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Preliminary Investigation of Seismicity in Parts of North Central Nigeria, Using High Resolution Aeromagnetic Data

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Authors' contributions

This work was carried out in collaboration among all authors. Author AA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors DUA and AAA managed the analyses of the study. Author EEU managed the literature searches. All authors read and approved the final manuscript.

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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

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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. At the northeast and southeastern part of the area which is made up of basement complex that corresponds to areas around Gitata, 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 sudden fracture and 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 [1]. 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 [2]. 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 [3]. The first widely reported occurrence of an earth tremor in Nigeria was in 1933 at Warri [1]. Similar events were reported in 1939, 1963, 1964, 1984, 1990, 1997 2000, 2006 [4]. 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 [5]. All the seismicity that has ever happened in Nigeria and West Africa is earth tremors [6]. 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 kilometre than a ground survey [7]. 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 study area which is part of North Central Nigeria is 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 of North-central Nigeria. It comprises rocks of the migmatite-gneiss and schist and generally intruded by the Pan African Older Granite rocks [8]. The rocks of the study area have undergone various episodes of deformation and have ages ranging from Precambrian to Pan African. The generalized geological map of the study area is presented in Fig. 1.

Fig. 1. Geology map of Nigeria showing study area (NGSA 2006)

Basement Complex covers about 50% of the total surface area of Nigeria. It is composed of the following litho structural units: - The Migmatite- Gneiss complex (MGC), The Metasedimentary and Metavolcanic rocks (The Schist Belt). The Pan - African granitoid (The Older Granites), underformed acid and basic dykes. The Nigerian Basement Complex (Fig. 2) forms part of the Pan African mobile belt and lies between the Congo Craton and south of the Taurage Shield [8]. The Nigerian basement was affected by the 600 Ma Pan African Orogeny and occupies the reactivated region which resulted from plate collision between the passive continental margins [9,10]. The basement rocks are believed to be the result of at least four major orogenic cycles of deformations, metamorphism and remobilization corresponding to the Liberian (1100 Ma) and the Pan African cycles (600 Ma) [8]. (Fig. 2) shows the geology of the study area and (Fig. 3) shows the structural map of Nigeria with paleo fracture zone.

3. METHODS

3.1 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

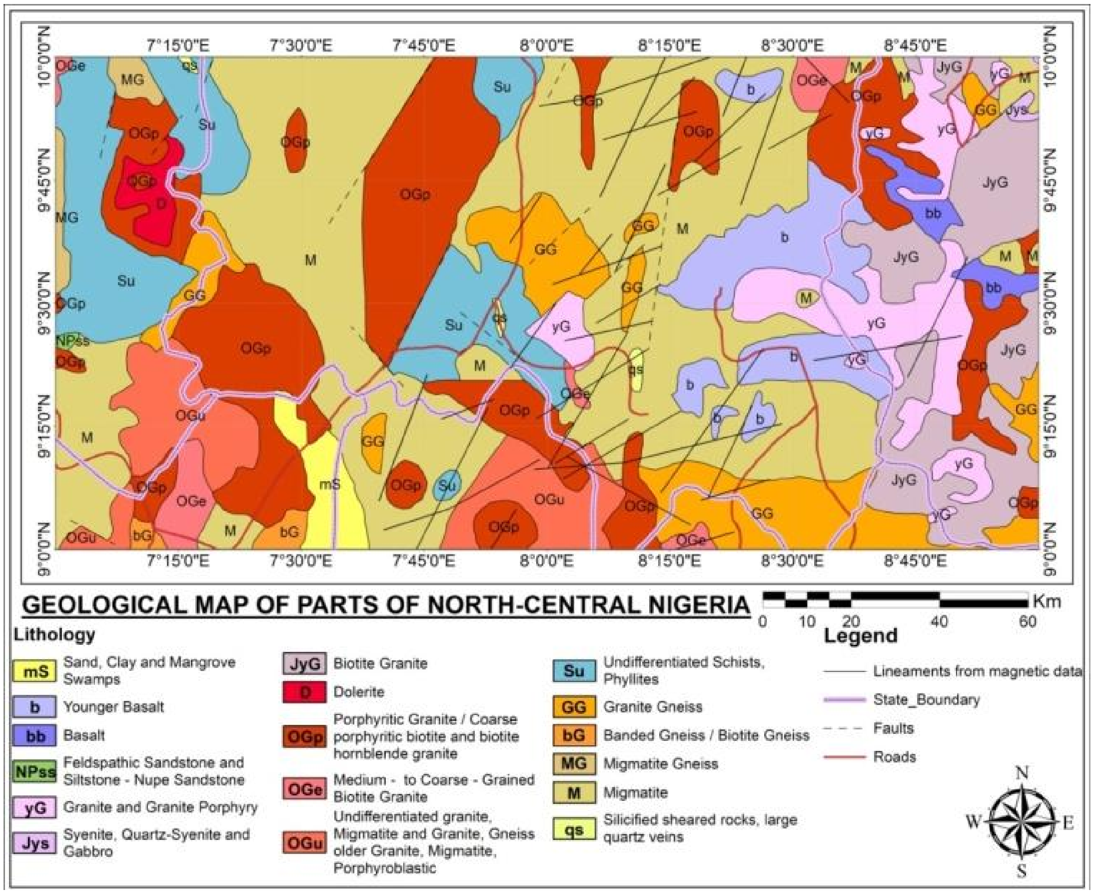

Fig. 2. Geological map of the study area adopted from Nigeria Geological Survey Agency [11]

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).

3.2 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):

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

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 [13].

3.3 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

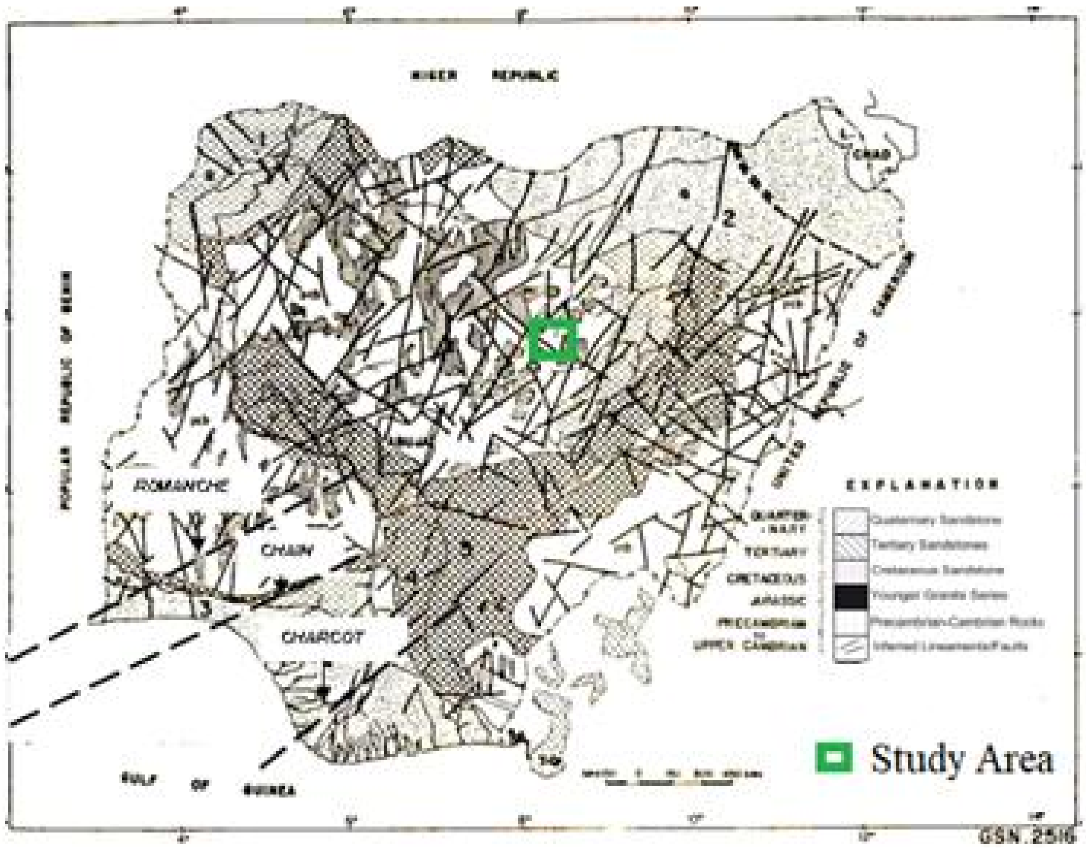

Fig. 3. Geological Map of Nigeria showing the Atlantic Fracture Zones Ajakaiye et al. [12]

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. RESULTS AND DISCUSSION

4.1 Total Magnetic Intensity Map

The total aeromagnetic field map of the study area (Fig. 4) 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 to 33800.9 nT 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 area. These are regions prone to high seismic activities, while the low magnetic signature which is of sediment deposition occupies south-western part of the study area corresponding to Abuja and Gitata. The greenish part of the study area indicates alluvium deposition around Bishini and Kachia area.

4.2 Vertical Derivative Maps

Vertical derivatives (FVD&SVD) are filters that enhance the shallowest geologic anomalies; the enhancement sharpens up anomalies over bodies and tends to reduce anomaly complexity, allowing clearer imaging of the causative structures. Major magnetic lineaments are observed in (Fig. 5a and 5b). Several lineaments were labeled from $F_1$to $F_{8,}$ the delineated lineament trend in the NE-SW and E-W directions, Structures (lineament) identify from first vertical derivative is an extension from Romanche Fracture Zone, Majority of this lineament trends in the same directions as the Romanche fault line. This is in agreement with the work of Megwara and Udensi [14]. The map reveals a significant magnetic pattern, such as linear structures and linear patterns are more prominent at the Northern part of the study area. Most of these are steeply dipping strikes.

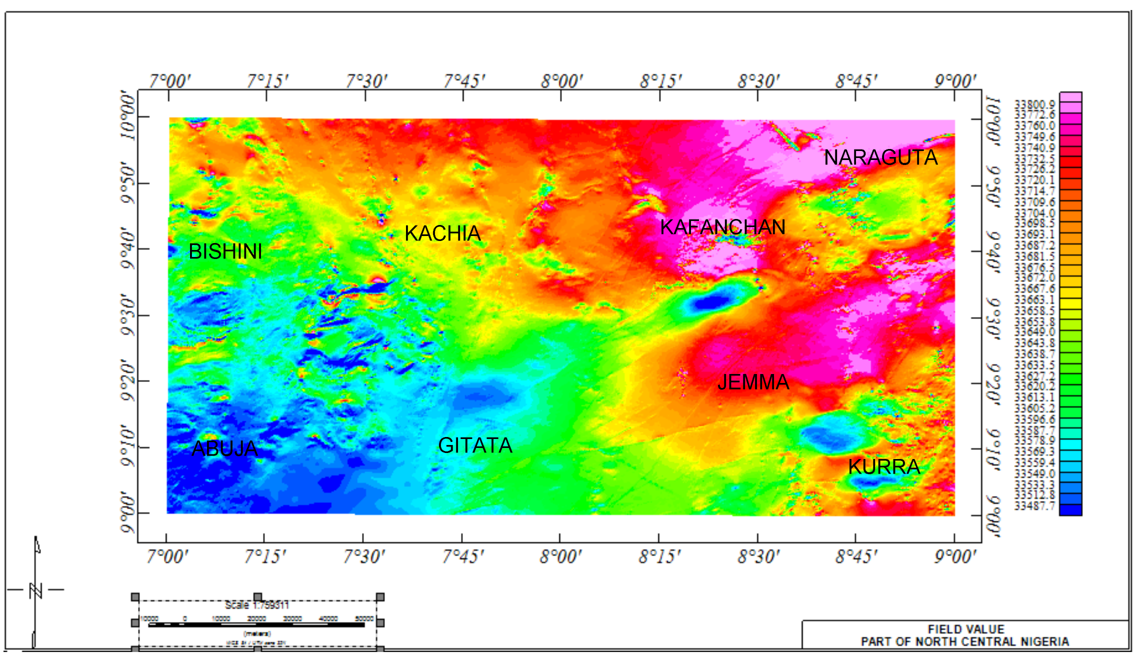

Fig. 4. Total magnetic intensity of the study area

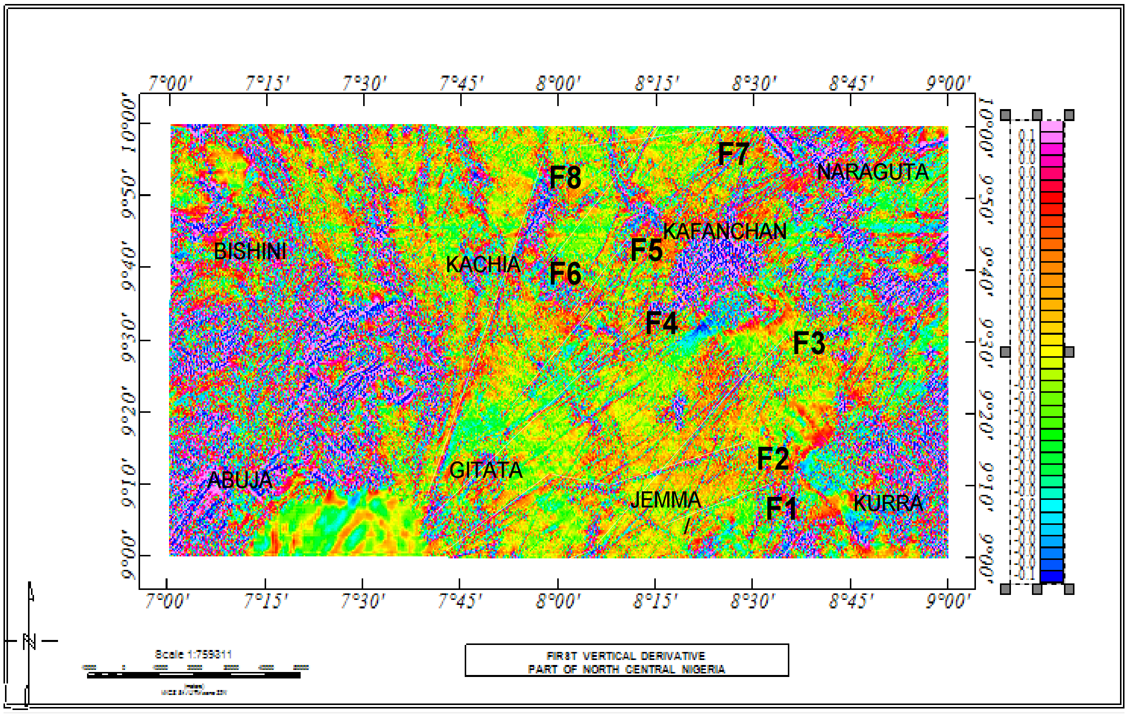

Fig. 5a. First vertical derivative of the study area

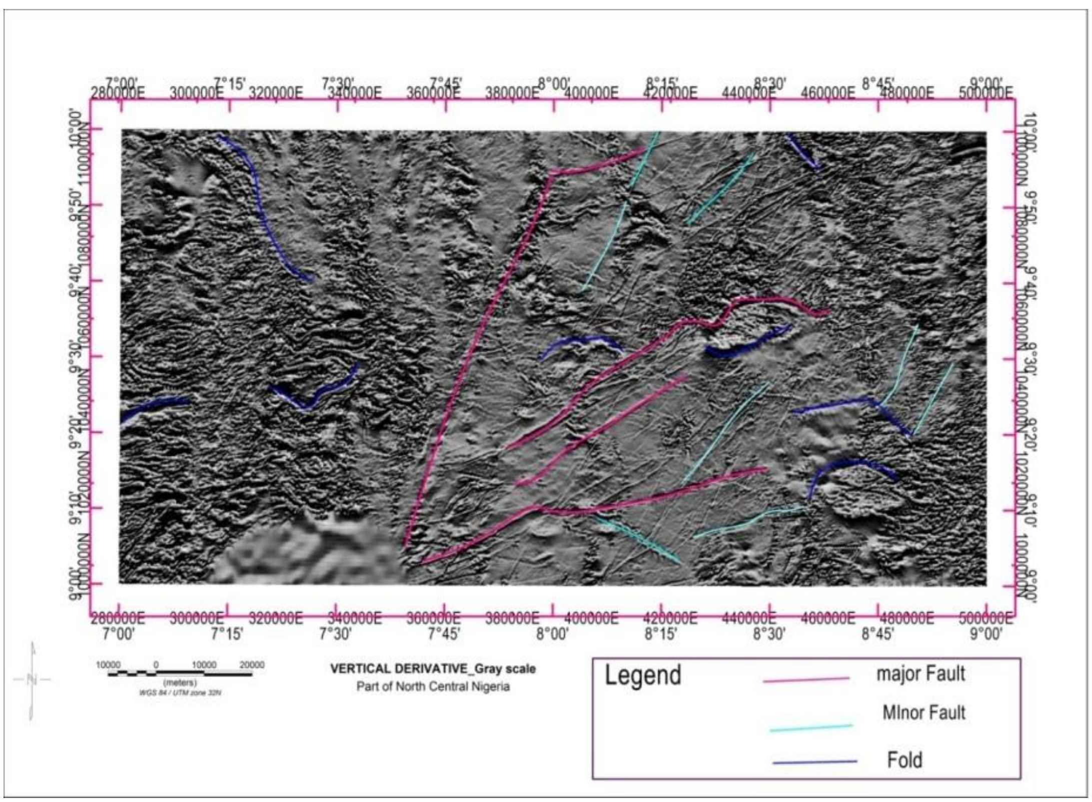

Fig. 5b. First vertical derivative – grey scale of the study area

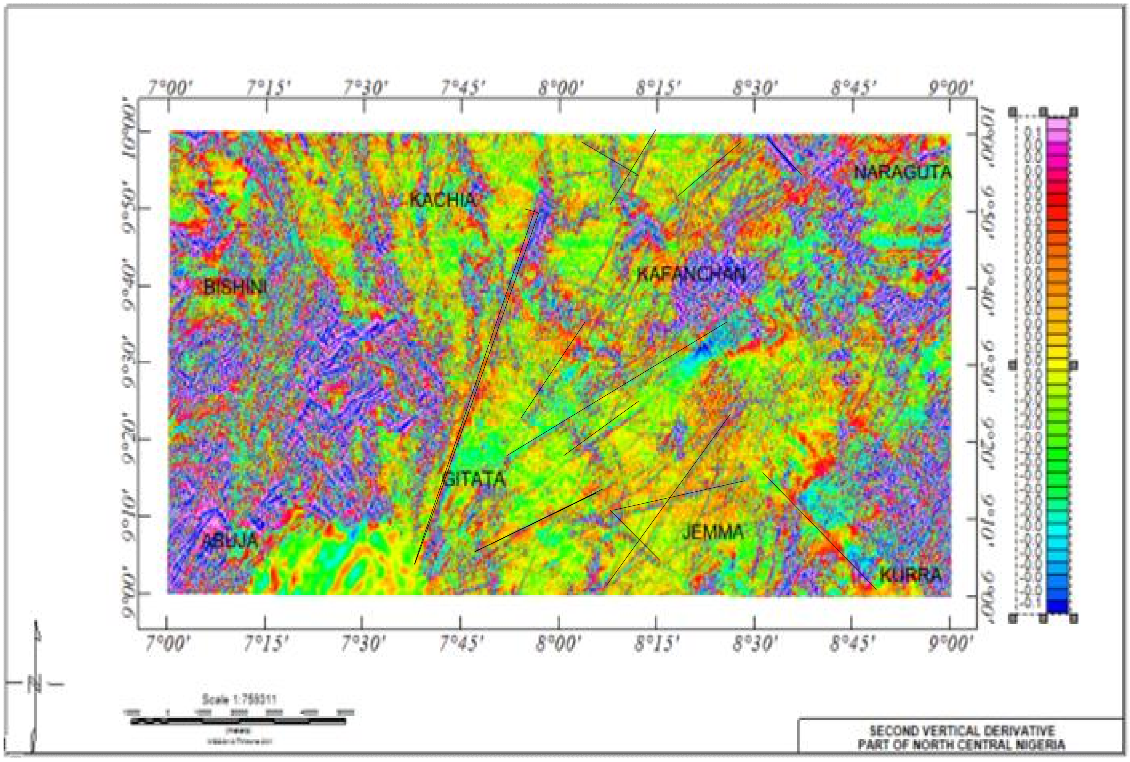

Fig. 6. Second vertical derivative of the study area

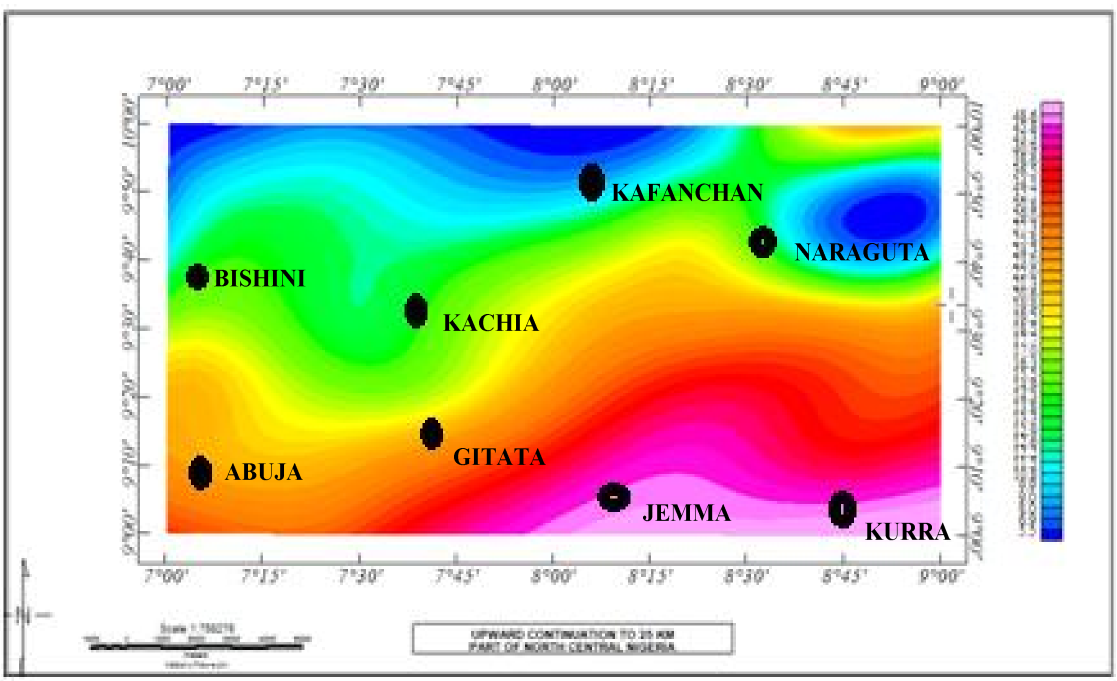

Fig. 7. Upward continuation at 25 km

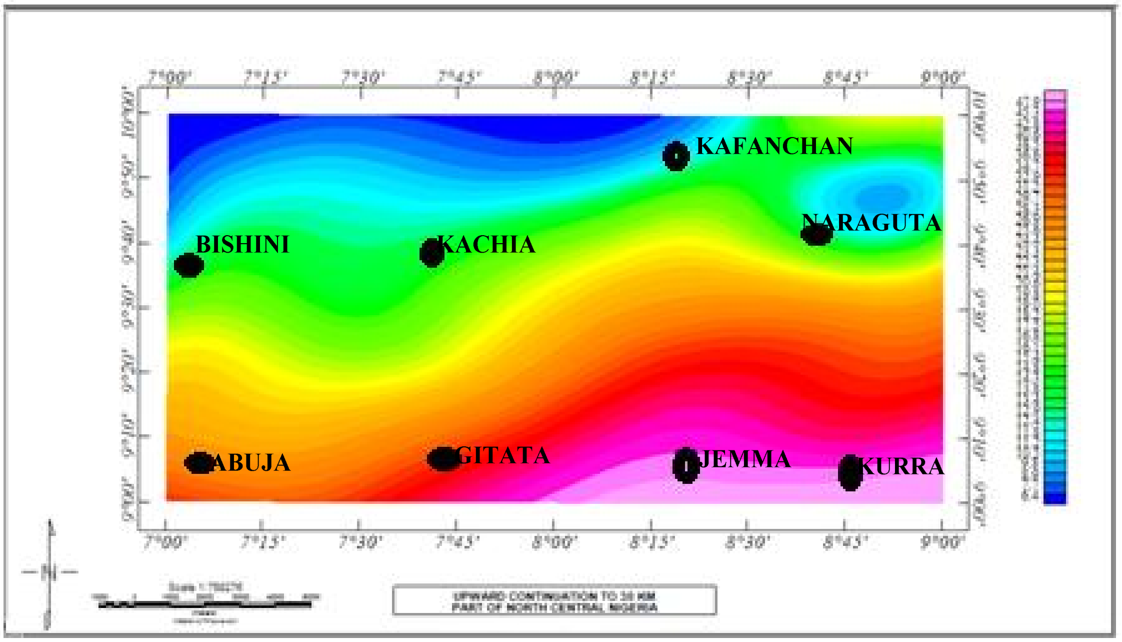

Fig. 8. Upward continuation at 30 km

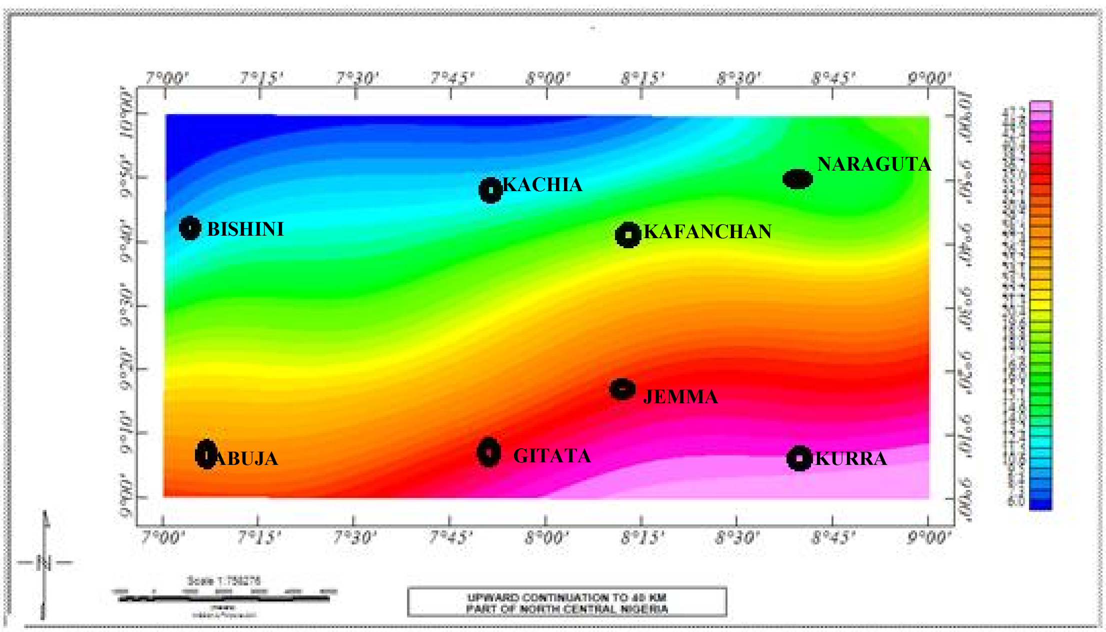

Fig. 9. Upward continuation at 40 km

Trending of structures (lineaments) found on the Second Vertical Derivative map (Fig. 6) agrees with the trends of structures (lineaments) found on First Vertical Derivative. The major structures delineated on the second vertical derivative map trends northeast-southwest and northwest-southeast respectively.

4.3 Upward Continuation

The total magnetic intensity was upward continued at the height of 25 km, 30 km, 40 km and 80 km to enhance the location of prominent deep-seated anomalies present in the study area. Upward continuation at 25 km and 30 km identify a 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 no closure was observed at that altitude. At depth of 80 km (Fig. 11) reveals a regional trend in the NE-SW direction.

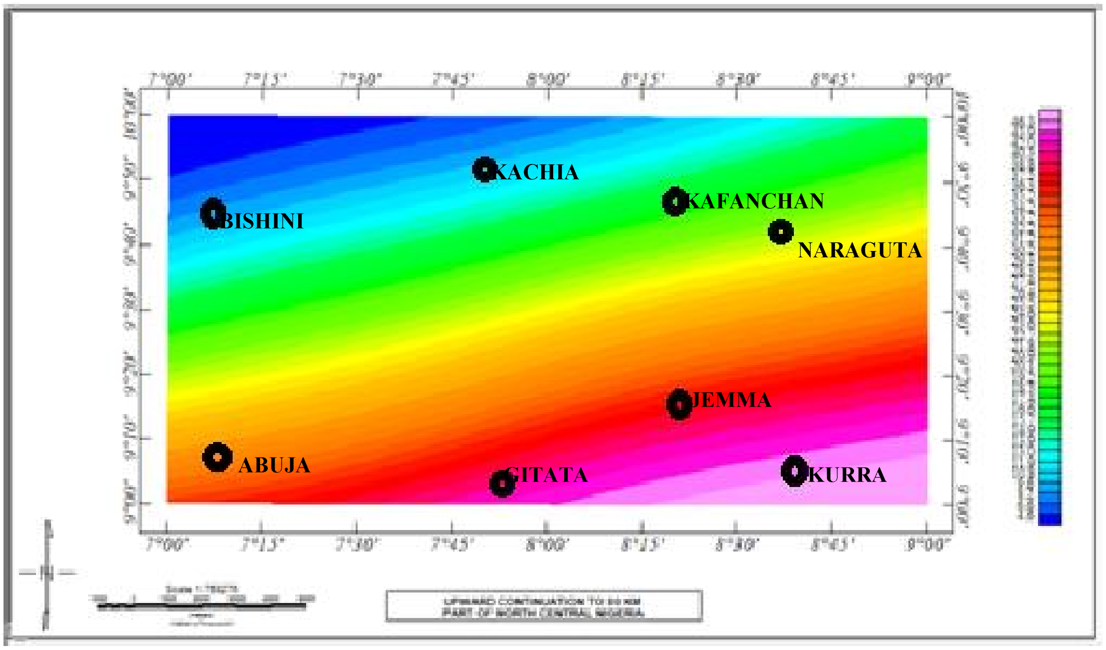

Fig. 10. Upward continuation at 80 km

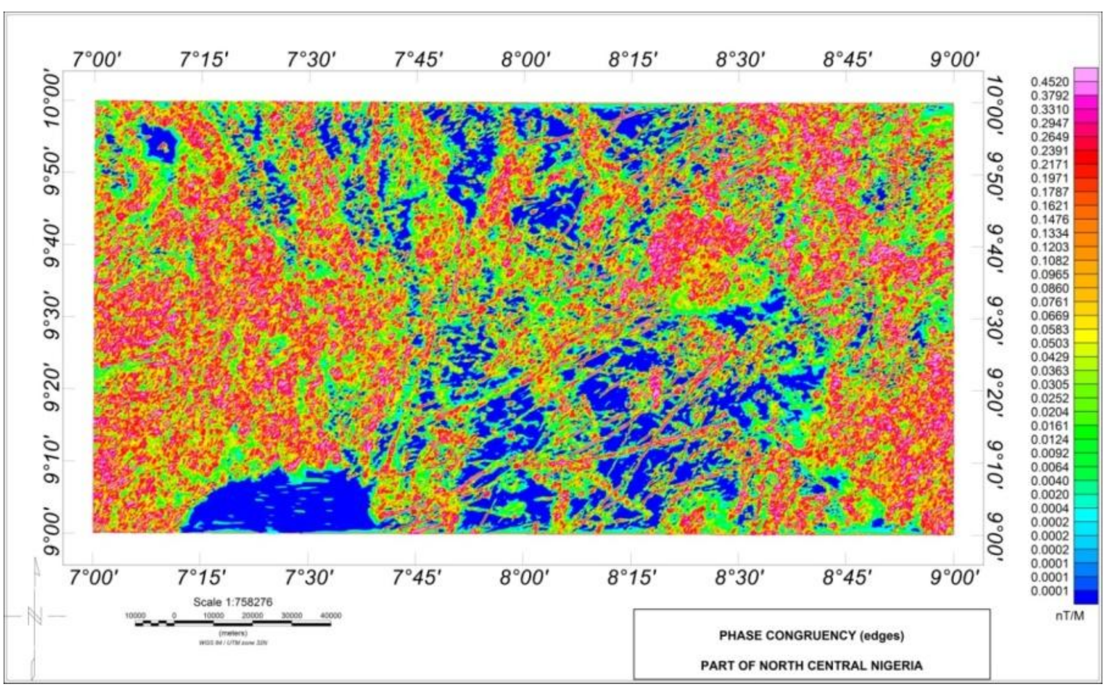

Fig. 11. Phase congruency map of the study area

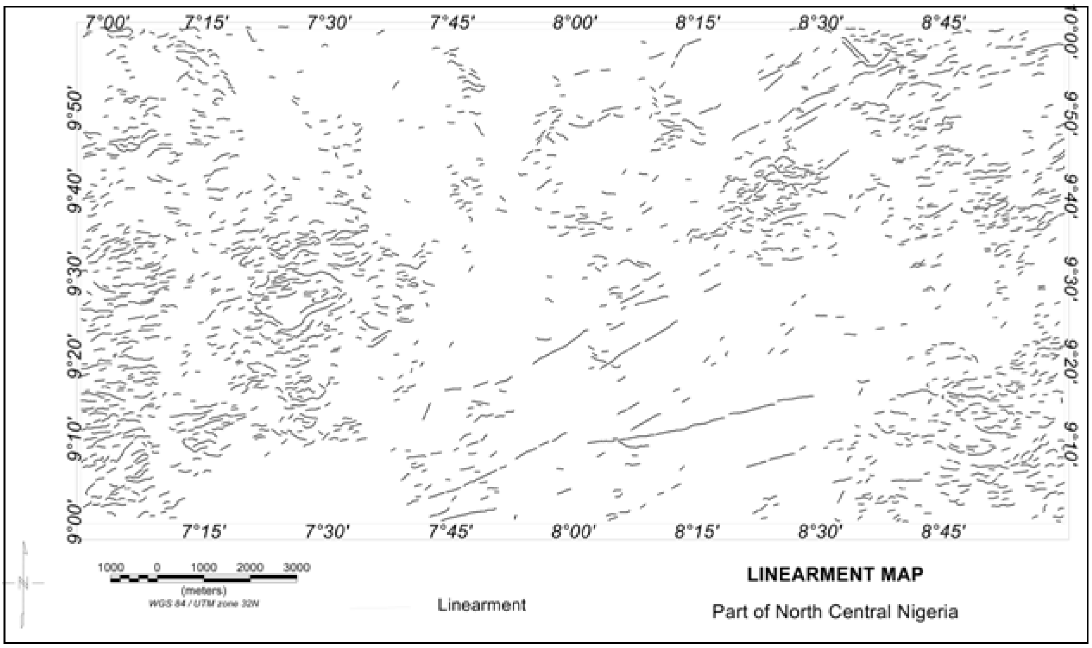

Fig. 12. Lineament map of the study area (CET)

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 area. The phase congruency map shows features (Porphyry) that are predominant within the outcrop basement rocks. Lineament map obtained from CET shows linear structures that trend in the NE-SW and E-W.

It is as a result of tectonic shear fault generated during the separation of American plate from the African plate [12]. The lineament obtained from CET correlates with that of First Vertical Derivative.

4.5 Correlation of Lineament (CET) and Second Vertical Derivative of the Study Area

Fig. 13 shows the correlation of both Lineament and the second vertical derivative map. The correlation identified in both maps shows various lineaments trending in the same direction for both maps, with trending along NE-SW direction. The relationship between the characteristics of magnetic lineament and Second vertical derivative shows that most of the fault is trending N-E direction areas around Jemma Naraguta and Kurra.

4.6 Superimposing of First Vertical Derivative on Structural Map of Paleo Fracture Zone

Fig. 14 shows superimposing of First vertical derivative on lineament of the paleo fracture zone. A Fault with red colouration indicates lineament From First vertical derivative which is the current lineaments in the area while the black colouration indicate lineament from the paleo fracture zone. From the map, it was observed that most lineaments from paleo fracture map agrees with that of first vertical derivative. Lineament from First vertical derivative is the new fault lines label (F1, F2, F3, F4, F5, F6, F7 and F8). from First vertical derivative label as (F8) is probably a continental continuation of the Romanche fracture zone trending along west-south to north-east region these fault trending in this direction represent the major tectonic trends which correspond to Romanche fracture zone and is believed to be part of the major zones of weakness, and is one of the Atlantic fracture zones that abut the west African coast into the Nigeria Basement complex and run across the study area. Other new fault lines label (F1, F2, F3, F4 and F5) are identified to be trending along

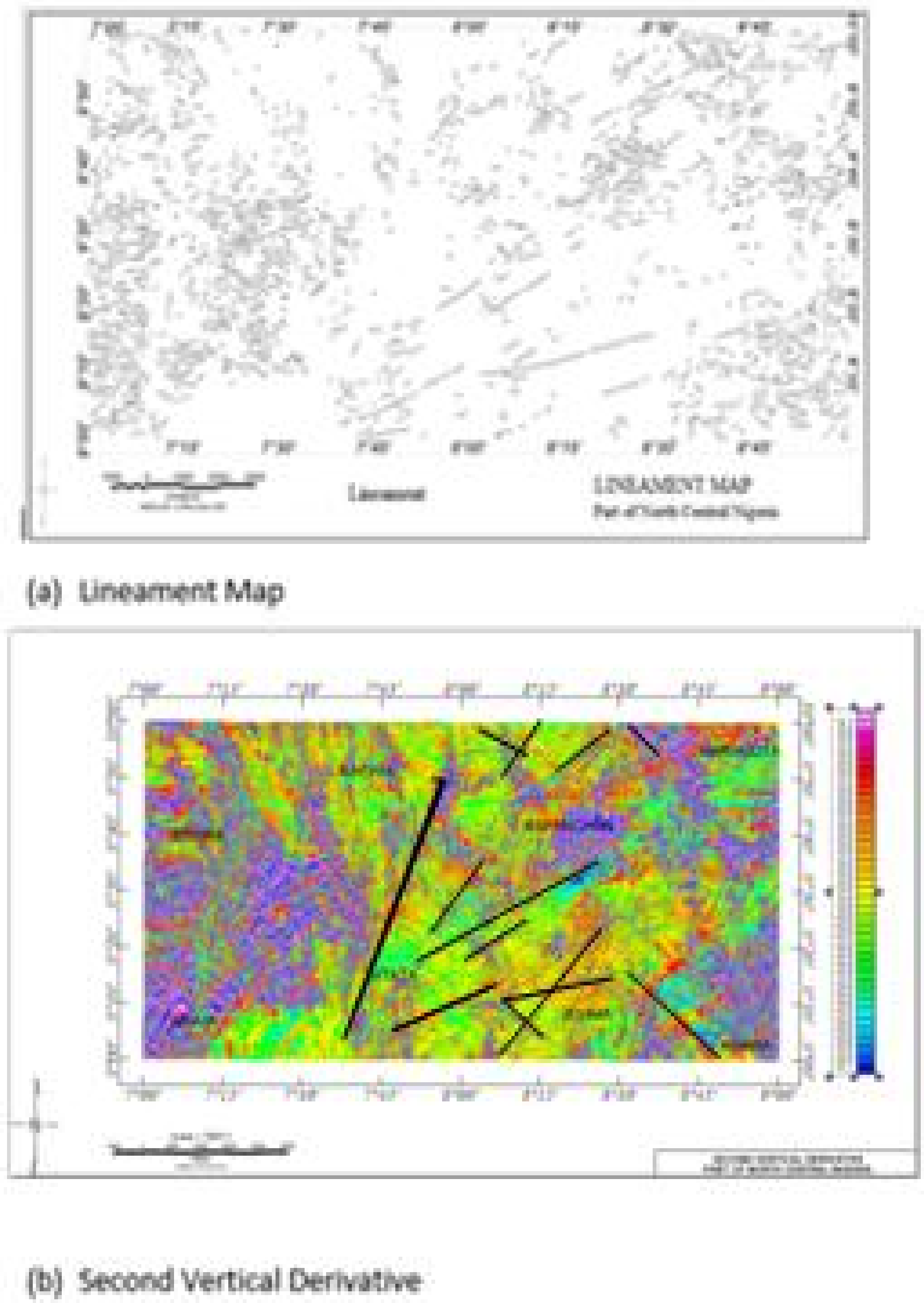

Fig. 13. Correlation of (a) Lineament map and (b) Second vertical derivative

south-eastern region, areas around Gitata, Kafanchaan and Jemma which could be attributed to some tectonic activity that could trigger the subsurface and result into earth tremor within the study area. The stresses built up around plate boundaries especially in pre-existing faults such as Romanche fracture zone could result in earth tremor as a result of new active fault formed within the study area.

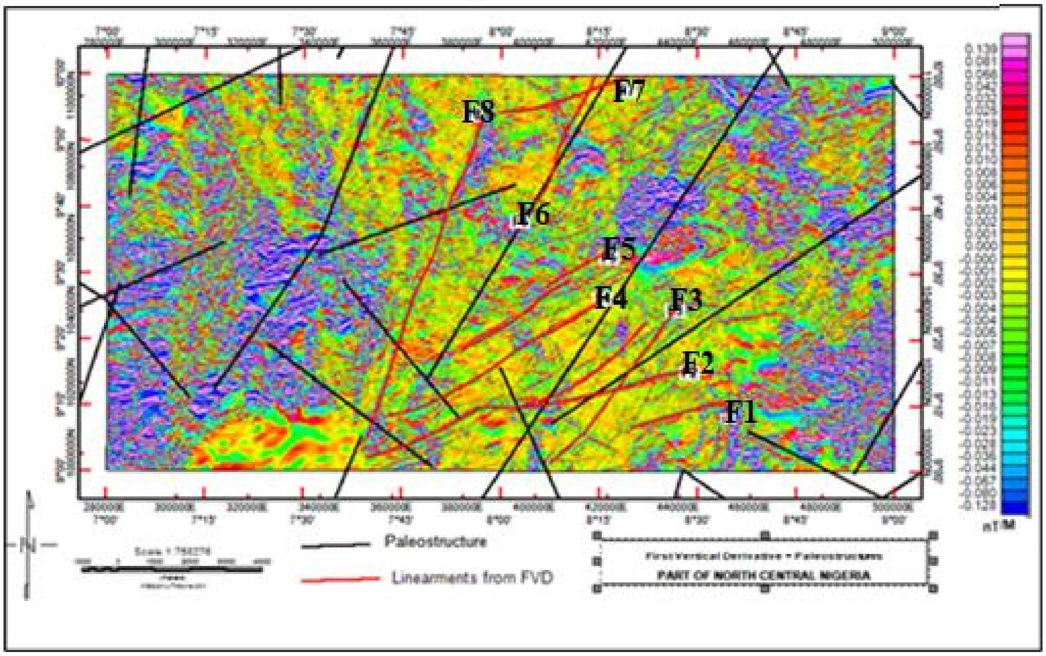

Fig. 14. Superimposing of paleostructure zone and first vertical derivative of the study area

5. CONCLUSION

Qualitative analysis of aeromagnetic data of parts of North Central Nigeria who 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 Gitata, 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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