DELINEATION OF SESIMIC-PRONE AREAS IN PARTS OF NORTH CENTRAL NIGERIA USING HIGH RESOLUTION AEROMAGNETIC DATA

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ABSTRACT

Qualitative analysis of Aeromagnetic data of parts of north central Nigeria had been carried out with the aim to delineate seismic prone areas. The study area is bounded with latitude 9. 00^o to 10. 00^o N and longitude 7.00^o to 9.00 ^{o}E with an estimated total area of 24, 200 km^2. Vertical derivatives and upward continuation filters were used to enhances long wavelength anomalies which could give preliminary information about the magnetic structures present in the study area. The total magnetic intensity map shows both positive and negative anomalies with susceptibility ranging from 33487.7 nT to 33800.9 nT. The high magnetic susceptibilities dominated in the basement region around the north-eastern and north-western parts of the study area which corresponds to Naraguta, Jemma and Kafanchan area. Based on the geology of the area this is attributed to granite, schist and migmatite rocks. The low magnetic values are made of sediment deposition also dominates the south-western part of the study area, corresponding to Abuja and Gitata. The area with magnetic susceptibility values ranging between 33506.6 nT and 33653.8 nT indicates alluvium deposite around Bishini and Kachia area. Lineament from First Vertical Derivative trend in the northeast-southwest and east-west directions, which is an extension from Romanche Fracture Zone. Majority of this lineament trends in the same directions as the Romanche Fault Line which continues at 25 km and 30 km into n inferred closure within the study area which is trending along north-west direction. This, closure occurs probably because of the existence of the paleo fracture zone (Romanche Fracture Zone) within the study area. At 40 km and at 80 km a regional trend in the NE-SW direction in (porphyritic) basement rocks were observed. At the northeast and southeastern part of the area which is made up of basement complex that corresponds to areas around Kafanchaan and Jemma are prone to tectonic activities while the southwestern part of the area around Abuja is seismic free. It is suggested that those lineaments identified, most especially at the southeastern part could be the reason for the shaking of the subsurface which result into earth tremors.

Keywords: CET, vertical derivative, IGRF, upward continuation

1. Introduction

Detailed Investigation of subtle, critically-stressed geological structures within earthquake prone areas are important because unexpected rupture along such structures typically result in devastating earthquakes. Earthquake is the sudden release of built-up elastic energy caused by movement of rocks along a fault. Most earthquakes occur along the fault lines when the plates slide past each other or collide against each other. Any shaking suffered by the earth which does not result in widespread devastations is regarded as Earth Tremor. Earthquake is a global phenomenon experienced in many regions of the world; it is classified as one of the most devastating natural disasters that pose threat and has the capability to impact negatively on both human lives, economy and the built environment. (Oluwafemi *et al.*, 2018). Some of the causes of earthquake or Earth tremors are rupturing and shifting of rocks at tectonic boundaries, volcanic eruptions, landslide induced seismicity, mining-induced seismicity, underground nuclear explosions and nuclear tests (Thorne and Terry, 1995). Other activities carried out on land surface can also stimulate earth tremor some of these activities include drilling of boreholes and erection of heavy buildings (Shannon *et al.*, 2013). The first widely reported occurrence of an earth tremor in Nigeria was in 1933 at Warri (Oluwafemi *et al.*, 2018). Similar events were reported in 1939, 1963, 1964, 1984, 1990, 1997 2000, 2006 (Akpan and Yakubu, 2010). Recent seismic events in Kwoi town in Kaduna State (2016), Abuja (2018) and Ifewara (2019) are probably suggesting that the stable shield is gradually transiting into unstable one (Adepelumi, 2019). All the seismicity that has ever happened in Nigeria and West Africa is earth tremors (Osazuwa, 1985). The study area comprises parts of North Central Nigeria which recently had earth tremors. Therefore, there is need to carefully monitor those activities that have the potential to trigger earth tremors in Nigeria by carrying out a detailed investigation of the cause of earth tremors using a geophysical technique to identify the major fault zones and other features that are responsible for the tremors using the magnetic method. The magnetic method which is the method adopted for this study involves the measurement of the earth's magnetic field intensity. Measurements of the horizontal and vertical magnetic field. Aeromagnetic survey is a powerful tool in delineating regional geology (lithology and structure) of buried basement terrain. Aeromagnetic surveying is rapid and cost effective, typically costing some 40% less per line kilometer than a ground survey (Kearey and Brookes, 1991). Vast areas can be surveyed rapidly without the cost of sending a field party into the survey area and data can be obtained from areas inaccessible to ground survey.

2. Location and Geology of the Study area

The area where this study was carried out is located in Nigeria, central part of West Africa, situated within the North Central part of Nigeria bounded by latitude 9. 00^o to 10. 00^o N and longitude 7.00^o to $9.00\ ^o$ E with an estimated total area of 24, 200 km^2. The study area lies entirely within the Basement complex Terrain of Nigeria. It comprises rocks of the migmatite-gneiss and schist and generally intruded by the Pan African Older Granite rocks (Obaje, 2009). Migmatites are the most predominant rock types which almost covered the entire area with the undifferentiated Schists phyllites that occur around NE-SW of the study area with the Basaltic rock that intruded into the porphyritic granite, coarse porphyritic biotite and biotite homblende granite rock around the NE portion of the map. Younger Basalt are found at the NE part of the map with isolated occurrence of other types of rocks which are undifferentiated older granite, Dolerite, Granite Gnesis, medium to coarse grained biotite granite. The structural elements in the study area include faults, lineaments from magnetic data. Some of the faults lines on the map are deep- seated in origin and ancient in age and was as a result of thermotectonic deformational events mostly of the Ebumean and Pan- African Orogeny.

The domain structural trend in the basement is essentially NE- SW and follows the tectonic grain of the schist belt. Widespread fracturing occurs throughout the area and follows the orientation of the major faults generally intruded by the Pan African older Granite rocks, like Biotite Granite, medium- to coarse- Grained Biotite Granite, undifferentiated granite, migmatite and Granite, Gneiss older Granite, Migmatite porphyroblastic and porphyritic Granite/coarse porphyritic biotite and biotite homblende granite. The rocks of the study area have under gone various episodes of deformation and have ages ranging from Precambrian to Pan African; the Basaltic rocks are the intruded rocks that have very high magnetic susceptibility. The Geology map of Nigeria showing study area is presented in Figure 1, Figure 2 is the generalized geological map of the study area, the Transatlantic Fault map is presented in Figure 3 and Figure 4 is the Geological Structural Map of the study area.

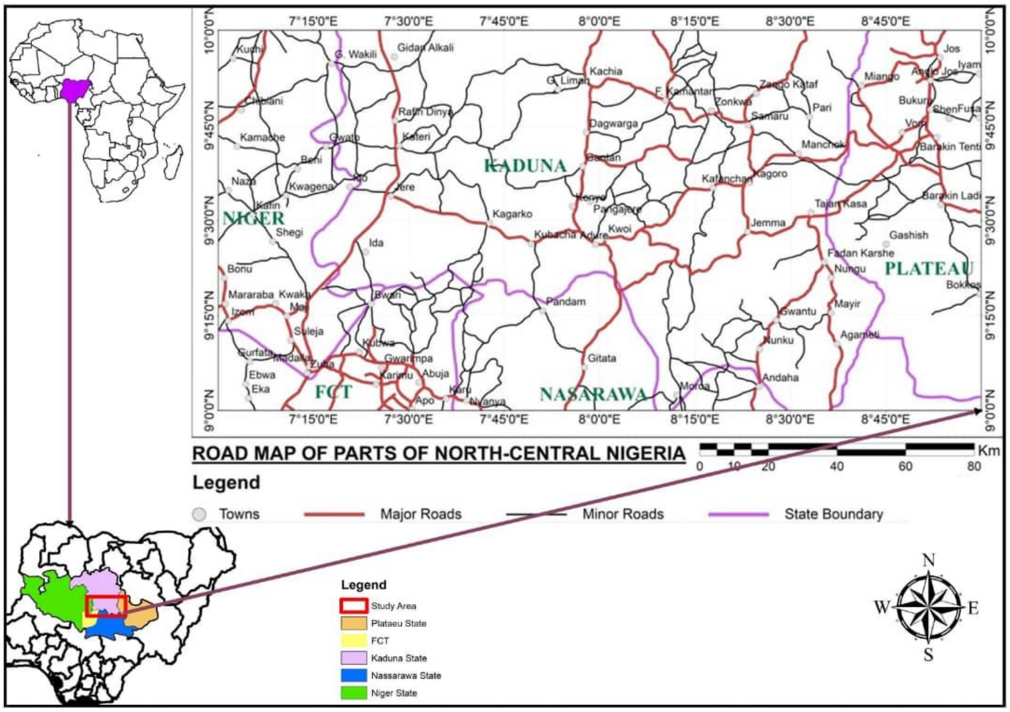

Figure 1: Geology map of Nigeria showing Study area (NGSA 2006)

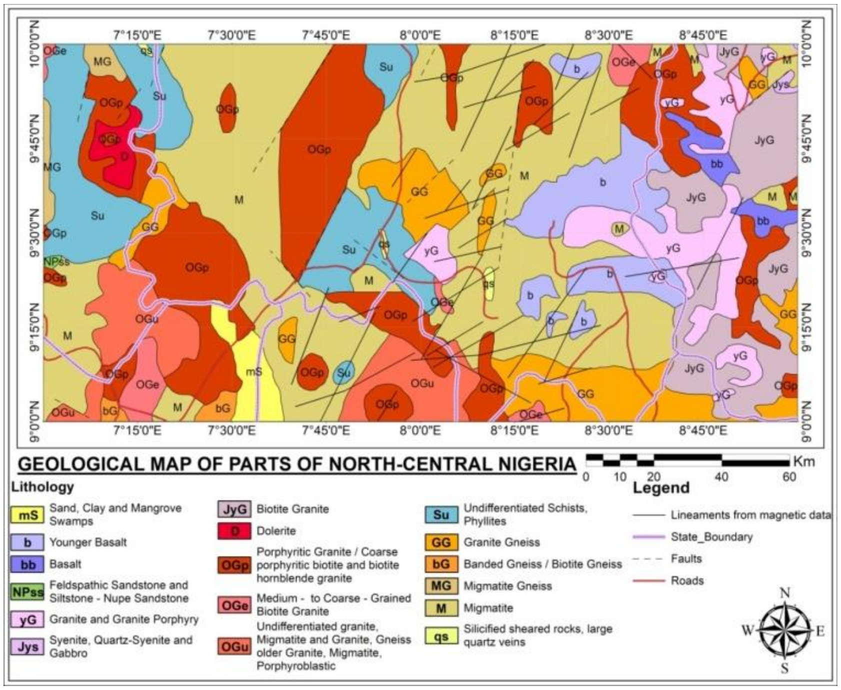

Figure 2: Geological Map of the Study Area adopted from Nigeria Geological Survey Agency, 2006

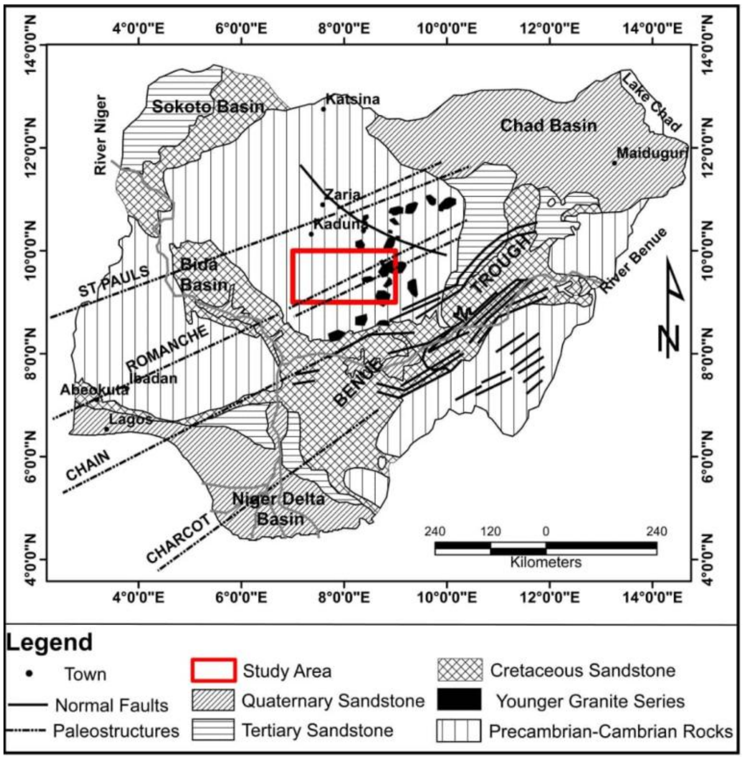

Figure 3: Transatlantic Fault map modified from Ananaba .S.E 1991

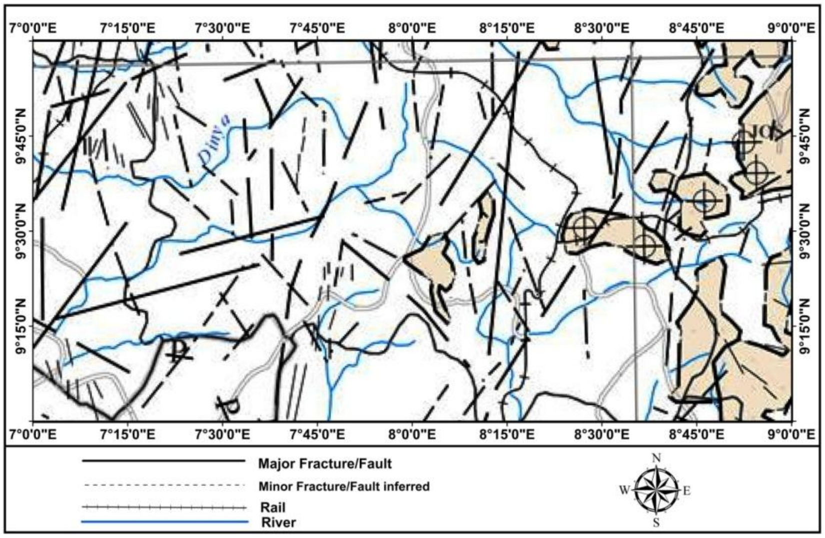

Figure 4: Geological Structural Map of the study area (Lineament map of Nigeria 2005)

3.1 Method

3.2 Vertical derivative filters

The vertical derivative is commonly applied to total magnetic field data to enhance the most shallow geological source and can be calculated either in space or frequency domain. The enhancement sharpens anomalies over bodies and tends to reduce anomaly complexity, allowing clearer imaging of a causative structure. The transformation can be noisy since it will amplify short -wavelength noise.

First vertical derivative data have become almost a basic necessity in magnetic interpretation projects. The second vertical derivative has more resolving power than the first vertical derivative.

$$L\,(r) = r^n \qquad (1)$$

Where n is the order of differentiation and r is the wave number (radians/ground-unit) Note: r =2pk where k is cycles ground unit. Ground unit is the survey ground units used in the grid (e.g. meter, feet, etc).

3.3 Upward continuation

Upward continuations are processes by which potential field data from one datum are mathematically projected upward to level surfaces above or below the original datum. In projecting to higher plane, we are suppressing the effect of the local (residual) anomaly and enhancing regional effects. Upward continuation helps us to establish the regional trend, estimate the depth of a basin and establish if there exist any inter-layer structures. This is the calculation of the potential field at an elevation than at which the field is measured.

Upward continuation is a method used in geophysics to estimate the values of the magnetic field by using measurements at the lower elevation and extrapolating upward, assuming continuity. The upward continuation (where z is positive upward) is given by the equation (2)

$$\int F(x,y,-h) = \frac{h}{2\pi}\iint \frac{F(x,y,0)\partial x\partial y}{\sqrt{\left(x-x^{i}\right)^{2}+\left(y-y^{i}\right)^{2}+h^{2}}} \qquad (2)$$

where F (x´,y´,-h) = Total field at the point P(x´,y´,-h) above the surface on which F(x,y,0) is known, h = elevation above the surface (Telford *et al*., 1990).

3.4 The Centre for Exploration Targeting (CET) grid analysis plug-in for structures

The CET (Centre for Exploration Targeting) Grid Analysis extension consists of a number of tools that provide automated lineament detection of gridded data which can be used for first- pass data processing. The CET grid Analysis extension contains tools for texture analysis, phase analysis and structure detection. The aim of this structural analysis is to:

i. Locate the contact between the basement of the study area
ii. Locate the extent and position of the outcrops and intrusive bodies (the basement and sedimentary formations) within the study area
iii Detect fracture or any fault that may exist within the area
iv Interpret the entire lineaments detected

Standard deviation provides an estimate of the local variations in the data at each location in the grid, it calculates the standard deviation of the data values within the local neighborhood. Features of significance often exhibit high variability with respect to the background signal. For a window containing N cells, whose mean value is μ, the standard deviation σ of the cell values xi is given by**:**

$$\sigma = \sqrt{\frac{1}{N}}\sum_{i=1}^{N}(\,x_{i-}\mu)^{2} \qquad 3$$

When interpreting the output, values which approach zero indicate very little variation, whereas large values indicate high variation (Kovesi, 1991). The next stage is to apply **Phase Symmetry**; this property is useful in detecting line-like features through identifying axes of symmetry. It is also known that the symmetry of a signal is closely related to the periodicity of its spatial frequency. Consequently, it is natural to utilize a frequency-based approach to detect the axes of symmetry. This plug-in implements the phase symmetry algorithm developed by Kovesi (1991). The result from phase symmetry is passed through **Amplitude Thresholding**, in conjunction with non-maximal suppression (NMS). The NMS is useful for finding ridges since low values are suppressed whilst points of local maxima are preserved, it also takes into account the local feature orientation so that the continuity of features is maximized and can be used to remove noise and highlight linear features Finally **Skeleton to Vectors** is applied. The Skeleton to Vectors plug-in is for vectorizing the skeletonised structures from the skeletonisation plug-in via a line fitting method described below. This vectorised data can then be used as input to the structural complexity map plug-ins. For each structure in the grid, a line is formed between its start and end points. If the structure deviates from this line by more than a specified tolerance the structure is divided into two at the point of maximum deviation and the line fitting process is repeated on these two new structure segments. This process is continued recursively until no structure segment deviates from its corresponding line segment by more than the specified tolerance. These line segments form the vectorised representation of the structures within the grid (Kovesi, 1991).

4 Result and Discussion

4.1. Total magnetic intensity map

The total aeromagnetic field map of the study area (Figure 5) was produced in colour aggregate with pink to red colour depicting positive anomalies while green to blue depicts negative anomalies. The Total Magnetic Intensity map of the study area exhibits both positive and negative anomalies ranging from 33487.7 nT minimum to 33800.9 nT maximum. The map reveals variations in the magnetic signature of highs and lows. The high magnetic signature occupies the north - eastern and north-western part of the study area which corresponds to Naraguta, Jemma and Kafanchan areas. These anomalies could be due to presence of basalt in the area as mapped by Figure 2. The low magnetic susceptibilities is around the south-western corner of the area, corresponding to Abuja, Gitata and Kurra areas and is due to level of weathering of the basement rock and thick over burden. The greenish part of the study area indicates alluvium deposition around Bishini and Kachia area.

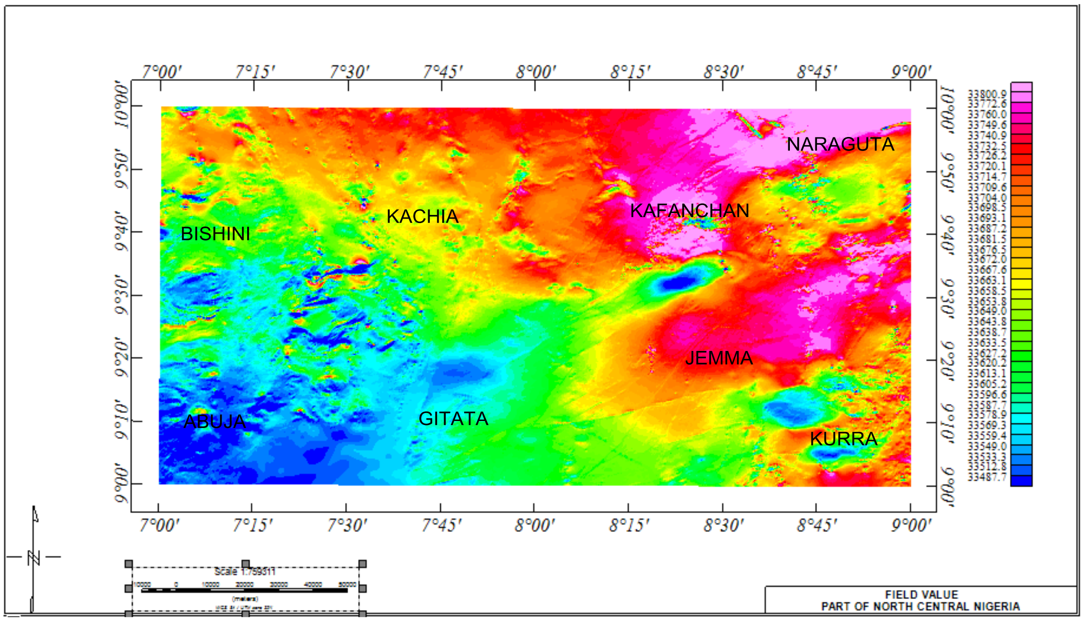

Figure 5: Total Magnetic Intensity of the study area

4.2. Vertical derivative maps

First Vertical Derivative Map (Figure 6a) which tend to amplify the high frequency short-wavelenght anomaly that are associated with geological structures in the study area. This filter when applied to aeromagnetic data tend to sharpen the edges of anomalies and reveal lineaments of the area and were mapped out here using black strikes represented by F1 to F8. From the map, the map revealed high frequency (short wavelength) anomalies along north western part of the map, these short wavelength are also observed at the north eastern part of the map. The delineated lineament obtained from the map are trending in NE-SW, NW-SE and E-W direction being the most predominant. Most of the lineament is trending in E-W direction around Jemma, Naraguta and Kurra areas. From the map, a discontinuity is identify which represent the lineament that cut across the study Area. Areas that correspond to XX^{I} are areas around Gitata, Kafanchan, Jemma Naraguta and Kurra areas. One of the transatlantic faults that passes through Nigeria trending NE-SW, (Romanche Fault) is believed to pass through the study area, which is in agreement with the work of Tawey *et al.*, 2020 were one of the transatlantic faults (Romache Fault) appear to pass through the study area. Figure 6b shows first vertical derivative in grey scale which intensify the lineament picture clearly and can easily identified minor fault, major fault lines which are fracture as well as lineament, in red colouration trending in NE-SW direction which is in agreement with First vertical derivative map (Figure 6a) and the geology map of the study area (Figure 2). The minor fault is identified in the map and is trending NE-SW direction. Fold is seen in blue coloration and is trending towards the western part of the map. Towards the extreme end of south eastern part a conelike fracture is seen which is as a result of high migmatite rock. The Second vertical derivative map (Figure 7) shows the existence of both high and short wavelength which is high in occurrence especially along E-W direction which corresponds to be undifferentiated schist including phyllites porphyritic granite and migmatiteGneiss rock. A small closure at the north-central which correspond to younger basalt with granite and granite porphyry intruded into the basement rock. The structures identify in both maps is the same and is in NE-SW and E-W direction which correspond to Figure 6a.

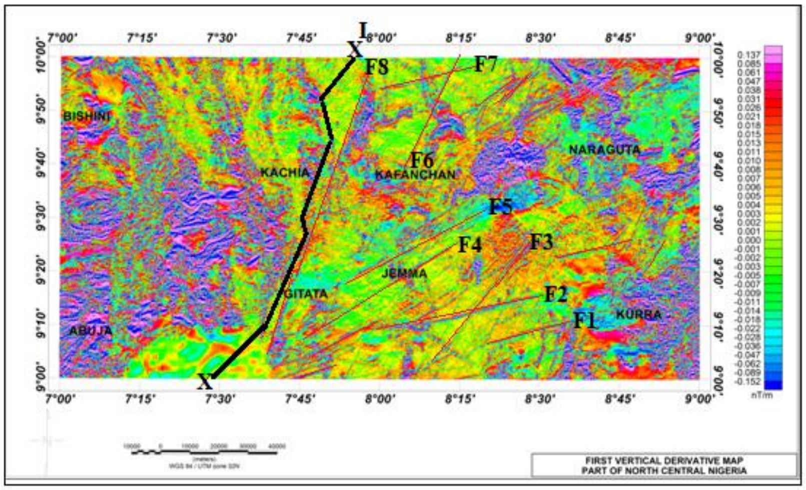

Figure 6a: First Vertical Derivative of the study area

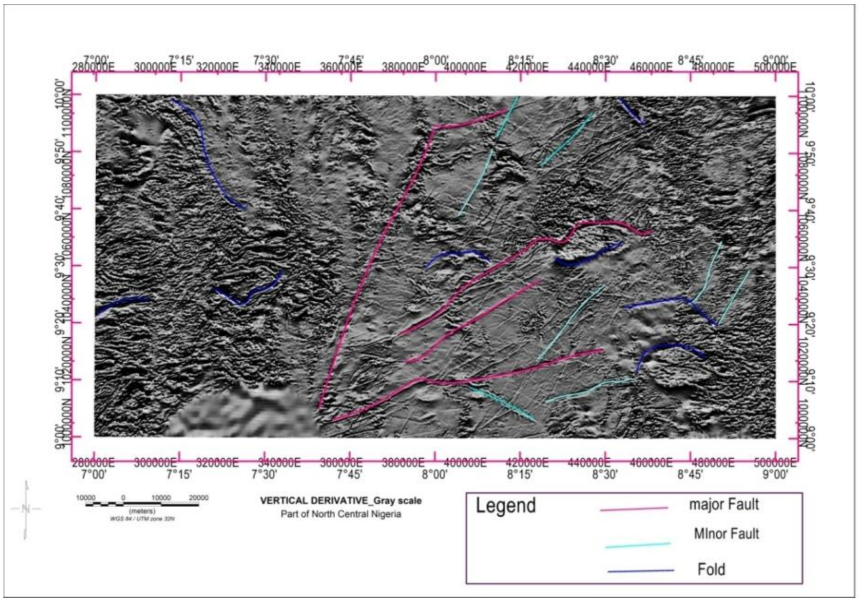

Figure 6b: First Vertical Derivative – Grey scale of the study area

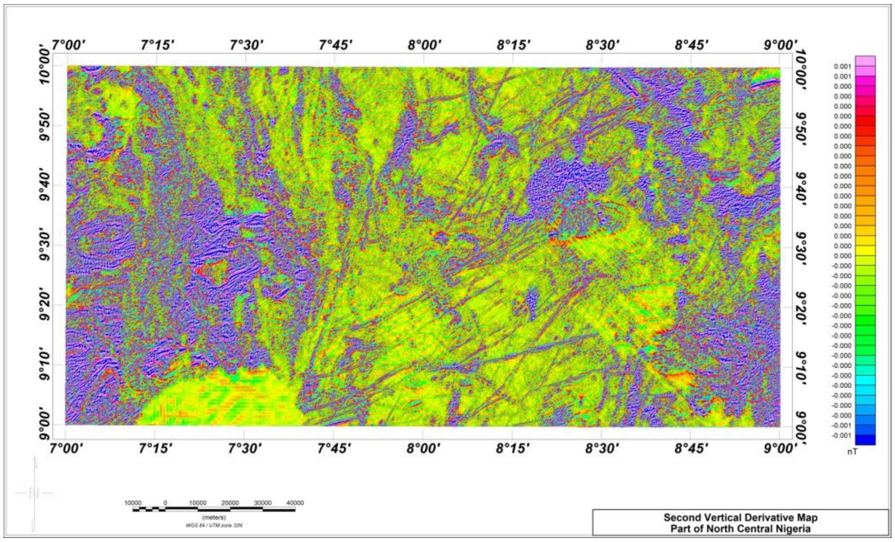

Figure 7: Second Vertical Derivative of the study area

4.3. Upward Continuation

The total magnetic intensity map was upward-continued to 10 km, 40 km and 80 km respectively. As we upward continued, we tend to look deeper into the basement. Thus, the residual is being filtered off with the advancement of the regional at each stage. Upward continuation at 10 km (Figure 8) identify a closure within the study area and this closure occurs probably because of the existence of one of the paleofracture zone (Romanche Fracture Zone) that cut across the study area. As we upward continued at 40 km, no closure was observed and the short wavelength anomalies are almost filtered off with the advancement of the regional. The upward continuation at 40 km and 80 km (Figures 9 and 10) do not have much difference in each of the maps, the regional trend becomes clearer showing NE-SW trend and emanation of younger granite intrusion into the basement are well pronounce, high magnetic susceptibilities around North-eastern part corresponding to Naraguta area are seen in the map. At 80 km altitude (Figure 10) reveals a regional trend in the NE-SW direction.

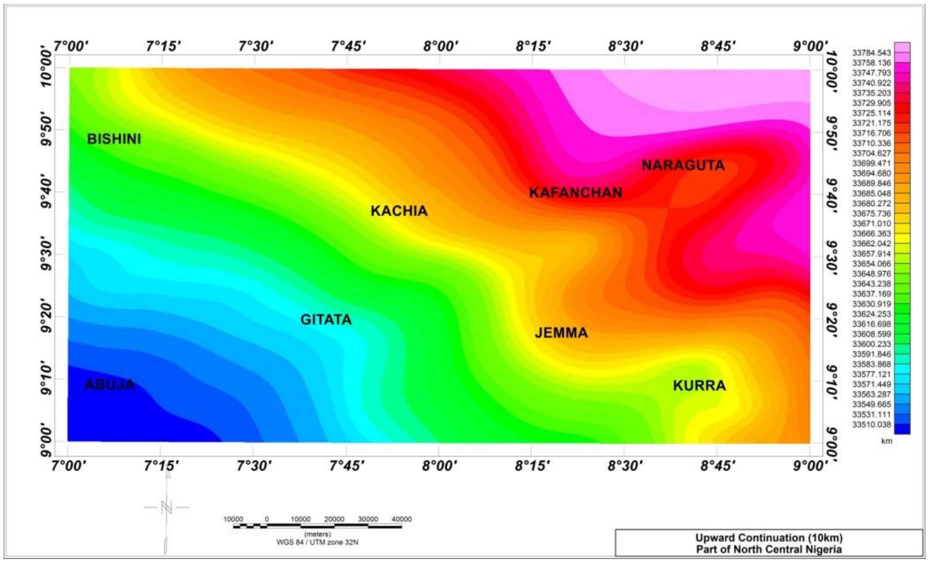

Figure 8: Upward continuation at 10 km

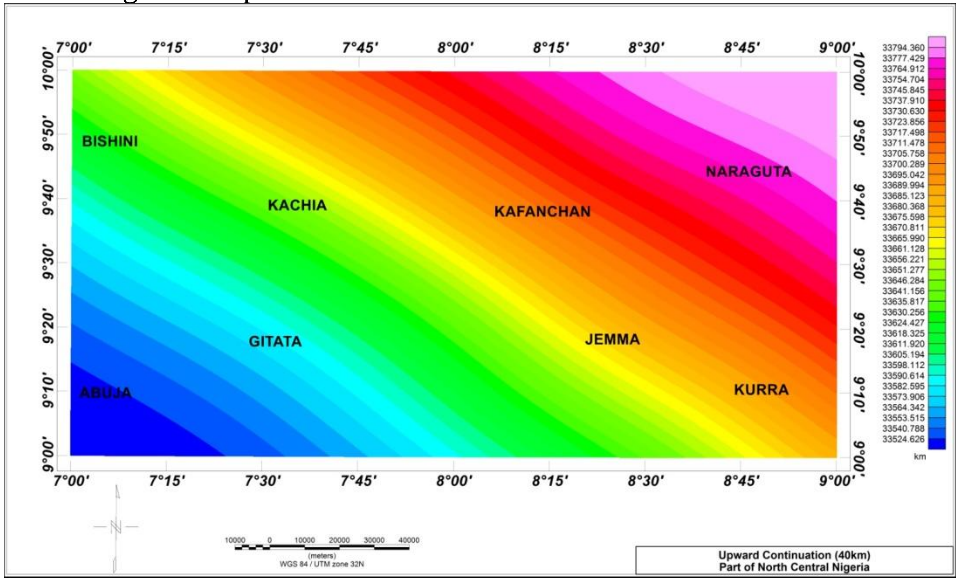

Figure 9: Upward continuation at 40 km

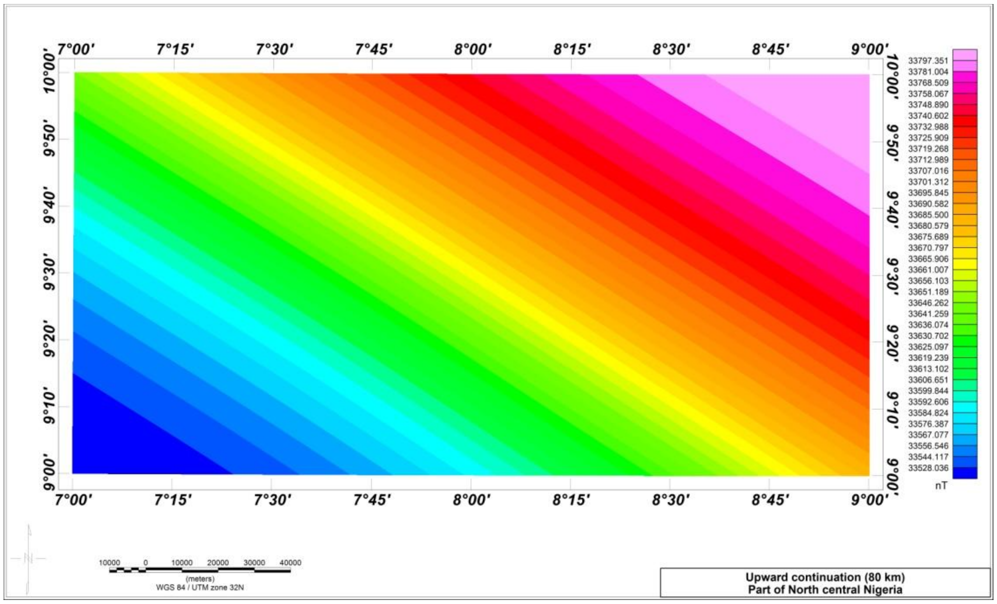

Figure 10: Upward continuation at 80 km

4.4. Center for Exploration Targeting (CET) Grid Analysis

The application of the center for exploration targeting (CET) grid image analysis technique was applied to the aeromagnetic data of the study area for rapidly locating regions of tectonic trend within the study. The technique automatically delineates lineaments using several statistical steps including textural analysis, lineament detection, and vectorisation. Lineament obtained from CET (Figure 11) shows linear structures that trend in the NE-SW and E-W direction which is in agreement with Figure 6a. The phase congruency map (Figure 12) show features (porphyry) that is predominant within the outcrop basement rocks.

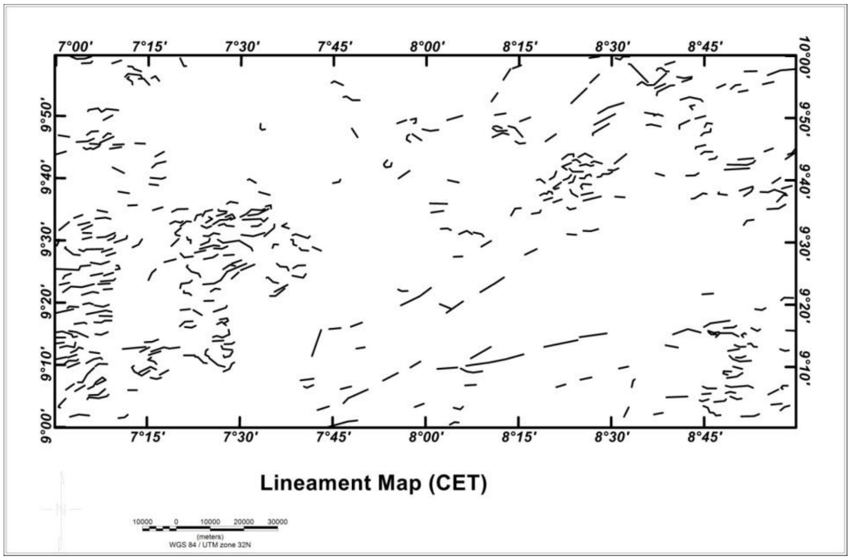

Figure 11: Lineament Map of the Study Area (CET)

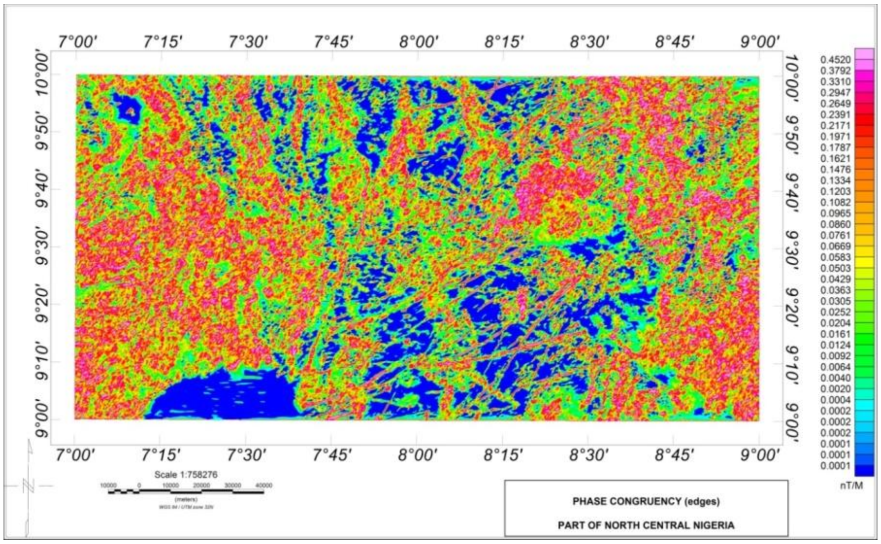

Figure 12: Phase Congruency Map of the study Area

4.5 First Vertical Derivative (FVD) Map compare with Center for Exploration Targeting (CET) Map

Figure 13 represent the First Vertical Derivative map and center for exploration targeting (CET) Map. The correlation identified in both maps shows various lineaments trending in the same direction for both maps, with trending direction along NE-SW and NW-SE direction. The relationship between the characteristics of magnetic lineament and that of CET map shows that most of the lineaments are trending in E-W direction areas around Jemma, Naraguta and Kurra. This is in agreement with (Olasehinde *et al.*, 1990), who analysed aeromagnetic data over central Nigeria's basement complex and concluded that the Nigeria basement complex's structural and tectonic framework comprises NE-SW and NW-SE lineaments superimposed on a dominant N-S trend. It is as a result of tectonic shear fault generated during the separation of American plate from the African plate (Ajakaiye *et al.*, 1991).

4.6 Geological structural Map of the area compare with First Vertical Derivative Map

Figure 14 represent geological structural map of the area on First vertical derivative map. The FVD map (Figure 6a) and geological structural map of the area (Figure 4) were both compared to ascertain significant differences on both maps. The geologic structural map of the area represent lineament in place but there are lineament that still exist in the study area that have not been map out but have been mapped out in the present study. These new lineament are mapped out and label as (F1, F2, F3, F4, F5, F6, F7 and F8) in the map. Lineament with red colouration indicates lineament obtained from First vertical derivative map (Figure 6a) and lineament with black colouration indicates lineament from structural map (Figure 4). From the map, it was observed that most of the lineaments trend in NE-SW direction for both maps. Lineament delineated from First vertical derivative, label F8 along Gitata is believe to be probably a continental continuation of the Romanche fracture zone and is suspected to be a paleostructure (Figure 15) and is trending around south -west to north-east direction. One of the four transatlantic faults that pass through

Nigeria through the Atlantic Ocean, is Romanche fracture fault and is believed to have pass through the study area (Figure 3) and this observed fault trending NE-SW cut across the southern portion of the study area, lineament identify trending in this direction represent the major tectonic trends which may correspond to Romanche fracture zone and is one of the Atlantic fracture zones that abut the west African coast into the Nigeria Basement complex and is believed to be part of the major zones of weakness and run across the study area. As stated by Ajakaiye *et al.* (1986) that these aeromagnetic lineaments depicted a possible continental continuation of the four Atlantic fracture zones (St Paul's, Romanche, Chain and Charcot) abutting the West African coast into the Nigerian basement complex. Lineament label F4 and F6 trending E - W direction areas around Kafanchaan and Jemma are the new lineament mapped out to be attributed to some tectonic activity due to existence of Romanche fracture zone within the study area. The stresses built up around plate boundaries especially in pre-existing faults such as Romanche fracture zone which is still active as a result produces a new active fault (F4 and F6) could trigger and cause an earth tremor within the study area.

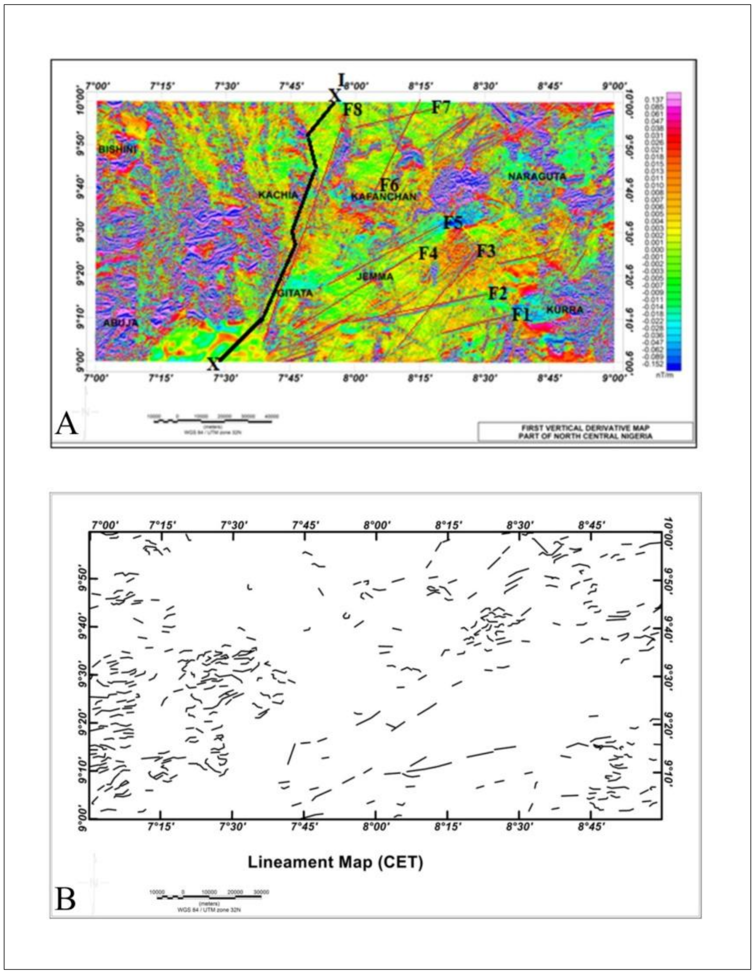

Figure 13: Correlation of (a) Lineament Map and (b) First Vertical Derivative

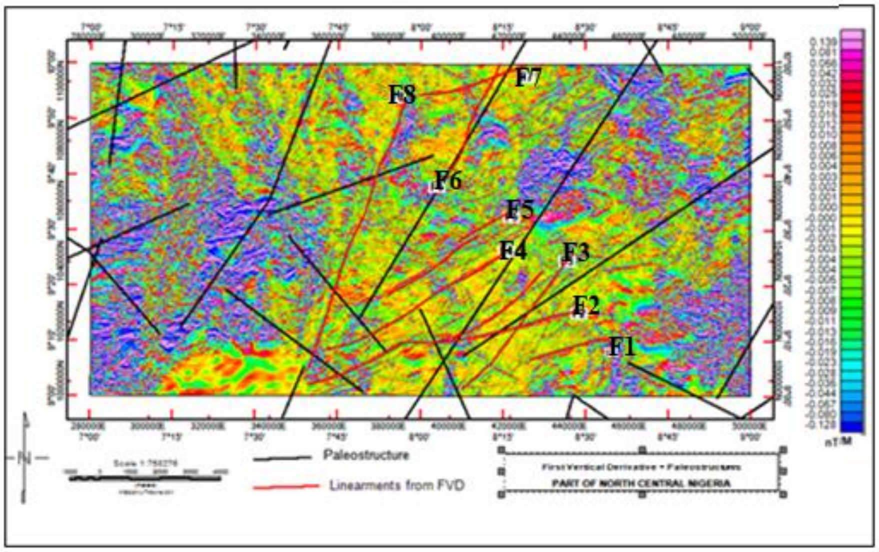

Figure 14: Superimposing of paleostructure zone and First vertical derivative of the study area

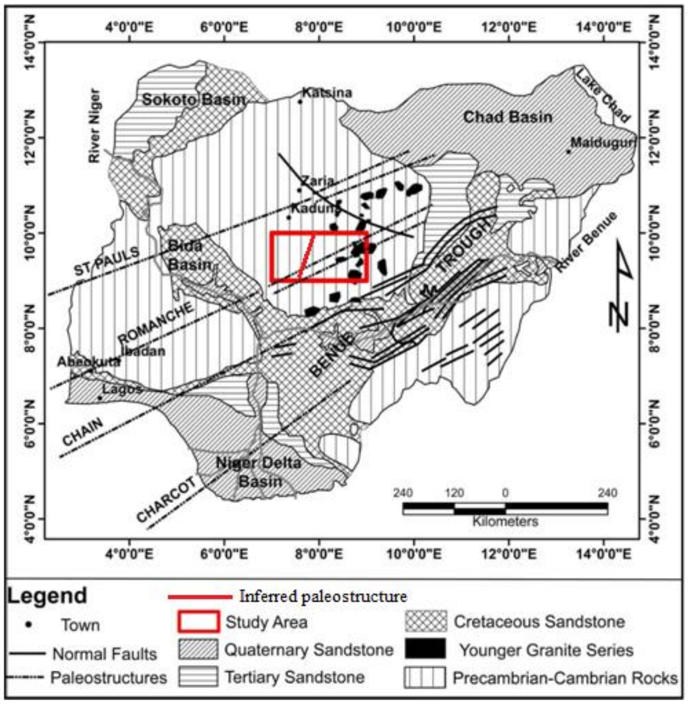

Figure 15: Inferred Paleostructure within the study Area

5. Conclusion

Qualitative analysis of aeromagnetic data of parts of North Central Nigeria had been carried out with the aim of delineating seismic prone areas. The results of this study show areas that are prone to seismic activities. At the northeast and southeastern part of the area which is made up of basement complex that corresponds to areas around Kafanchaan and Jemma are prone to tectonic activities while the southwestern part of the area around Abuja is seismic free. It is suggested that those lineaments identified, most especially at the southeastern part could be the reason for the shaking of the subsurface which results in earth tremors.

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