobrowsky, P.T., Marker, B. (Ed). Springer, Cham. https:// doi.org/ 10.1007/ 978-3 -319 -7355689_8.