ZIBELINE INTERNATIONAL

ISSN: 2521-0920 (Print)

ISSN: 2521-0602 (Online)

CODEN: MJGAAN

Malaysian Journal of Geosciences (MJG)

DOI : <http://doi.org/10.26480/mjg.01.2019.51.60>

CrossMark

REVIEW ARTICLE

DELINEATION OF HIGH-RESOLUTION AEROMAGNETIC SURVEY OF LOWER BENUE TROUGH FOR LINEAMENTS AND MINERALIZATION: CASE STUDY OF ABAKIKILI SHEET 303

Cyril C. Okpoli*

Department of Earth Sciences, Faculty of Science, Adekunle Ajasin University, PMB 1, Akungba-Akoko, Ondo State, Nigeria.

*Corresponding author email: cyril.okpoli@aaua.edu.ng

This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

ARTICLE DETAILS

ABSTRACT

Article History:

Received 23 November 2018

Accepted 24 December 2018

Available online 10 January 2019

High resolution aeromagnetic dataset of Abakiliki (sheet 303 SW) was used for the characterization of the subsurface lithostructural features in part of the Lower Benue Trough, Nigeria. This study was necessitated for mapping and delineating hydrocarbon prospecting zones, in order to boost the Nation's economy. The aeromagnetic data were subjected to several forms of filtering, reductions, and enhancement techniques for both qualitative and quantitative interpretations. The result of the reduction to equator- total magnetic intensity (RTE-TMI) revealed the magnetic intensity of subsurface rocks ranging from 34.14nT to 61.40nT. These range of magnetic intensity values characterized the rocks in the area as shale and Limestone within the Asu River Group, Awgu shale, Eze-Aku shale and Nkporo shale. The upward continued RTE-TMI data to 500m, 1 km, 2 km, 3 km, 7 km and 10 km revealed regional trends of these rocks and structure thin -out with measure depth continuation. The second vertical derivative (SVD), Tilt-angle derivative (TDR) and Analytical signal (AS) revealed three (3) major faults; F1-F¹, F2-F² and F3-F³ in NE-SW, ENE-WSW and NW-SE directions respectively. The depth to top of magnetic source were revealed by the radially averaged power spectrum (RAPS) and Euler deconvolution as 27m and 2.64km for shallower and deeper sources respectively. This study has demonstrated the efficiency of aeromagnetic methods, with their improved techniques as tools for regional mapping of lithologies and structures that may host important minerals and/or aid hydrocarbon accumulation and their probable depths.

KEYWORDS

Aeromagnetic, Abakiliki, Lower Benue Trough, Qualitative and Quantitative, Lithostructural, Depths

1. INTRODUCTION

Geophysical techniques investigate a unique physical property of the earth crust, which tends to solve a peculiar problem within the earth's subsurface. While in some cases; a combination of two or more of these methods gives better results [1]. Magnetic method is the oldest geophysical exploration method used in prospecting. Magnetic method measures variation in the Earth's magnetic field caused by changes in the subsurface geological structure or the differences in near-surface rocks' magnetic properties [2]. The aim of a magnetic survey is to investigate subsurface geology on the basis of anomalies in the Earth's magnetic field resulting from the magnetic properties of the underlying rocks. Although most rock-forming minerals are effectively non-magnetic, certain rock types contain sufficient magnetic minerals to produce significant magnetic anomalies. Similarly, man-made ferrous objects also generate magnetic anomalies. Magnetic surveying thus has a broad range of applications, from small scale engineering or archaeological surveys to detect buried metallic objects, to large-scale surveys carried out to investigate regional geological structure [1].

This non-destructive technique has numerous applications in engineering and environmental studies, including the location of voids, near-surface faults, igneous dikes, and buried ferromagnetic objects like storage drums, pipes etc. Magnetic field variations can be interpreted to determine an anomaly's depth, geometry and magnetic susceptibility. Magnetic data measured in gammas and either collected as total field or gradient measurements are collected in a grid or along a profile with stations spacing.

Aeromagnetic survey is a common type of geophysical survey carried out using a magnetometer aboard or towed behind an aircraft. The principle is similar to a magnetic survey carried out with a hand-held magnetometer but allows much larger areas of the Earth's surface to be covered quickly for regional reconnaissance. The aircraft typically flies in a grid-like pattern with height and line spacing determining the resolution of the data [1].

The Benue Trough of Nigeria in which the study area lies, is a major tectonic feature in West Africa. It is an elongated rifted depression that trends NE-SW from the south, where it merges with the Niger Delta to the north, where it sediments are part of the Chad basin succession. The origin and evolution of the Benue Trough of Nigeria is now fairly well documented [3-10]. Generally, the Benue Trough is believed to have been formed when the South America separated from Africa. The major component units of the Lower Benue Trough include the Anambra Basin, the Abakiliki Anticlinorium and the Afikpo syncline.

A researcher produced a detailed report on the geology of Abakiliki domain, likened its development to that which occurs in a complete Orogenic cycle including sedimentation, magmatism, metamorphism and compressive tectonism [6,7,11]. The same researcher suggested that the compression responsible for the large-scale folding and cleavage was directed N155°E [11]. The magmatism that occurred resulted in the injection of numerous intrusive bodies into the shale of the EzeAku and Asu River Group.

Ananaba and Ajakaiye generated a regional magnetic field intensity map from aeromagnetic data of the Southern Benue Trough and Niger Delta [12]. The produced regional map showed prominent features and major tectonic trends in the NE-SW direction which when compared with those indicated on the tectonic map of Africa, suggested a linear extension of the Chain and Charcot fracture zone.

The study area is characterized by several economic mineral deposit which have generated a lot of interest on the economic importance of this mineral zone. Intense geological investigations have been carried out in these areas at different times in search for different mineral deposits [9,13].

This study aim at contributing to our understanding of the geology and hydrocarbon potentials of this part of the Lower Benue Trough using high resolution aeromagnetic dataset. The aeromagnetic dataset will be used to delineate the subsurface structures which control the anomalous mineralization in the area. Forward and inverse modeling techniques were employed for these purposes. This is with a view to characterize the subsurface litho-structural features as well as their lateral and depth extents.

1.1 Location and Geology of the Study Area

The study area is located within latitudes 6000' and 6030'N and longitudes 8000' and 8030' E (Figure 1). The Benue Trough was formed as a result of series of tectonics and repetitive sedimentation in the Cretaceous time when South American continent separated from Africa and the opening of the South Atlantic Ocean. The geology of the Lower Benue Trough has been described by several authors [6,7,14].

The Lower Benue Trough is underlain by a thick sedimentary sequence deposited in the Cretaceous. The oldest sediments belong to the Asu River group (Figure 1) which uncomfortably overlies the Precambrian Basement Complex that is made of granitic and magmatic rocks. The Asu River group found in the Abakaliki-Afikpo basins has an estimated thickness of 2000 m and is Albian to Cenomanian [10,15]. It comprises of argillaceous sandy shale, laminated sandstone, micaceous sandstone and minor limestone with an inter fingerings or mafic volcanic deposited on top of the Asu River group [6]. Sediments in the area were the upper Cretaceous sediments, comprising mostly the Eze-Aku shale. The Turonian Eze-Aku shale consist of nearly 1000m of calcareous flaggy shale and siltstone, thin sandy and shaly limestone and calcareous sandstone [15]. The Eze-Aku shales at the Afikpo Basin for the Amasiri sandstones. The Nkporo shale is the youngest unit of the Cretaceous sequence and overlies the Eze-Aku shale unconformably. They are Campanian-Maestrichtian in age and are mainly marine in character, with some sandstone intercalations. The sediments of the Abakaliki Anticlinorium are exposed from about 8 km North-East of Okigwe where the folded Eze-Aku shale and the Asu River group are unconformably overlain by the Nkporo shale [6,7,16].

Figure 1: Section of the Map of Nigeria showing the Lower Benue Trough [12].

1.2 Regional Geology of Nigeria

The geology of Nigeria is made up essentially of the Basement Complex,

the Younger Granite and the Sedimentary Basins. The Basement Complex, which is Precambrian in age, is made up of the Migmatite-Gneiss Complex, the Schist Belts, the Older Granites and the Undeformed basic and acidic dykes. The Younger Granites comprise several Jurassic magmatic ring complexes centered on Jos and other parts of North Central Nigeria [17]. The Sedimentary Basins, containing sediment fill of Cretaceous to Tertiary ages, comprise the Niger Delta, the Anambra Basin, the Benue Trough (Lower, Middle and Upper), the Chad Basin, the Sokoto Basin, the Mid-Niger (Nupe/Bida) Basin and the Dahomey Embayment (Figure 2).

The Benue Trough is a Sedimentary Basin located in Nigeria, extending from the Gulf of Guinea in the South to the Chad Basin in the North. It is believed to have originated from a 'pull-apart' basin associated with the opening of the Atlantic Ocean which ended in Early Tertiary with the development of the Tertiary Niger Delta. The Benue Trough is characterized by extensive magmatic activities as evidenced by the widespread occurrence of intrusive and extrusive rocks. These rocks are the result of the tectonic activities within the trough. The Benue Trough originated from Early Cretaceous rifting of the central West African basement uplift. It forms a regional structure which is exposed from the northern frame of the Niger Delta and runs northeastwards for about 1000 km to underneath Lake Chad, where it terminates. Regionally, the Benue Trough is part of an Early Cretaceous rift complex known as the West and Central African Rift System. The Trough is subdivided into Lower, Middle and Upper Benue Troughs. The Lower Benue Trough is underlain by a thick sedimentary sequence deposited during the Cretaceous and made up of Albian shales, subordinate siltstones of the Asu River and the presence of volcanic. The Benue trough of Nigeria is a major tectonic feature in West Africa. It is an elongated rifted depression that trends NE-SW from the south, where it merges with the Niger delta to the north, where it sediments are part of the Chad basin succession. The origin and evolution of the Benue trough of Nigeria is now fairly well documented [3-10].

Generally, the Benue Trough is believed to have been formed when the South America separated from Africa [8]. The major component unit of the Lower Benue trough includes the Anambra basin, the Abakaliki Anticlinorium and the Afikpo synclinorium. The Benue Trough was formed as a result of series of tectonics and repetitive sedimentation in the Cretaceous time when South American continent separated from Africa and the opening of the South Atlantic Ocean. The geology of the Lower Benue Trough has been described by several authors [6,7].

Figure 2: Modified geological Map of Nigeria showing the study area inset Geological Map of Abakaliki, Sheet 303 SW [17].

1.3 Stratigraphic Settings of the Study Area

Sedimentation in the Lower Benue Trough commenced with the marine Neocomian – Albian Asu River Group, although some pyroclastics of Aptian – Early Albian age have been scantily reported (Figure 3). The Asu River Group sediments in the Lower Benue Trough comprises predominantly of shales with localized sandstones, siltstones and limestones as well as extrusive and intrusive material of the Abakaliki Formation in the Abakaliki area and the Mfamosing Limestone in the Calabar. In addition, described the Asu River Group as consisting of arkosic sandstones, volcanoclastics, marine shales, siltstones and limestone which overly the Precambrian to Lower Paleozoic Crystalline Basement rocks. The arkosic sediments were derived principally from the extensive weathering of the basement rocks which were invaded by alkaline basaltic rocks prior to the initial rapid marine flooding of the Middle Albian times. The Asu River Group is interpreted as sediments of the first transgressive cycle into the Lower Benue Trough [8].

The marine Cenomanian – Turonian Nkalagu Formation (black shales, limestones and siltstones) and the interfingering regressive sandstones of

the Agala and Agbani Formations (Cross River Group) rest on the Asu River Group. Although, sequences of sandstones, limestones and shales with calcareous sandstones of Odukpani Formation were deposited unconformably on the Basement rocks in the Calabar Flank during the Late Albian and Santonian was a period of non-deposition, folding and faulting. This was followed by uplift and erosion of the sediments [8].

The intensive Middle–Santonian deformation and magmatism in the Benue Trough displaced the major depositional axis westward which led to the formation of the Anambra Basin [6,7]. Post deformational sedimentation in the Lower Benue Trough, therefore, constitutes the Anambra Basin. Sedimentation in the Anambra Basin thus commenced with the Early Campanian – Early Maastrichtian of the Enugu and Nkporo Formations (lateral equivalents) which consist of a sequence of bluish to dark grey shale and mudstone locally with sandy shales, thin sandstones and shelly limestone beds [8].

The shaly facies grade laterally to sandstones of the Oweli and Afikpo Formations in the Anambra Basin. The Enugu and Nkporo Formations are essentially marine sediments of the third transgressive cycle. These, in most parts of the Anambra Basin is overlain by the Lower Maastrichtian sandstones, shales, siltstones and mudstones and the inter-bedded coal seams of the deltaic Mamu Formation. The deltaic facies grade laterally into the overlying marginal marine sandstones of the Ajali and Nsukka Formations [18].

Figure 3: Stratigraphic settings of the Lower Benue Trough [10].

1.4 Mineral Resources Associated with Lower Benue Trough

Geological Survey of Nigeria Agency has played an active role in the exploration for mineral deposits in Nigeria. The Lower Benue Trough like other Sedimentary Basins in Nigeria is found to be endowed with mineral resources. The mineral resources so far reported in the Lower Benue Trough of Abakiliki study area by the Geological Survey of Nigeria Agency are discussed below [4, 17,19].

1.5 Lead-zinc

Deposits of zinc and lead minerals in the form of their ores of Sphalerite and Galena respectively often associated with Barytes mineralization in the Cretaceous sediments of the Lower Benue Trough. The general geology of Lower Benue Trough in Abakiliki area is made up of thick sequences (500m) of slightly deformed Cretaceous sedimentary rocks made up of essentially of Albian shales, subordinate siltstones of the Asu River Group. There is also the presence of volcanic and pyroclastic materials forming elongated conical hills in the cores of the Anticlinal structures. The Abakiliki lead–zinc is believed to be of hydrothermal origin emplaced at a low temperature of about 140 oC and it is made up of primarily four lodes namely: Ishiagu, Enyigba, Ameri and Ameki in the Lower Benue Trough located in Ebo [4,20].

1.6 Fluorspar

Fluorspar occurs in small quantities in the lead-zinc lodes in the Albian shales, siltstones and limestones of Asu River Group in Ishiagwu and Ogoja, but the deposits are generally too small to be of value. Fluorspar or Fluorite is a mineral composed of calcium fluoride (CaF₂), the principal fluorine-bearing mineral. The main use of fluorite has been for the production of hydrofluoric acid, an essential raw material in the manufacture of synthetic cryolite and aluminum fluoride for the aluminum industry, and in many other applications in the chemical industry. It is also employed as a standard flux used in the making of steel, in the smelting of

lead ores, in ceramic industry and in the production of enamel and opal glass, and perfect crystals are used for the manufacture of apochromatic lenses [17,19].

2. MATERIALS AND METHODS OF STUDY

2.1 Materials used for study

The data set used for this research and the software package are:

- Grid and line Aeromagnetic data covering Abakiliki Area, Sheet 303.
- Geosoft® Oasis Montaj™ software version 6.4.2 H.J.
- A digitized map of the Study Area.

This work used the aeromagnetic data Sheet 303 of Abakiliki area in the Lower Benue Trough, the aeromagnetic data was acquired from Nigerian Geological Survey Agency, which undertook aeromagnetic survey and digitizing of aeromagnetic data in some parts of Nigeria between 2005 and 2009 (stratigraphy model of interpreting aeromagnetic data) [18]. The data was collected at a nominal flight altitude of 80 meters along N-S flight lines spaced approximately 1000 meters apart. The aeromagnetic sheet is on a scale of 1:100,000. Diurnal variation effects on the magnetic field, which arise due to solar activities, were recorded using additional unit of base station magnetometer (the ScintrexCS3CesiumVapour). Also, International Geomagnetic Reference Field (IGRF) was subtracted from the total magnetic measurements to get rid of the regional gradient of the earth's magnetic field due to the continual changes in the magnitude and direction of the earth's magnetic field from one place to another [18].

2.2 Methods of Study

The data was processed using Geosoft® Oasis Montaj™ software, other software include; Surfer and Microsoft Excel.

Data reductions such as: removal of near surface noise (NSN) using Butterworth filter, reduction to magnetic equator, regional field, residual field, automatic gain control (AGC), upward continuation, tilt-angle derivative (TDR), second vertical derivative (SVD), analytic signal (AS), radial average power spectrum (RAPS) and 3D Euler Deconvolution were performed for better result output. The data reductions and enhancements were done using the MAGMAP Step-by-Step filtering processing. The Magnetic data processing flow chat in Figure 4 shows the data processing stages employed.

Figure 4: The data processing stages employed.

2.3 Re-projection of Coordinates and Near Surface Noises (NSN) Removal

The NGS Total Magnetic Intensity (TMI) data coordinates were reprojected from UTM Zone 32N to UTM Zone 31N of the Greenwich Mercator. This was necessary because the coordinates of the data must correspond to their actual locations. These re-projected data were gridded and adopted as the new TMI data and was filtered to remove Near Surface Noises (NSN) caused by metallic materials, fences, cables (both buried and surface), flight height.

2.4 Reduction to magnetic equator

The Reduction to Magnetic Equator (RTE) filter was used to produce the RTE_TMI image, in order to Centre structures and anomalous bodies over their exact positions. To produce anomalies, depend on the inclination and declination of the body's magnetization, inclination, and declination of the local earth's field and orientation of the body with respect to the magnetic north. As discussed in a study, problems can arise in the reduction to the pole process at magnetic latitudes less than 15°, as the Fourier domain transformation process becomes unstable, owing to the need to divide the spectrum by a very small term, thereby introducing north-south alignment of the anomalies into the data. The RTE_TMI gridded data was adopted as our new processed data for subsequent data analyses and enhancement [21].

2.5 Regional and Residual field

Field associated with deep masses were filtered out to produce the residual data for the area covered. The data were smoothed upward to 4 km to evince the regional field caused by deep basement rocks and high wavelength anomalies. The Residual data left after near surface noise and the regional have been removed is produced using equation 1:

$$\text{Residual field} = \text{observed total field (RTE TMI)} - \text{Regional} \quad (1)$$

2.6 The Upward Continuation Filter

Upward continuation is considered a clean filter because it produces almost no side effects that may require the application of other filters or processes to correct. Because of this, it is often used to remove or minimize the effects of shallow sources and noise in grids. Also, upward continued data may be interpreted numerically and with modeling programs. This is not the case for many other filter processes. Upward continuation was carried out on the RTE_TMI data to depth of 0.5 km (i.e. 500 m) and 1 km respectively. Equation [2] below can be used for the calculation of the upward continuation [22].

$$F(x,y,-h) = \frac{h}{2\pi} \iint \frac{f(x,y,0) dx dy}{[(x-x^1)^2 + (y-y^1)^2 + h^2]^{3/2}} \quad (2)$$

Where, $F(x,y,-h)$ is the total field at the point $P(x_1, y_1, -h)$ above surface on which $F(x_1, y_1, 0)$ is known, h is the elevation above ground surface.

2.7 The Downward Continuation Filter

Downward continuation enhances the response of sources at a depth by effective bringing the plane of measurement closer to the source. Downward continuation highlights the component of higher wave number, increases the anomaly resolution of the individual sources. Its usefulness depends on the elimination of noise, as the computation of downward continuation is unstable and easily distorts the true feature of potential field data. According to a study, when applied to potential field data brings the observation surface closer to the source therefore enhancing the responses from sources at depth as shown in equation (3) [21,22].

$$T(x,y,h) = T(x,y,0) + \frac{dy}{dx} h + \frac{1}{2!} \frac{d^2}{dx^2} h^2 + \dots + \frac{2}{m!} \frac{d^m}{dx^m} h^m \quad (3)$$

2.8 The Second Vertical Derivative Filter

The significance of vertical derivatives is locating the position of the density or magnetization boundaries were given. The RTE-TMI image contains all the anomalies both shallow and deep sources. Therefore, second vertical derivatives (SVD) filtering was used to suppress unwanted sources that were obscured by broader regional trend. In this case, it accentuates short wavelength components to sharpen the edges of the anomalies; tends to reduce anomaly complexity and allow clearer contrast between the geologic unit sand causative structures like lineaments/faults and smaller trends [22].

2.9 Automatic Gain Control (AGC)

Automatic gain control is used to accentuate coherent assemblages and to align anomalies that appear characterless in RTE_TMI image by accentuating equal signals with both low and high amplitudes anomalies that mapped out the structures in the areas. Thus, the filter makes smaller trends and fractures to be distinct and clearly seen by unaided eyes [23].

2.10 Analytic Signal (AS)

Analytic Signal (AS) or total gradient is formed through the combination of the horizontal and vertical gradients of the magnetic anomaly and it is applied either in space or frequency domain, generating a maximum directly over discrete bodies as well as their edges. The generated maximum directly over the causative body and depth estimation abilities of this filter make it a highly useful technique for magnetic data interpretation. The maximum can be used to detect the structures responsible for the observed magnetic anomalies over an area. Analytic Signal images are useful as a type of reduction to the pole, as they are not subjected to the instability that occurs in transformations of magnetic fields from low magnetic latitudes; source positions regardless of any remanence in the sources. The amplitude A of the Analytic Signal (AS) of the total magnetic field F is calculated from the two or three orthogonal derivatives of the field for 2D or 3D bodies respectively (equation 4). It is therefore defined as the square root of the squared sum of the vertical and horizontal derivatives of the magnetic field [23].

$$AS = |A(x,y)| = \sqrt{(\partial F/\partial x)^2 + (\partial F/\partial y)^2 + (\partial F/\partial z)^2} \quad (4)$$

$|A(x,y)|$ is the analytic signal amplitude and F is the observed magnetic field at (x,y) .

2.11 Tilt-angle Derivative (TDR)

The Tilt Derivative (TDR) is produced from the tilt derivative filter. It is used to determine structures, trends, contacts and edges or boundaries of magnetic sources, as well as to enhance both weak and strong magnetic anomalies of the area by placing an anomaly directly over its source, especially at shallow depths by using the theory that the zero contours are the edges of the formation equation (5)

$$HD_TDR = \sqrt{(dT/dx)^2 + (dT/dy)^2} \quad (5a)$$

$$TDR = \arctan(1VDT/HD_TDR) \quad (5b)$$

Where; 1VDT is the first vertical derivative in z-direction, dT/dx is the derivative in x-direction and dT/dy is the derivative in y-direction.

2.12 Radial Average Power Spectrum (RAPS)

Also known as spectral plot was run for depth to top of magnetic sources estimations. The frequency unit is in radians per kilometer (rad/km), the mean depth of burial of the ensemble is given by equation 6 (Oasis Montaj TM help file)

$$z = m/4\pi \quad (6)$$

Therefore, various maps produced through reductions and enhancements were qualitatively and quantitatively interpreted.

2.13 Euler Deconvolution (ED)

Euler deconvolution (ED) is a well-known method to determine the shape of causative bodies from potential field data. Hood uses this method for aeromagnetic data interpretation and demonstrated that, the method is valid for point-pole and point-dipole sources [24]. Thomson elaborated the application of the method to 2D sources and derived the structural indices for several elementary bodies [25]. A group researcher extended the method to 3D and discusses its applicability to gravity anomalies of finite steps and magnetic anomalies of thin dykes and sloping contacts [26]. The Euler deconvolution has emerged as a powerful tool for direct determination of depth and probable source geometry interpretations. The method can locate or outline the confined sources, dykes and contacts with remarkable accuracy. The Euler deconvolution has been widely used in the automatic interpretation model. Usually the structure index (SI) is fixed and the locations and depths (x_0, y_0, z_0) of any sources are found using the equation 7.

$$(x - x_0) \partial T/\partial x + (y - y_0) \partial T/\partial y + (z - z_0) \partial T/\partial z = N(B - T) \quad (7)$$

Where f is the observed field at location $(x, y$ and $z)$ and B is the base level of the field (regional value at the points x, y, z and SI is the structural index or degree of homogeneity [26].

3. RESULTS AND DISCUSSION

The total magnetic intensity map was analyzed and interpreted, in order to delineate and characterize the lithologies and structures in the study area.

3.1 Total Magnetic Intensity (TMI)

The Total Magnetic Intensity (TMI) map (Figure 5) shows positive magnetic intensity value as high as 93.76 nT which dominated the southern with small segment at the western and northwestern part of the map. The high magnetic intensity at the southern part was cut by an intermediate magnetic intensity (68.48 nT to 86.67 nT). The high magnetic intensity corresponds to the Awgu shale and the intermediate magnetic intensity corresponds to the Nkporo shale.

The north, north central and northwestern parts of the study area is dominated by intermediate magnetic intensity. These areas were interpreted as the Asu River Group which comprises the shale, limestone and sandstone. At the central part of the map, fairly low magnetic intensity response (37.38 nT- 68.48 nT) and low magnetic intensity (34.14 nT to 61.40 nT) were identified. These features were interpreted as the carbonaceous shale within the Asu River Group. The low magnetic intensity response is also observed at the northern region of the map with a trend of E-W direction and at the northeastern part showing a trend in same direction. At the eastern and northeastern part of the map there exist low magnetic intensity (34.14 nT to 61.40 nT) and intermediate magnetic intensity (68.48 nT to 86.67 nT) respectively. Both the low and intermediate magnetic intensity correlates with the Eze-aku shale Formation. As it can be seen on the map (Figure 5), faults are observed at the southeastern region of the map showing two major trends, NE-SW and NW-SE trends.

Figure 5: Total Magnetic Intensity (TMI) Image of Abakaliki Sheet 303.

3.2 Reduction to Magnetic Equator (RTE)

The Reduction to equator (RTE) of the total magnetic intensity (TMI) map (Figure 6) shows positive magnetic intensity value as high as 93.79 nT which dominated the southeastern and extended towards the southern and southwestern part of the study area. Similar feature is noticed at the northwestern part of the study area striking NE-SW direction. The north, north central and northwestern parts of the study area is dominated by rocks with intermediate to high magnetic intensity. The intermediate to high magnetic intensity correlate with the Asu River Group within the study area.

The map (Figure 6) shows variation in the magnetic intensity, possibly indicating variations in mineral composition of the rocks in the study area. The central part of the map is dominated by fairly low magnetic intensity (34.14 to 61.40 nT) which can be depicted as the limestone within the Asu River Group (Arls). This feature is also observed at the northern region of the map with a trend of approximately E-W direction and at the northeastern part showing a trend in same direction. Intermediate magnetic intensity (61.40 to 83.63 nT) feature is seen at the southwestern part of the map trending almost in E-W direction. This body with intermediate magnetic intensity is considered as the Nkporo Shale (Nsh). Features with high magnetic intensity (86.63 to 93.79 nT) was observed at the southwestern and southeastern part of the map showing a trend of

NE-SW direction. The high magnetic intensity was observed to correlate with the Awgu Shale (Ash). Low magnetic intensity (29.39 to 34.14 nT) response is seen at the northern part of the area striking almost in E-W direction. It is also identified at the western part of the map trending in the same direction as that of the one at the northern part of the area. This low magnetic intensity corresponds to the carbonaceous shale within the Asu River Group (Arcs).

As it can be seen on the map (Figure 6), three faulting systems, F1-F11', F2-F22' and F3-F33' were observed with trends of NE-SW, E-W and NW-SE direction respectively. According to a study, the variation in trends of the faults was attributed to deeper heterogeneity of the earth crust during the sequence of events at possible opening up of South American and African plate [3,27].

Figure 6: Reduction to Equator of Total Magnetic Intensity (RTE_TMI) Image.

3.3 Regional and Residual Magnetic Intensity (RMI)

The TMI data continued upward to depth of 4 km produced a regional field assumed to have resulted from relatively deep-seated structures. On the regional map (Figure 7), high magnetic intensity (76.97 nT - 80.99 nT) to intermediate magnetic intensity (64.23 nT - 76.97 nT) were observed at the southern part of the map with a trend of approximately N-S direction. At the western, northwestern and northeastern part of the map there exists intermediate magnetic intensity (64.23 nT - 76.97 nT) striking in E-W direction. Low magnetic intensity was identified at the eastern part of the map trending in E-W direction. Clearer image on the general magnetic intensities of the study area is clearly seen on the residual map than what we have on the TMI map because the regional trends have been removed.

The RMI map (Figure 7) displays different magnetic intensity, with most of them trending in E-W and NE-SW directions. Based on the residual map, the rocks in the study area can generally be classified into four (4) major lithologies, (1.) the Asu river Group, (2.) Awgu shale, (3.) Nkporo shale and (4.) Ezeaku shale. The magnetic zone division was based on the intensity of magnetic signatures. On the northern, northwestern part of the map, there exist rocks with high magnetic intensity (12.76 nT- 15.59 nT) which can be regarded as Asu River Group. The high magnetic intensity may be linked with galena and associated minerals which may be present within the study area. Low magnetic intensity (-22.62 nT to -5.22) nT) was observed at the northwestern part of the map. This low magnetic can be attributed to magnetic response coming from deep basement complex within the study area. This feature is noticed to correlate with carbonaceous shale within the Asu River Group. High magnetic intensity (12.76 nT- 15.59 nT) is noticed at the western region of the map which can be considered as the shale within the Asu River Group. At the southern part of the map, high magnetic intensity is observed. This high magnetic intensity is seen to be separated by intermediate magnetic intensity (2.05 nT- 12.76 nT). The high and intermediate magnetic intensity corresponds to the Awgu Shale and Nkporo Shale respectively. Fairly low (-5.22 nT-

2.05 nT) magnetic intensity was observed at the northeastern part of the map and can be interpreted as the Eze-aku Shale.

Figure 7: Residual Magnetic Intensity Image of Abakiliki Sheet 303.

3.4 Automatic Gain Control (AGC)

It gives sensible view of well aligned anomalous structures with positive intensity signals that ranged from 138.46 nT to 141.58 nT and 135.26 nT to 120.44 nT for low anomalous. From the map (Figure 8), high magnetic intensity body can be noticed at the southeastern part. This feature strikes in approximately NE-SW direction. The high magnetic is seen to have been cross cut by fairly magnetic intensity, trending in same direction. The high and low magnetic intensity can be interpreted as Awgu Shale (Ash) and Nkporo Shale (Nsh) respectively. The map is seen to be dominated by intermediate magnetic intensity (136.72 nT - 138.46 nT) which shows a trend of approximately NE-SW direction. At the northern, western and central region of the map, rocks ranging from fairly low (135.74 nT - 136.72 nT) to Intermediate magnetic intensity (136.72 nT - 138.46 nT) was noticed and it can be interpreted as the Asu River Group (Arsh). Small segment of low magnetic intensity was identified at the southwestern part of the map and it correlate with the carbonaceous limestone within the Asu River Group (Arshs). High magnetic intensity was observed at the northwestern part of the map. This feature corresponds with the shale within the Asu River Group (Arsh).

Figure 8: Automatic Gain Control Image.

3.5 Upward Continuation and Downward Continuation Maps

Upward continuation is often used to remove or minimize the effects of

shallow sources and noise in grids. It is basically used to infer the attitudes of structures with depth. Figures 9,10 and 11 show the RTE (grid) upward continued to 500 m, 1 km, 2 km, 3 km, 7 km and 10 km, respectively; i.e. they show images of the magnetic intensity that would be obtained assuming the data were recorded at heights of 500 m, 1 km, 2 km, 3 km, 7 km and 10 km higher than the original datum the data was collected. In physical terms, as the continuation distance is increased, the effects of smaller, narrower and thinner magnetic bodies progressively disappear relative to the effects of larger magnetic bodies of considerable depth extent. As a result, upward-continuation maps give the indications of the main tectonic and crustal blocks in an area [28].

Comparing the Figures, the 500 m upward continuation (Figure 9) shows similar features as seen in the RTE image (Figure 6). Thus the magnetic body that is producing the anomaly may be at a deeper depth other than the 500 m depth. Moreover, comparing the 1 km, 2 km and 3 km upward continuation images (Figures 9, 10 and 11) with the RTE image (Figure 6) and 500 m upward continuation image (Figure 9), it is seen that linear feature at the southern part of the map striking approximately in NE-SW direction in Figures 6 and 9 are not seen in Figures 9 and 11. The linear feature in Figures 9 and 10 at the southern region of the area diminished until it is not visible in the 2 km images (Figure 11). This may indicate that the signature is coming from depth shallower than 2 km.

The positive anomalies displayed by these images at the northwestern is seen to be absent from the 3 km image (Figure 12). On the other hand, on Figure 9 and 10 the low magnetic anomalous (21.09 nT - 33.20 nT) rounded body noticed at the southwestern part is not obvious in the 3 km image.

The upward continuation images Figures 9, 10, 11, 12, 13 and 14 revealed that the regional trend of the rocks in the study area is in NE-SW and E-W direction.

Figure 9: Upward Continued RTE_TMI (500m) Image.

Figure 10: Upward Continued RTE_TMI (1000) Image

Figure 11: Upward Continued RTE_TMI (2000) Image.

Figure 14: Upward Continued RTE_TMI (10000m) Image.

Figure 12: Upward Continued RTE_TMI (3000) Image.

Figure 13: Upward Continued RTE_TMI (7000m) Image

The downward continuation filter enhances responses from shallow depth sources by effectively bringing the plane of measurement closer to the source. However, the data contain short wavelength that appear as signals coming from very shallow sources in the continuation. Figures 15 and 16 shows the RTE (grid) continued downward to 20 m and 50 m respectively. Comparing Figures 5 4.2, 15 4.10 and 16 4.11, the 20 m downward continuation in comparison with the 50 m image shows similar features as seen in both images (Figure 15 and 16). Thus, the magnetic body that is producing the anomaly may be at a depth within the range of 20 m to 50 m depth. Moreover, comparing both the 20 m and 50 m downward continuation images (Figures 15 and 16) with the RTE image (Figure 5). It is seen that the high magnetic intensity (86.87 nT- 92.95 nT) at the western part of Figures 15 and 16 are observed to appear as an intermediate magnetic intensity (64.85 nT- 86.87 nT) on the Figure 5. From the downward continuation map, it is seen that the boundaries of the different formations were not well demarcated compared to the upward continuation. The downward continuation map enables the easy observation of short wavelength anomalies not seen in the original RTE map.

From these maps, structural interpretations were carried out through visual inspection. Two major lineaments/faults systems were identified on these images by observing the abrupt changes between the positive and negative magnetic anomalies. The lineament/faults systems are: F1-F11' and F2-F22' trending NE-SW and ENE-WSW respectively.

Figure 15: Downward Continued RTE_TMI (20m) Image.

Figure 16: Downward Continued RTE_TMI (50m) Image

3.6 Second Vertical Derivative (SVD)

The SVD filter decreases broad and more regional anomalies and rather enhance local magnetic responses which are interpreted as structures in the area.

A grey scale is applied to the second vertical derivative of the RTE map. This helped in the identification of features such as lineaments/faults, contacts, edges and trends of various rocks. The grey scale of the second vertical derivative (SVD) image of the RTE gridded data (Figure 17) enhanced the image by showing major structural and lithological details which were not obvious in RTE image (Figure 5).

Prominent lithological contacts observed are: the Awgu shale (marked as A) boundaries with other Formation. Points B, C and D, highlight areas occupied by Nkporo Shale, the Asu River Group and Eze-aku shale respectively. The Awgu shale boundaries are well defined when compared with other Formations in the area.

3.7 Analytical Signal (AS)

To know the source positions of the magnetic anomaly regardless of direction and remnant magnetization of the sources effects that are mostly associated with the RTE, the analytical signal filter was applied to the RTE grid. The significant characteristic of the analytical signal is that, it is independent of the direction of the magnetization of the source. Moreover, the amplitude of the analytical signal can be related to the amplitude of magnetization. The most significant concentrations of mineral deposits in an area are correlated with high analytical signal amplitudes [28].

Figure 18 (analytical signal map) shows that, the most prominent features are the high analytic signal amplitude that runs in an approximately NE-SW direction along the southeastern part of the area and small segment around the northwestern border of the area. Four major magnetic amplitude zones i.e high magnetic amplitude zone (> 0.03 nT/m) which are defined as Awgu shale (Ash), intermediate magnetic anomalous zone (ranges from 0.02 to 0.03 nT/m) as Asu river Group (Arsh), fairly low magnetic anomalous zone (ranges from 0.01 to 0.02 nT/m) as (Nkporo shale) and low magnetic anomalous zone (< 0.01 nT/m) as Ezeaku shale (Esh), were delineated (Figure 18). These four different amplitude zones are based on the magnetization contrast, produced by varying mineralogy composition and depth of the magnetic sources.

Figure 17: Second Vertical Derivative Image.

Figure 18: Analytical Signal Image.

3.8 Tilt-angle Derivative (TDR)

To determine structures (lineament, fault, joints, etc.), the contacts and edges or boundaries of magnetic sources, and to enhance both weak and strong magnetic anomalies of the area, the Tilt-angle Derivative (TDR) filter was applied to the RTE grid. The TDR filter attempts to place an anomaly directly over its source [29-31]. Structural deformations such as faults, joints, and arched zones are well pronounced on grey TDR map (Figure 19).

From Figure 19, three major fault systems were noticed on this image by observing the abrupt changes between the positive and negative magnetic anomalies. The lineament systems are: F1-F11', F2-F22' and F3-F33' trending NE-SW, ENE-WSW and NW-SE respectively.

3.9 Radially Averaged Power Spectrum (RAPS)

Power Spectrum is a 2D function of the energy and wave number and can be used to identify average depth of source assemblages [18]. Radially Averaged Power Spectrum or Spectral plot (Figure 20) shows the total depth estimate to the top of magnetic sources that produced the observed anomalies in the study area using spectral analysis. The gradient of the layers were calculated based on the wavelength of the magnetic sources. The gradient of the shallower and deeper magnetic sources are 3.51 and 33.15 respectively. Therefore, the total depth estimates to the top of magnetic shallower and deeper sources in the area are 0.279 km (27.9 m) and 2.64 km respectively.

Figure 19: Grey Tilt Derivative Image

Figure 20: Radially Averaged Power Spectrum/Spectral Plot

3.10 Euler Deconvolution

Euler solution was applied in determining the depth to the magnetic sources in the survey area by setting different Structural Index, SI 0.0 (Figures 21). The gridding interval enables recognition of any anomaly that is up to 100 min wavelength, hence many solution points which sum up to 34,595. Result with tightest cluster around recognized sources is likely to give the best solution and therefore accepted [32-34]. Solutions for Abakaliki Southwest regions indicate relatively deep magnetic source, greater than 2000 m in depth as seen underlying Asu River Group at the northern, western and southwestern to southern part of the map and reduced progressively towards southeastern part [35-38]. Euler depths result ranged for regions in the study area such as Abakaliki at the central part of the map (>2000 m).

Figure 21: Standard Euler solutions of Abakaliki Sheet 303.

4. CONCLUSION

The study considered the use of aeromagnetic dataset, to interpret and map the lithological and structural features of Abakaliki (Sheet 303 SW). The aeromagnetic data was subjected to different forms of filtering processes in order to enhance the total magnetic intensity (TMI) data. The magnetic image enhancing filters applied to the Total Magnetic Intensity (TMI) are Reduction to Equator (RTE), analytic signal, Second Vertical Derivative (SVD), Tilt-angle Derivative (TDR), Radially Averaged Power Spectrum (RAPS) and Euler Deconvolution using Geosoft Oasis Montaj package. These filters helped define the lithological boundaries and geological structures such as lineaments, faults, joints, etc. The images have revealed different range of magnetic intensity values, suggesting different rock types of varying mineralogical compositions, tectonic framework and structural features.

The results of the interpretation of the aeromagnetic dataset shows that the study area is dominated by four to five lithology as proven by the total magnetic intensity image, reduction to equator, residual magnetic intensity map, analytic signal image. The lithologies include shale and limestone belonging to Asu River Group, Awgu shale, Eze-aku shale and Nkpore shale.

From the upward continuation maps, it can be concluded that the subsurface geology has regional trend of NE-SW and E-W direction.

The interpreted subsurface Faults; F1-F11, F2-F12, F3-F13 elements delineated in the study area were oriented into three major directions which are NE-SW, ENE-WSW and NW-SE respectively as seen on the tilt angle derivative and second vertical derivative. The total depth estimation to the top of magnetic sources for the study area as shown on the spectral plot ranged from 0.279 km (27.9 m) to 2.64 km for shallower and deeper sources respectively. The aeromagnetic dataset proved valuable in the delineation of most of the lithologies and structures in the study area and estimating the depth to magnetic source body. It serves a valuable tool for characterizing the rock formation in the study area. The varied depth range especially the deeper sources makes the study good for hydrocarbon accumulation but due to diverse intrusive bodies in the study area makes it not viable.

REFERENCES

- [1] Kearey, P., Brooks, M., Hill, I. 2002. An Introduction to Geophysical Exploration. 3rd ed. Blackwell Publishing. 255p.
- [2] Telford, W. M., Geldart, L. P., Sheriff, R.E. 1998. Applied Geophysics, (2 148 Nd Ed), Cambridge University Press, USA, 113 – 114.
- [3] Wright, J.B. 1968. South Atlantic continental drift and the Benue Trough. Tectonophysics, 6, 301 – 310.
- [4] Wright, J.B., Grant, K. 1985. The Benue Trough. In: Geology of mineral resources of West Africa Springer. 98p ISBN 0-04-556001-3.

- [5] Grant, F.S. 1971. Aeromagnetic, geology and ore environments, In: magnetite, in igneous, sedimentary and metamorphic rocks: an overview. *Geoexploration*, 23, 303 – 333.
- [6] Nwachukwu, S.O. 1972. The tectonic evolution of the southern portion of the Benue Trough. *Journal of Geology and Mining Research*, 11, 45-55.
- [7] Olade, M.A. 1975. Evolution of Nigeria's Benue Trough (Aulacogen); a tectonic model. *Geological Magazine*, 112, 575 – 583.
- [8] Petters, S.W. 1978. Stratigraphic Evolution of the Benue Trough and its implication for the Upper Cretaceous Paleogeography of West Africa. *The journal of Geology*, 86 (3), 311-322.
- [9] Olade, M.A. 1979. The Abakaliki pyroclastics of southern Benue, Nigeria: their petrology and tectonic significance. *Journal of Mining and Geology*, 16, 17 – 25.
- [10] Ofoegbu, C.O. 1985. Interpretation of Magnetic anomalies over the lower and Middle Benue Trough of Nigeria. *Geophysical Journal Royal Astronomical Society*, 79, 813-823.
- [11] Benkhelil, J. 1988. Structure. Centres Rech., Explor. Prod. Elf and Geodynamic Evolution of the Intracontinental Benue Basin (Nigeria) *Bull Aquitaine* in 1207, 29-128.
- [12] Ananaba, S.E., Ajakaiye, D.E. 1987. Evidence of tectonic control of mineralization of Nigeria from lineament density analysis: a land set study. *International Journal. of Remote Sensing*, 1 (10), 1445-1453.
- [13] Uzuakpunwa, A.D.B. 1974. The Abakaliki Pyroclastics, Eastern Nigeria: New Age and Tectonic Implications. *Geological Magazine*, 11, 65 – 70.
- [14] Ofoegbu, C.O., Onuoha, K.M. 1991. Analysis of Magnetic Data over the Abakaliki Anticlinorium of the Lower Benue Trough. *Nigeria Journal of Marine Geology*, 45 – 51.
- [15] Ukaegbu, V.U., Akpabio, I.O. 2009. Geology and stratigraphy Northeast Afikpo Basin Lower Benue Trough Nigeria. *Pacific Journal of Science and Technology*, 10518-527.
- [16] Ofoegbu, C.O., Onuoha, K.M. 1990. A review of geophysical investigations in the Benue Trough. In: *The Benue Trough, Structure and Evolution* (Edited by Ofoegbu, C. O.), 171 -201. Vieweg and Sohn, Braunschweig, Germany.
- [17] Obaje, N.G. 2009. *The Benue Trough Geology and Mineral Resources of Nigeria*. Springer, Dordrecht Heidelberg, New York, London P.57 ISBN 3-540-92684-4.
- [18] Spector, A., Grant, F.S. 1970. Statistical models for interpreting aeromagnetic data. *Geophysics*, 35, 293-302.
- [19] Nwachukwu, S.O. 1975. Temperature formation of vein minerals in the southern portion of the Benue Trough, Nigeria. *J. Mineral. Geology*, 11, 45-54.
- [20] Ezema, P.O., Ezech, I.D., Ugwu, G.Z., Abudullahi, U.A. 2014. Hydrocarbon and mineral exploration in Abakikili southeastern Nigeria. *International journal of Engineering Sciences*, 3(1), 24-30.
- [21] Blakely, R.J. 1995. *Potential theory in Gravity and Magnetic Application*. Cambridge University Press, Cambridge. 441p.
- [22] Faboye, F.B., Gideon, Y.B. 2003. Improved downward continuation of potential field data. *Exploration Geophysics*, 34, 249-256.
- [23] Nabighian, M.N. 1972. The analytic signal of two-dimensional magnetic bodies with polygonal cross-section: Its properties and use for automated anomaly interpretation. *Geophysics*, 37, 501-517.
- [24] Hood, P.J. 1965. Aeromagnetic gradiometer program of the geophysical survey of Canada. *Geophysics*, 54, 1012-1022.
- [25] Thompson, D.T. 1982. EULDPH. A new technique for making computer- assisted depth estimate from magnetic data. *Geophysics*, 47, 31-37.
- [26] Reid, A.B., Allsop, J.M., Granser, H., Milette, A.J., Somerton, I.W. 1990. Magnetic interpretation in three dimensions using Euler deconvolution. *Geophysics*, 55, 80-91.
- [27] Ajakaiye, D.E., Hall, D.H., Ashieka, J.A., Udensi, E.E. 1980. Magnetic Anomalies in the Nigerian Continental Mass based on Aeromagnetic Surveys. In: Wasilewski, P and Hood, P. (Eds.), *Magnetic Anomalies-Land and Sea*. Tectonophysics, 192, 211-230.
- [28] Reeves, C.V., Macnab, R., Maschenkov. 1998. Compiling all the world's magnetic anomalies EOS American Geophysical Union, July 14, 338.
- [29] Salem, A., Williams, S., Fairhead, J., Ravat, D., Smith, R. 2007. Tilt-depth method: a simple depth estimation method using first-order magnetic derivatives. *The Leading Edge*, 26, 1502-1505.
- [30] Akingboye, A.S. 2017. Derivatives and Analytic Signals: Improved Techniques for Lithostructural Classifications. <https://www.researchgate.net/publication/321341519>, pp. 1-14.
- [31] Okpoli, C.C., Oladunjoye, M.A. 2017. Precambrian Basement Architecture and Lineaments Mapping of Ado-Ekiti Region Using Aeromagnetic Dataset. *Geosciences Research*, 2 (1), 27-45.
- [32] Barraclough, D.R., Malin, S.R.C. 1971. Synthesis of International Geomagnetic Reference Field Values. *Inst. Geol. Sci. Rep.*, 71 (1), 24-36.
- [33] Kearey, P., Nabighian, M.N., Grauch, J.S., Hansen, R.O., LaFehr, T.R., Li, Y., Peirce, J.W., Phillips. 2003. The historical development of the magnetic method in exploration. *Geophysics*, 70, 33ND-61ND.
- [34] MontajTM Tutorial. 2004. Two – Dimensional frequency domain processing of potential field data.
- [35] Milsom, J. 2003. *Field Geophysics(3rdedn.): The geological field guide series*. John Wiley & Sons Ltd., John Milsom University College, London, 51-70.
- [36] Mussett, A.E., Khan, M.A. 2000. 11 Magnetic surveying. Looking into the earth; an introduction to geological geophysics (1. Publ., repr. Ed.) Cambridge university press. pp. 162-180. ISBN 0-521-78085-3.
- [37] Obaje, N.G., Wehner, H., Abubakar, M.B., Isha, M.T. 2009. Nasara-I will, Gongola basin Benue Trough Nigeria; source-rock evaluation. *Journal of Petroleum*, 27 (2), 191-206.
- [38] Reilly, W.I. 1972. Gravitational expression of the Dunedin volcano. New Zealand. *Journal of Geology and Geophysics*, 15 (1), 16-21