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Evaluation of aeromagnetic data for delineation of geological structures in earth tremor area in parts of Kaduna State, Nigeria

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ABSTRACT

This work utilized two high resolution sheets of aeromagnetic data obtained from the Nigerian Geological Survey Agency (NGSA), to delineate the geological features responsible for earth tremor occurrences in parts of Kaduna State. The total aeromagnetic data was separated into regional-residual anomalies. On the residual aeromagnetic data, filtering action, such as the directional derivative, reduction to pole, upward and downward continuation at 10 km were applied and this gave rise to various qualitative maps depicting subsurface geological structures trending in the NE-SW, NW-SE, N-S, E-W, NNE-SSW and NNW-SSE directions. Six distinct lithologic boundaries were delineated on the residual aeromanetic map.These tectonic trends, particularly the NE-SW trends

represent lineaments, fractures, faults and shear zones controlled by volcanism. These geological features are the possible cause of the occasional earth tremors experienced within the study region.

Keywords: Earth tremors; Aeromagnetic data; Geolocical features; Basement complex

1. INTRODUCTION

Earthquakes and tremors are natural disaster with great or little devastating impact on the environment, economy and human life. Hence, it is very vital to understand the actual causes and consequently predict and mitigate their imparts. Though it is impossible to curb such sub-surface tectonic activities, there is a need for inhabitants in areas prone to these disasters to be well prepared and equipped for any probable occurrence. The investigation of the geologic features using appropriate geophysical prospecting methods would help to predict actual causes of earthquake in any region. Earthquakes originate from the rapid release of accumulated strain stored in the rocks, resulting in movement along a fault, but in some earthquakes, the connections with faulting are difficult to ascertain.

Knowledge of subsurface structures is very important in evaluating the cause of an earthquake and earthquakes. The magnetic method is very important for such research (Hassoup et al., 2009). The study area experienced an earth tremor in August 7, 1847 (Fayoum earthquake). Nigeria has been known as a seismically stable Country with no trace of earth quake but few earth tremors have occurs in some places. Geophysical methods such as seismic, gravity and magnetic techniques are widely used for the investigation of the subsurface. These methods are also used for investigating the geological features responsible for earthquakes in most places.

Aeromagnetic data can be interpreted qualitatively or quantit atively. The qualitative interpretation of the aeromagnetic maps, aims to get a clear view of the subsurface structures. It also involves the description of anomalies, with respect to their symmetry, extension, width, and amplitude (Nettelton, 1976).

Some researchers have carried out studies on the possible causes of these earth tremors (Tshala et al., 2015; Sykes 1978; Anifowose et al., 206). Eze et al. (2011) in “Mechanical model for Nigerian intraplate earth tremors” studied 15 recorded seismic events in Nigeria, examining the possible trigger mechanisms for these tremors. A regional stress formed by the Congo Craton and the West African Craton with an inferred primary stress acting W, NWE, SE was seen as the possible trigger of the intra-plate tremors. They also suggested the zones of weakness and inhomogeneities in the crust, which originated from past magmatic intrusions and other tectonic activities as possible sources of the Nigerian seismic events.

Akpan et al. (2014) investigated the earth tremor which occurred on 11th September, 2009 in the southwestern part of Nigeria. They proposed that the earthquake was a reactivation of a buried high-angle fault in the Precambrian basement shown by the existing NE-SW trending regional horizontal compressive stress and related the seismic activities of the area to the Atlantic fracture zones. Onuoha (1988) attributed the causes of earth tremors within Nigeria to the zones of weakness and regional stress in the crust or transfer of stress from plate and not the fracture zones extending from the Atlantic Ocean. The objective of this research is to determine the geologic features responsible for the earth tremor occurrence in2016 in parts of Kaduna State, Nigeria.

Geology of the study area

The study area is within Jaba local government area in Kaduna state, Nigeria. It lies between lat 9.0^0 – 9.5^0N and long $7.5.0^0$ – 8.5^0E within the North Central Nigerian Precambrian basement complex (Figure 1). Oyawoye (1965), subdivided the Basement Complex rocks in Nigeria into three major groups which he described as (a) the older metasediments, (b) the migmatite, gneissess and the older granites, (c) the younger meta-sediments. Obaje (2009), recognized the following petro-lithogical unit within the Nigerian Precambrian Basement complex; Migmatite-Gneiss Complex (MGC), Schist Belts Marbles, Older Granites, and the basic dyke.

Kaduna consists of the Migmatite – Gnesis Complex (Obaje, 2009). This rock unit is considered as the *sensu strict* of the basement complex (Dada, 2006 and Akano et al., 2015). MGC comprises of migmatites, paragneisses, orthogneises, and a series of basic and ultrabasic rocks which have been metamorphosed. Obaje (2009) stated that Migmatite - Gnesis Complex ranges from Pan –African to Eburnean in age.

According to Olaniyain et al. (2010) most authors who have worked on Nigerian basement complex are of the view that the MGC rocks consist mainly a sedimentary series with associated minor igneous rocks transformed by metamorphic, granitic and migmatitic processes. Abraham et al. (2014) stated that most Nigerian crystalline basement rocks have experienced various deformations of diverse intensities throughout the geologic periods. Omeje et al. (2012), on “investigation of the structural features of the triple junction area of the upper Benue trough, Northeastern Basement complex of Nigeria” observed the presence of the NE-SW structural trend which is an evidence that the basement region is polygenetic, and has experienced magmatism, metamorphism and structural deformations.

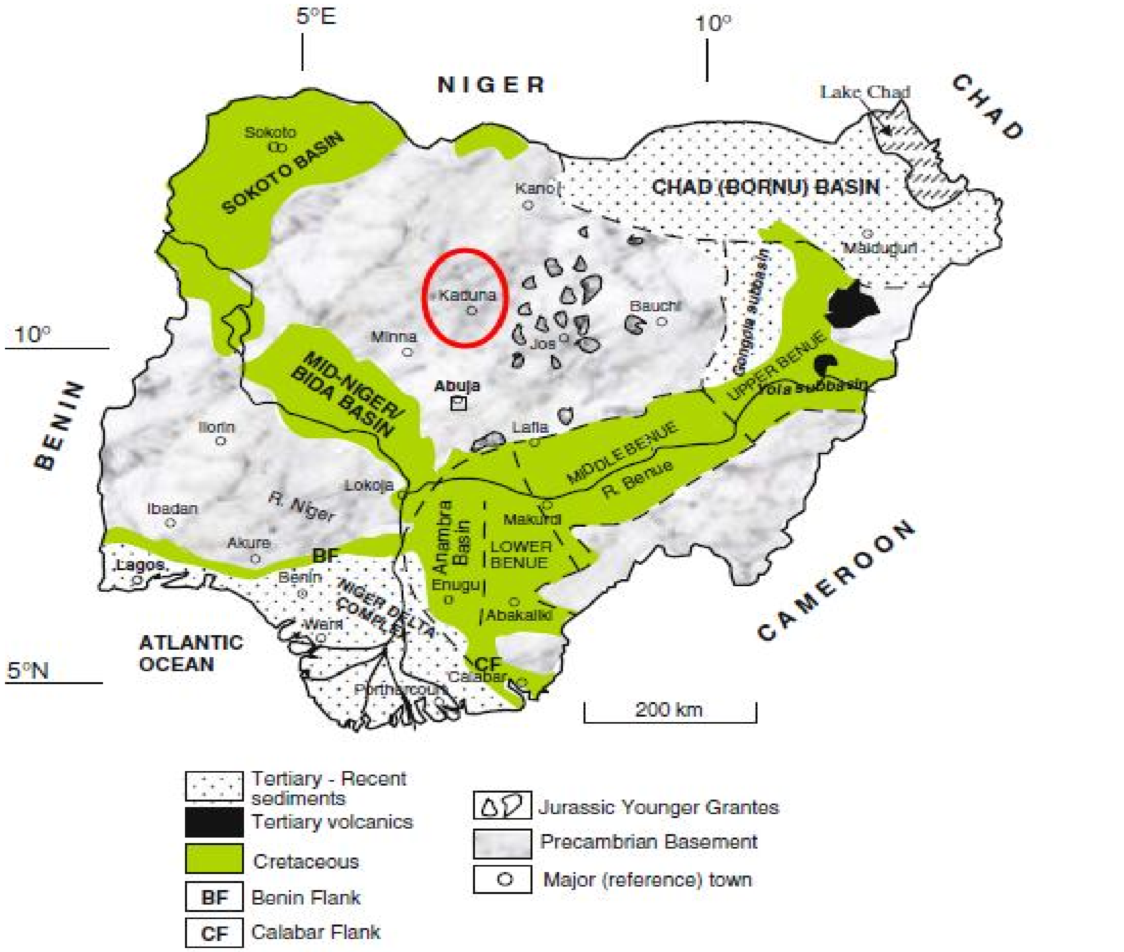

Figure 1 A sketch of Nigerian map showing the geology of the study region (Obaje,2009).

Nigeria is not situated within the key seismic region, but some parts of the country (including the study area) have witnessed minor earthquakes or tremors over the years (Ajakaiye et al., 1987). The occurrence of earth tremors within the basement complex of Nigeria generated much interest because the region is assumed to be tectonically stable. Ajakaiye et al. (1986) attributed the causes of seismic events in Nigeria to the position of Earth movements linked with the zones of weakness and the NE-SW fracture extending from the Atlantic Ocean to the onshore part of Nigeria.

2. MATERIALS AND METHODS

This study utilized two sheets of digitized high resolution aeromagnetic data obtained from the Nigerian Geological Survey Agency (NGSA). The data sets were obtained at flight line spacing of 500 meters, tie line spacing of 2 km and flight clearance of 100 meters in the NE-SW flight line direction. The aeromagnetic maps were processed and analyzed using Oasis Montaj software. The aeromagnetic dataset was acquired and presented with a scale of 1:100000 as a total magnetic intensity field map by the NGSA. However, the gridded aeromagnetic map was re-gridded using a scale of 1:3.647103 in order to get a high resolution data for easy visualization.

During the processing, various enhancement techniques were applied to the data set to aid interpretation.However, before the enhancement techniques were applied the two sheets of the aeromagnetic data were joined together using the knitting tool of the Montaj software to form a composite map (Figure. 2). On the composite map, regional–residual separation was applied after which filtering actions were carried out on the residual maps. Subsequently,filtering, enhancement technique channels were then generated from the residual channel. The following qualitative enhancement techniques were carried out on the residual aeromagnetic data.

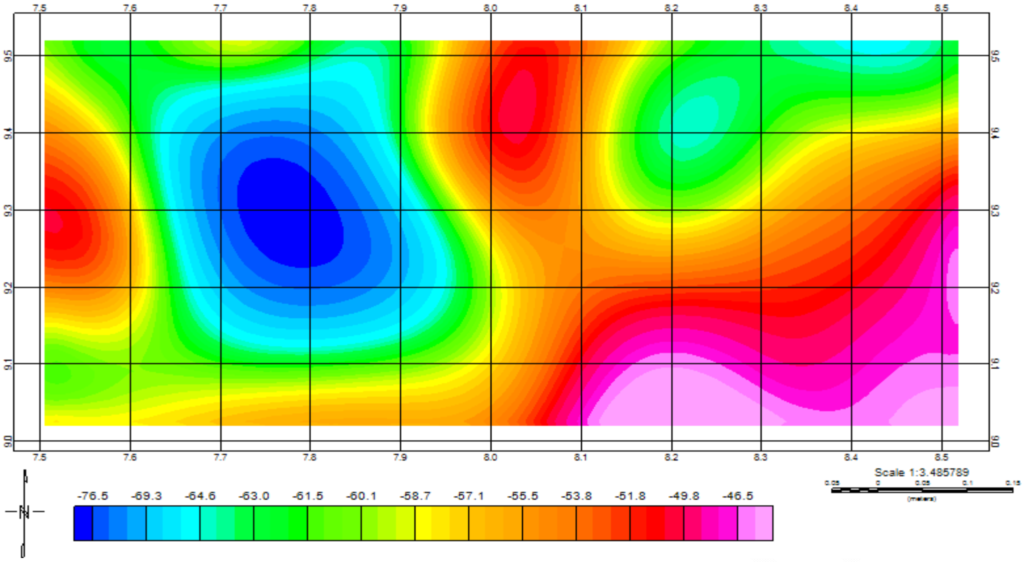

Figure 2 Total aeromagnetic intensity composite map of the study area (nT)

Regional and Residual Separation

For purpose of obviating the influence of the deep and shallow seated magnetic sources, regional-residual separation was applied on the datasets. In order to carry out regional-residual separation, the composite map was digitized into X, Y and Z channels. Regional-residual separation was applied on the principal Z channel by means of polynomial fitting of degree two (2). Consequently, the regional and residual channels were generated.

First Vertical Derivative

First vertical derivative filtering technique was applied on the residual data so as to highlight shallow related causative sources with lesser noise effect. Gunn (1997) proposed that the first vertical derivative of the anomalous bodies should be calculated using the equation;

$$A^i(f) = A(f).(if)^n \qquad 1$$

Where

$A^i(f)$ = amplitude at a frequency after filtering

$A(f)$= corresponding amplitude before filtering

$$i = \sqrt{-1}$$

n = 1

First Horizontal Derivative

First horizontal derivative filtering action was applied to the residual in order to make obvious lateral zones of interest that correspond to shallow related features. The first horizontal derivative is given as (Kearey, 2002):

$$HGM = \sqrt{(\frac{\partial M}{\partial x})^2} + \sqrt{(\frac{\partial M}{\partial y})^2} \qquad 2$$

Where

HGM = horizontal gradient magnitude

$\frac{\partial M}{\partial x}$ = the rate of change of magnetic field with respect to the x axis

$\frac{\partial M}{\partial y}$= the rate of change of magnetic field with respect to y axis

Downward Continuation

Structural features relating to shallow features can be highlighted using downward continuation. Martinec (1996) stated that the downward continuation can be expressed as:

$$D_c = \frac{R}{4\pi(R+H_i)}\sum_j K_{ij}\Delta g_j^g + F_{\Delta g} \qquad 3$$

Where

D_x = downward continuation

g = the geoid

i and j = the respective computation and integration points

Hi = height of a computation point

Kij = the kernel coefficients

$F_{\Delta g}$ = represents the contribution outside the chosen near-zone cap called the far-zone contribution.

Upward Continuation

Basement related structures could have possibly contributed to the magnetic intensity within the study area, hence the need for upward continuation filtering. Discrimination of the regional (or the deeply seated causative sources) from the residual (or the shallow related sources) can be observed when the upward continuation filter is applied. The upward continuation equation is given as;

$$U(x,y,z_o-\Delta z) = \frac{\Delta z}{2\pi}\iint_{-\infty}^{\infty}\frac{U(x^I,y^I,z_o)}{[(x-x^I)^2+(y-y^I)^2+\Delta z]^{\frac{3}{2}}}dx^I dy^I, \qquad 4$$

$$Where \Delta z > 0$$

Equation 4 which is measured on a level $z = z_o$ at point $P = (x,y,z_o - \Delta z)$ governs upward continuation filtering action. Applying the Fourier convolution to equation 4, we obtained

$$\mathcal{F}[U_u] = \mathcal{F}[U]\mathcal{F}[\psi_u] \qquad 5$$

Where

$$\psi_u(x,y,\Delta z) = \frac{\Delta z}{2\pi(x^2+y^2+\Delta z^2)^{\frac{3}{2}}} \qquad 6$$

Equation 6 is the analytical expression of $\mathcal{F}[\psi_u]$ and $\mathcal{F}[U_u]$ is the Fourier transform of the upward continued field. Mathematically,

$$\mathcal{F}[U_u] = e^{-\Delta z|k|}, \qquad 7$$

Where

U_u = Upward continuation at the initial level

ψ_u = Upward continuation at a new level

and $\Delta z > 0$

3. RESULTS AND DISCUSSION

The aeromagnetic data grid consists of colour contrast that varies from blue, green, red, yellow and the magenta. The aeromagnetic map of total intensity exhibits some positive (red colored) and negative (blue colored) anomalies, and reveals a prominent negative feature, as a circular shape, located at the western part of the study area. The eastern part of the map is occupied by a magnetic zone majorly positive.

The colour contrast indicates magnetic field changes, either due to difference in basement morphology, lithology or magnetization contrast of the anomalous sources. Two magnetic zones (units) were distinguished based on colour differences observed on the generated maps.

Regional Aeromagnetic Map

Figure 3 shows the regional aeromagnetic map of the study area. Smoothened and elongated regional trends are evident in the regional aeromagnetic data. The smoothness of the contours indicates that magnetic causative sources are within the basement while the elongated regional trends indicate that the anomalies are of deeper origin. The regional-map highlights low frequency component regions having NE-SW tectonic trends. The regional values range between -66.8 nT and -47.8 nT.

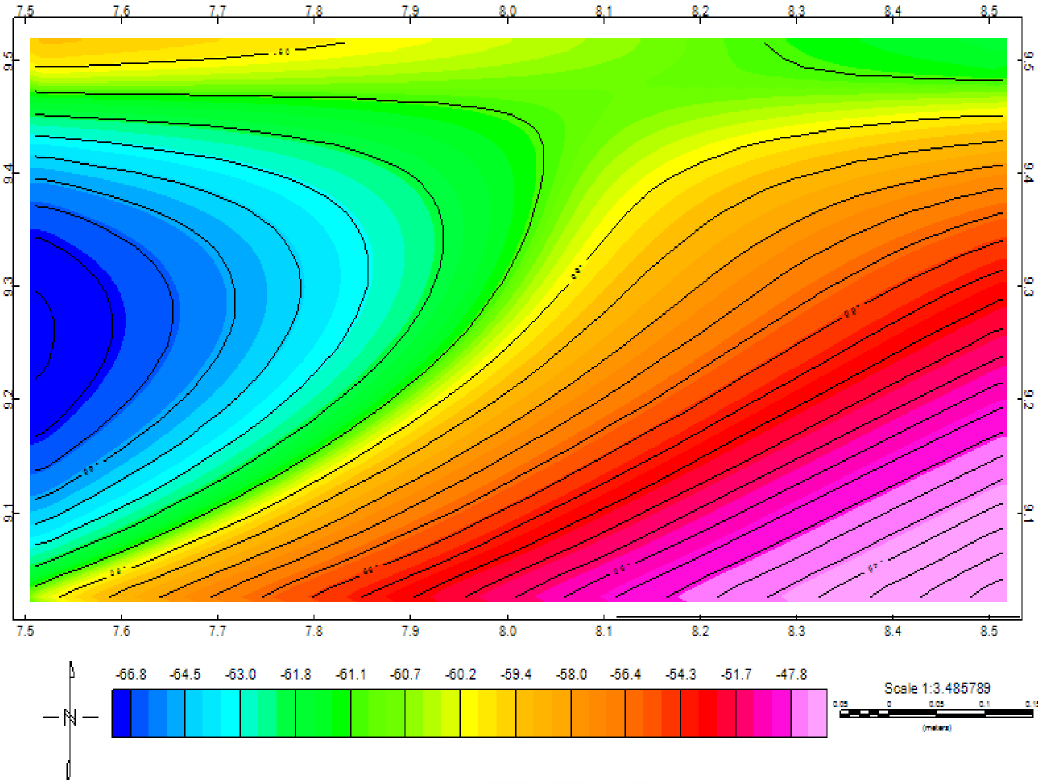

Figure 3 The regional aeromagnetic map of the study area (nT)

Contours within the high anomalous zones (red and magenta), are linear and they occur in the southeastern region of the study area with NE-SW directional trend. The contours of low magnetic zones are semi elliptical shape and they are also trending in the NE-SW direction. The magnetic low zones are visualized at the northwestern part of the study area.

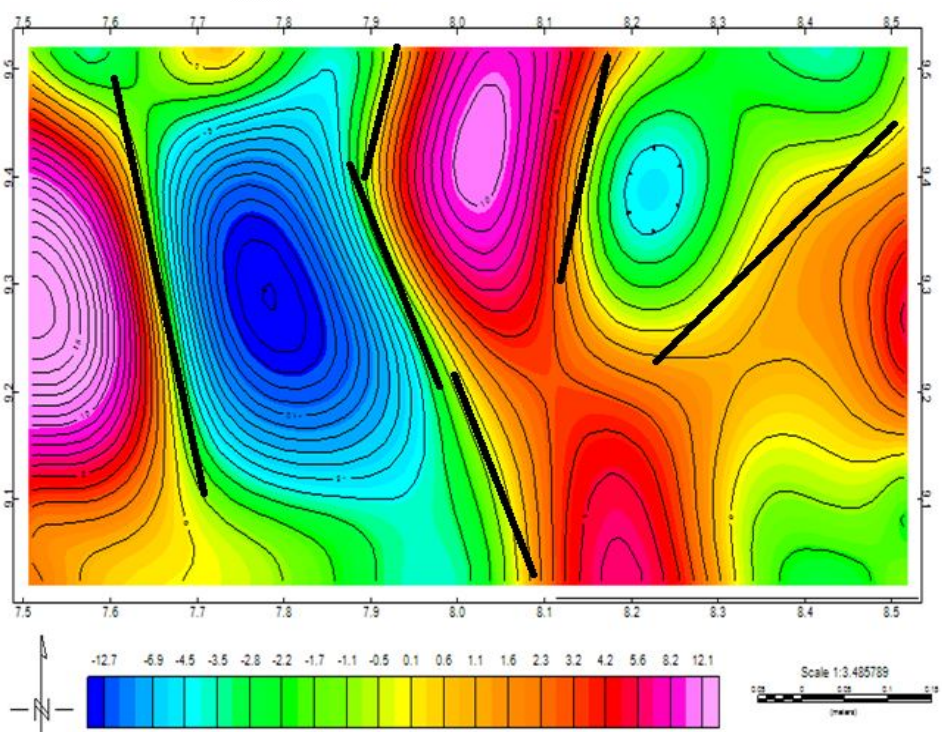

Figure 4 The residual aeromagnetic data

Residual Aeromagnetic Map

The residual aeromagnetic map (Figure 4) exposes high wave number component of the resultant field as exemplified by the closeness of the signatures. Various configurations are delineated in the residual map. Very obvious on the map are closed and linear signatures. These contours are of high amplitude and short wavelength. A low (blue colour) magnetic portion occurs in the middle section of the western portion of the map.

This low magnetic value occurs within the closed elliptical structure. Low magnetic zone with faint blue colouration, which lies within an elliptical structure can also be observed at the northeastern portion. These zones consist of negative magnetic values. High magnetic values occur in the western, northern, eastern and southeastern portions of the map. These magnetic high zones are denoted with the yellow, red and mangenta colours.

The positive residual anomalous values (yellow, red and magenta colouration) on the residual map are interpreted as high magnetic relief on the total magnetic field map. In a similar vein, the low magnetic relief areas are associated with negative anomalies (blue and green colouration). The positive residual values fall within 0.1 nT to 12.1 nT with an average value of 3.55 nT while the negative residual values ranges from -12.7 nT to -0.5 nT with an average of -4.45 nT. The positive values occupy about 80 percent of the study area while the remaining 20 percent is dominated by the negative values. Zones having negative values are regions with low magnetization contrast while zones with positive values are areas of high magnetization. It can therefore be inferred that the region has been prone to magmatic activities induced by tectonics. The magnetic signatures trend in the NE-SW and NW-SE directions. Lithologic boundaries trending in the NNE-SSW and NNW-SSE directions were delineated on the map.

First Vertical Derivative Map

Figure 5 is the first vertical derivative map showing expressions of shallow causative sources. Synonymous anomalous signatures are observedin the first vertical derivative and the residual maps except the signatures located within eastern portion of the maps. Circular signatures are obvious within the eastern part of the first vertical derivative map unlike that observed on the residual map. Ghazala (2003) suggested that such circular contours are due to lithological variations of mafic ultramafic rock type. The circular contours which are surrounded by high magnetic values are interpreted to be an indicator of magnetic aureole by Gunn (1997). He explained further that such region is prone to high tectonics. Accumulation of magnetite formed during tectonic activity in the area could have led to such circular anomalies. Spaced contours are farther from the magnetic aureole. These anomalies have a strike orientation of NNE-SSW, NNW-SSE and E-W directions, but with the former two dominating. The magnetic field values for the first vertical derivative map ranges between -48.1 nT and 121.8 nT with an average value of 47.7 nT.

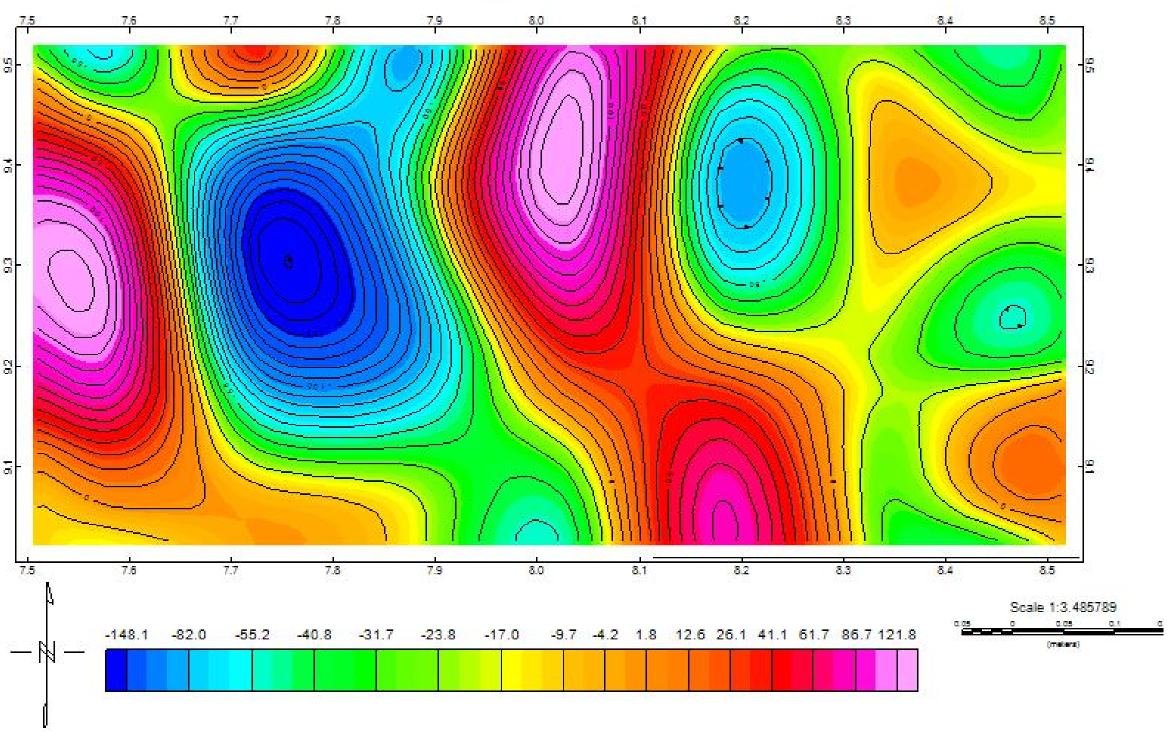

Figure 5 The first vertical derivative aeromagnetic map of the study area (nT)

Upward Continuation Map at 10 km

In the upward continuation map (Figure 6), elongated regional trend running from the east to west is delineated. The elongated regional tectonic trend is typical of deeply seated sources. The anomalies observed on the upward continuation map are synonymous to that on the regional aeromagnetic map. The regional contours strike in the E-W direction which coincide with litho-tectonic domains (Jiakang and Igor, 2005). Regional aeromagnetic values of the upward continuation range between 0.2 nT to 6.0 nT with an average value of about 2.65 nT.

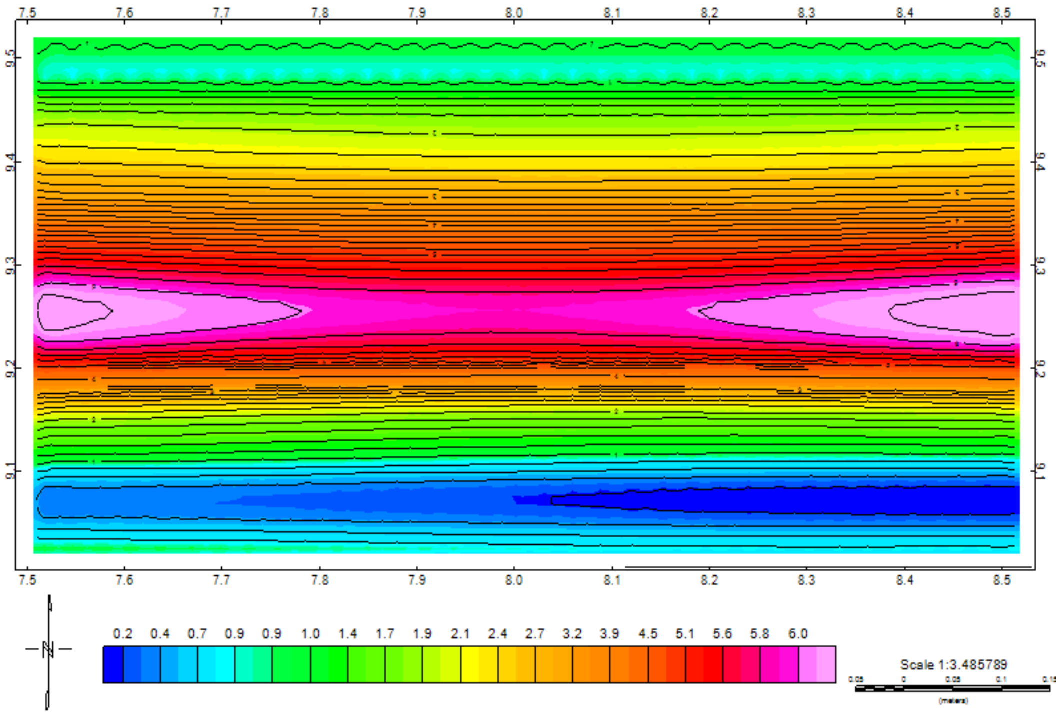

Figure 6 The upward continuation map of the study area (nT)

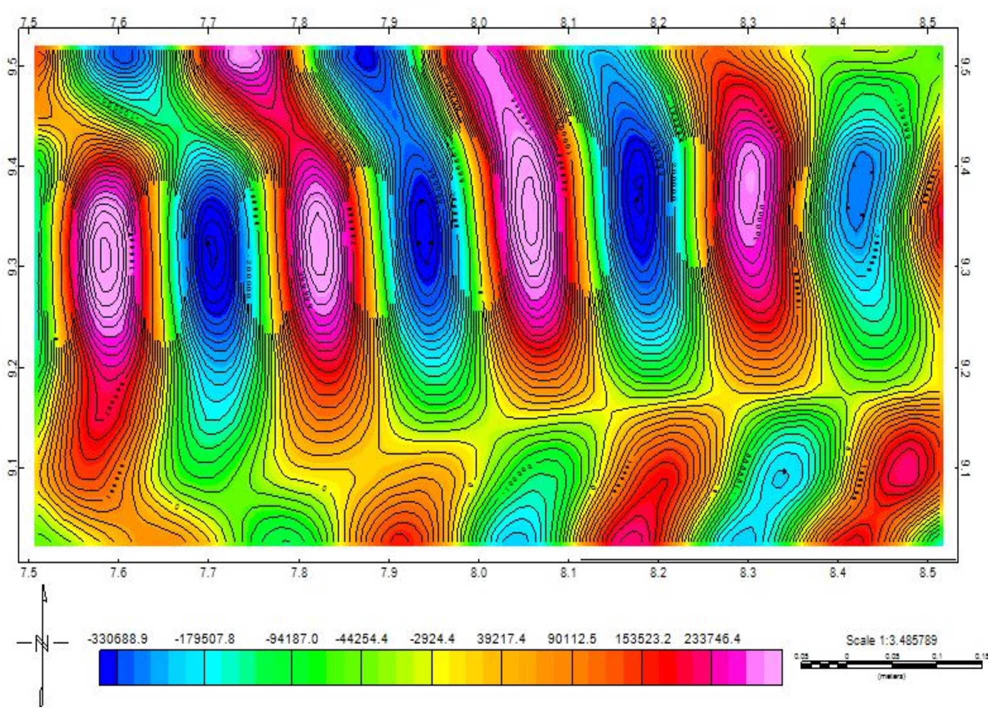

Figure 7 Downward continuation map of the study (nT)

Downward Continuation Map at 10 km

Unlike the upward continuation map, the downward continuation map (Figure 7) shows shallow sources that are of interest. Closely packed contour patterns are observed on the map. Obvious on the map are numerous dykes like structures with anomalous values ranging from -330688.9 nT to 233746.4 nT and trending in N-S direction. However, most of the dykes have NE-SW trends.

Horizontal Derivative Map

The horizontal derivative map (Figure 8) attenuates deeply seated sources and it provides sources whose wavelengths are short with sharp edges. Smoothened anomalies are visible on the map. Similarly, at the eastern portion of the map are circular anomalies that are classified as high magnetic zone. The anomalies which generally trend in the NW-SE, NNE-SSW and E-W directions have values ranging from -159.1 nT to 100.8 nT.

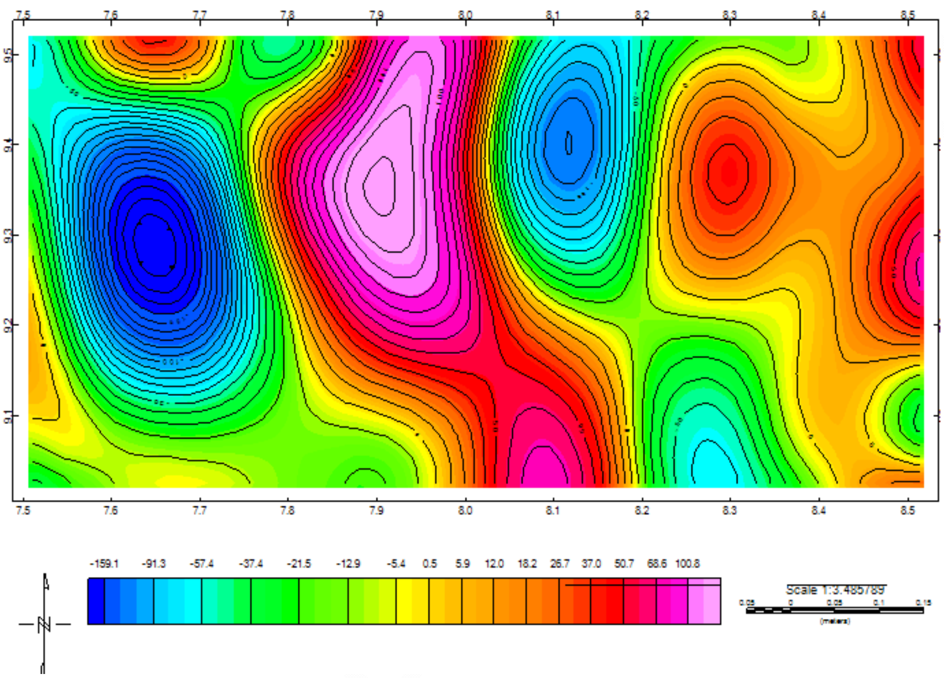

Figure 8 First horizontal derivative map of the study area (nT)

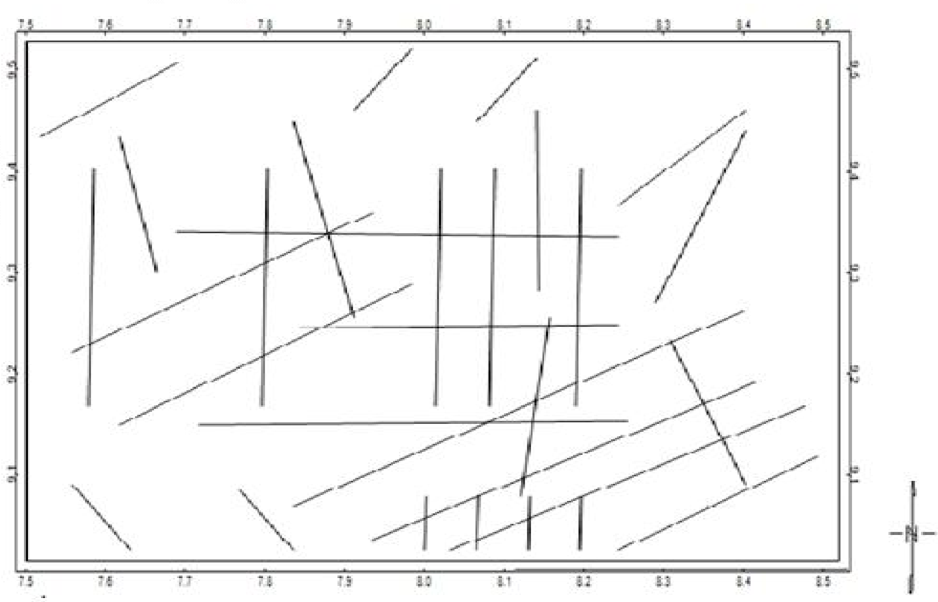

Figure 9 Lineament map of the study area

Lineament Map

The lineament map (Figure 9) reveals several lineaments traces prevailing in the area. The map highlights basically four trends of linear features, namely: E-W, N-S, NNW-SSE and NE-SW tectonic. These trends expose those fault and fracture zones expressed as litho tectonic trends. Majority of the lineaments are of regional extent. Onyewuchi (2011) opined that Pan African is characterized by NNW-SSE tectonic trends. He further stated that the NE-SW tectonic trends are possible shear zones and fractures controlled by volcanism. These NE-SW volcanic trends are the possible sources of the earth tremors observed within the study area. They can be linked to the NE-SW fractures extending from the Atlantic Ocean into the precambian basement of Nigeria.

4. CONCLUSION

This research work examines geological structural features and their relation to the occurrence of earth tremors in the study area, using high resolution aeromagnetic data. In order to understand the tectonics that is peculiar to the study area, filtering and transformational techniques were applied on the datasets. Structural trends representing the tectonics of the study area were observed to strike in the N-S, NE-SW, NW-SE, E-W, NNE-SSW and NNW-SSE directions, but with the N-S, NE-SW, NNE-SSW and NNW-SSE dominant. These tectonic trends are possible evidence that the study area has been subjected to tectonic deformations as a result of magmatism, or metamorphism. The NNE-SSW and NNW-SSE structural trends are possible indication of the Pan African Oregeny existing within the area. The possible trigger mechanism for the tremors are linked to the NE-SW tectonic trends representing the possible shear zones, faults and fractures controlled by volcanism. These tectonic trends are associated with the NE-SW fractures and zones of weakness extending from the Atlantic Ocean to the Precambrian basement of Nigeria.

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