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Structural Pattern Evaluation Using Aeromagnetic Data; A Case Study of Mpape, North Central Nigeria

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ABSTRACT
This study is aimed at investigating the subsurface stability of Mapape, a community in Abuja, against tremor occurrence and to check how safe the subsurface is for civil engineering constructions. High resolution aeromagnetic data of Abuja were processed using automated approach. The data were further enhanced producing the residual aeromagnetic data, in order to determine the orientations of the lineaments in the study area. The orientations of the lineaments obtained from the residual map revealed that the Pan African orogeny constitutes 50%; Kibaran orogeny constitutes 33%, while Liberian orogeny constitutes 17% lineaments in the study area. Edge detection and structural depth techniques were implored so as to determine the depth to basement of the subsurface structures. Based on orientation of faults on magnetic fault map obtained residual map and also the depth analysis, three distinct set of sinistral/dextral faults were recognized in Abuja. These include: NE-SW, ENE-WSW and NW-SE fault trend. This suggests that NE-SW fault-set could be responsible for the tremor experienced in Mpape state.

Keywords:
Aeromagnetics,
Faults,
Stability,
Tremors.

INTRODUCTION

The surface of the earth is covered with more than a dozen huge plates (plate-like masses of rock). The plates move in different directions at a speed of several centimeters per year (plate motion). Looking at things on a large scale, most earthquakes occur in the belt-like zones along the plate boundaries. Tremendous forces are applied by plate motion to the inside of the underground rock masses near the plate boundaries. Over many years a vast amount of energy builds up inside the rock masses as a strain and accordingly stress is accumulated. If a rock mass fractures due to the accumulated stress, an earthquake occurs (Nelson et al., 2021).

Nigeria lies on the eastern flank of the Atlantic Ocean, and since Jurassic times, the Atlantic Ocean margins have been opening consistently. Unlike the Pacific Ocean margins which are characterized by subduction tectonics and occurrence of devastating earthquakes, the Atlantic margins are generally thought to be quiet and as a result, there was little consciousness and preparedness for earthquake occurrences and mitigation in Nigeria and West Africa (Akpan and Yakubu (2010)). However, earthquakes have been reported in some countries in the west coast of Africa that border the Atlantic Ocean like Ghana, Ivory Coast and Liberia (Burke, 1969; Kogbe & Delbos, 1984). Also, some seismic events have occurred within the last seventy years especially in the southwestern part of Nigeria, but no destruction and loss of lives were reported or documented; they were only felt as vibrations. Most recent was the effect that took place at Mpape and surrounding environments, in Abuja. A disturbing ground shaking was experienced by the inhabitant of Mpape which lasted for about a second but reoccurred three hours later and the vibration lasted for about ten seconds (Nwabughiogu, 2018). This sudden vibration, sometimes violent (fortunately on this occasion was not) of the earth's surface that follows a release of elastic energy in the earth's crust, is known as an earthquake. This energy is generated by a sudden dislocation of the crust when the built stress exceeds the strength of the rock mass. The rock ruptures and assumes new position. The process of breaking generates vibrations called seismic waves that travel outward in all directions from the point of initial rupture.

These events have prompted the need for integrated research towards evaluating the remote causes of the tremors for informed decision making and proper management of their after-effects. Nigeria does not have a seismic building code of practice. This might be due to an earlier misconstrues about the seismicity of Nigeria.

Adepelumi *et al.* (2008) questioned the age-long belief that Nigeria is seismically safe and opined that the occurrence of ground shakings at Mpape has opened the possibility window that earth tremors are potential hazards in Nigeria. This study presents preliminary assessments of the subsurface structural set up at the site of recent earth tremors (Mpape region) in Abuja.

Geophysical processing techniques using high resolution aeromagnetic was considered for this study. The aim is to investigate regional subsurface geologic structures, a thorough assessment of their links to the recorded tremors, and map the disaster-prone areas for informed decision making. Analysis of aeromagnetic data has been found useful in the interpretation of buried features in PreCambrian basement rocks as well as Sedimentary terrain (Okoli & Eyitoyo, 2016) such as location of lineaments and structures, which could be host for resources like minerals, hydrocarbon and groundwater. It has also been used to map igneous rocks, metamorphic rocks and related structures due to their high magnetization when compared to other rocks. Aeromagnetic survey has been able to reveal the geospatial distribution and trend of magnetic and nonmagnetic bodies in the upper region (probably up to 10 km) of the Crust.

Mpape is one of the districts in Bwari Area Council of the Federal Capital Territory (FCT.), Abuja. It lies on the foothills and on top of the famous Mpape rocks that are easily sighted from the neighboring Maitama district (Dawam, 2000). Geographically, Mpape lies between latitudes9.113010˚ and 9.175699˚ North of the equator and Longitudes 7.463892˚ and 7.524349˚ East of the Greenwich Meridian (figure 1). With the rural-urban migration reportedly on the rise in Nigeria, the village has grown into an informal settlement with a population tethering over 1.1 million inhabitants without the commensurate infrastructure (Jimoh, 2017).

Mpape is predominantly underlain by high grade metamorphism and igneous rocks of Precambrian age generally trending, these rocks consist of gneiss, migmatites, granites and schist belt outcrops along the eastern margin of the area (FCDA, 1998). The rocky nature of Mpape makes it suitable for quarry business which thrives there (Jimoh, 2017; Okeke 2018).

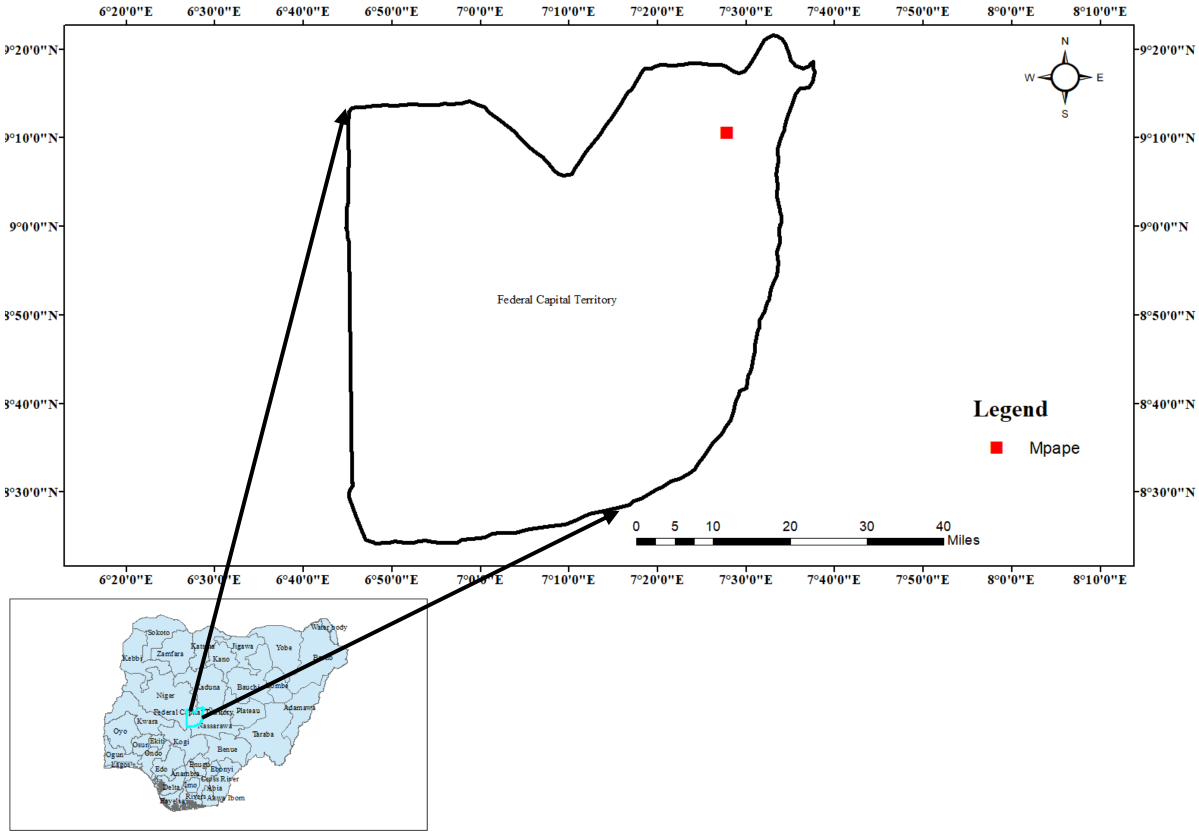

Figure 1: Map of Federal Capital Territory showing the study area.

The rocks are highly fractured and jointed showing essentially two fracture patterns, NE-SW and NW-SE. These fractures control the drainage and flow patterns of rivers in the area. However, minor cretaceous deposits of Nupe sandstones occur in the southern part of the FCT between Kwali and Abaji, extending to Rubochi and the border with Nasarawa state. Similarly, metasediments have also been mapped along a general

NNE-SSW direction through the west of Kusaki and east of Takushara (USGS, 1977). Mica schists occur around Kusaki and Buze villages.

The migmatite constitutes about 35% of the study area, outcropping in the SW part, while the migmatitic gneiss occur in the central and eastern part constituting 40% of the area. The gneisses outcropping as fine to medium grained granites gneisses in the NE part, cover about 13% of the surface area, while the coarse-grained older granites are exposed in the extreme NE corner where they constitute about 6% of the area forming small sized residual hills with rounded tops. The general NNE-SSW orientation of lithological facies exist in the area, and it is apparently related to Pan-African Orogeny.

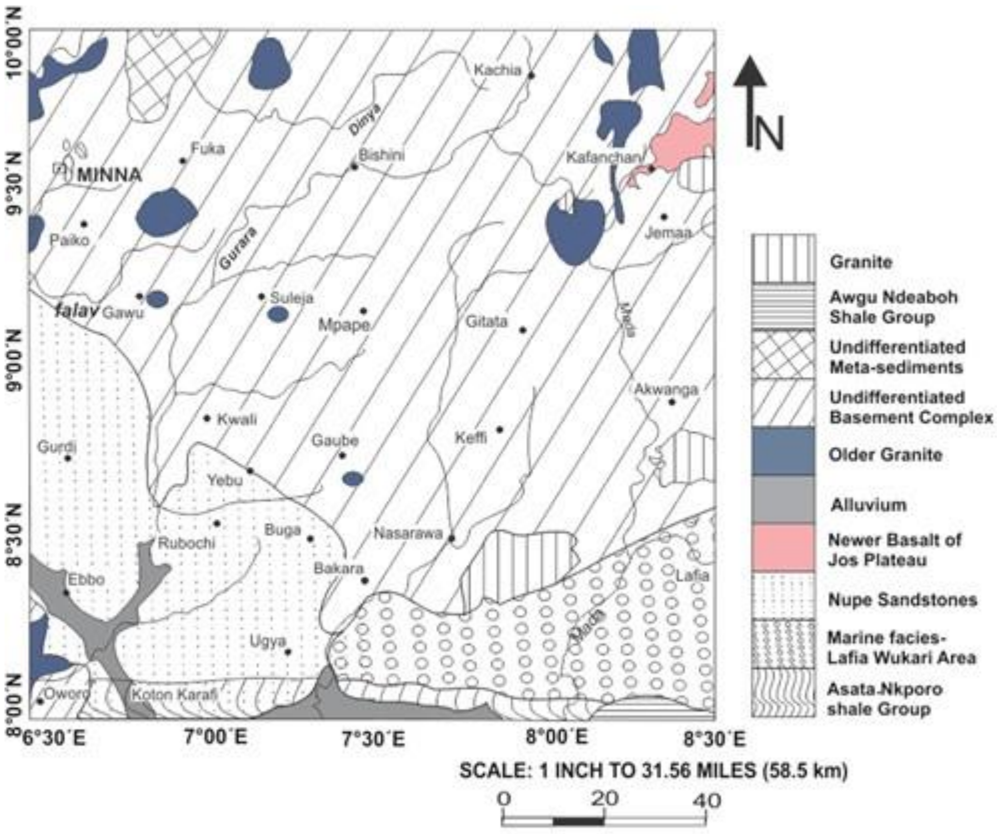

Figure 2: Geological map of the study area, showing the rock types (modified after NGSA, 2022).

MATERIALS AND METHODS

The Total Magnetic Intensity (TMI) aeromagnetic data that covers the study area, was used for this study. The TMI data was acquired by the Nigerian Geological Survey Agency (NGSA) popular geophysical campaign, which was done by Fugro Airborne Survey Limited, between 2005 and 2009. The data acquisition mode and necessary data corrections during the field campaign are in line with the NGSA rule for aeromagnetic data acquisition. The obtained data were in the Universal Transverse Mercator (UTM) coordinate format. The geomagnetic gradient was eliminated from the aeromagnetic data using the International Geomagnetic Reference Field (IGRF) formula of 2005. The aeromagnetic data was recorded in x, y, y format (that is, x and y are the coordinates, while z is the TMI for that point). The magnetic field intensity ranges from 33901 to 33099 nT (Figure 3).

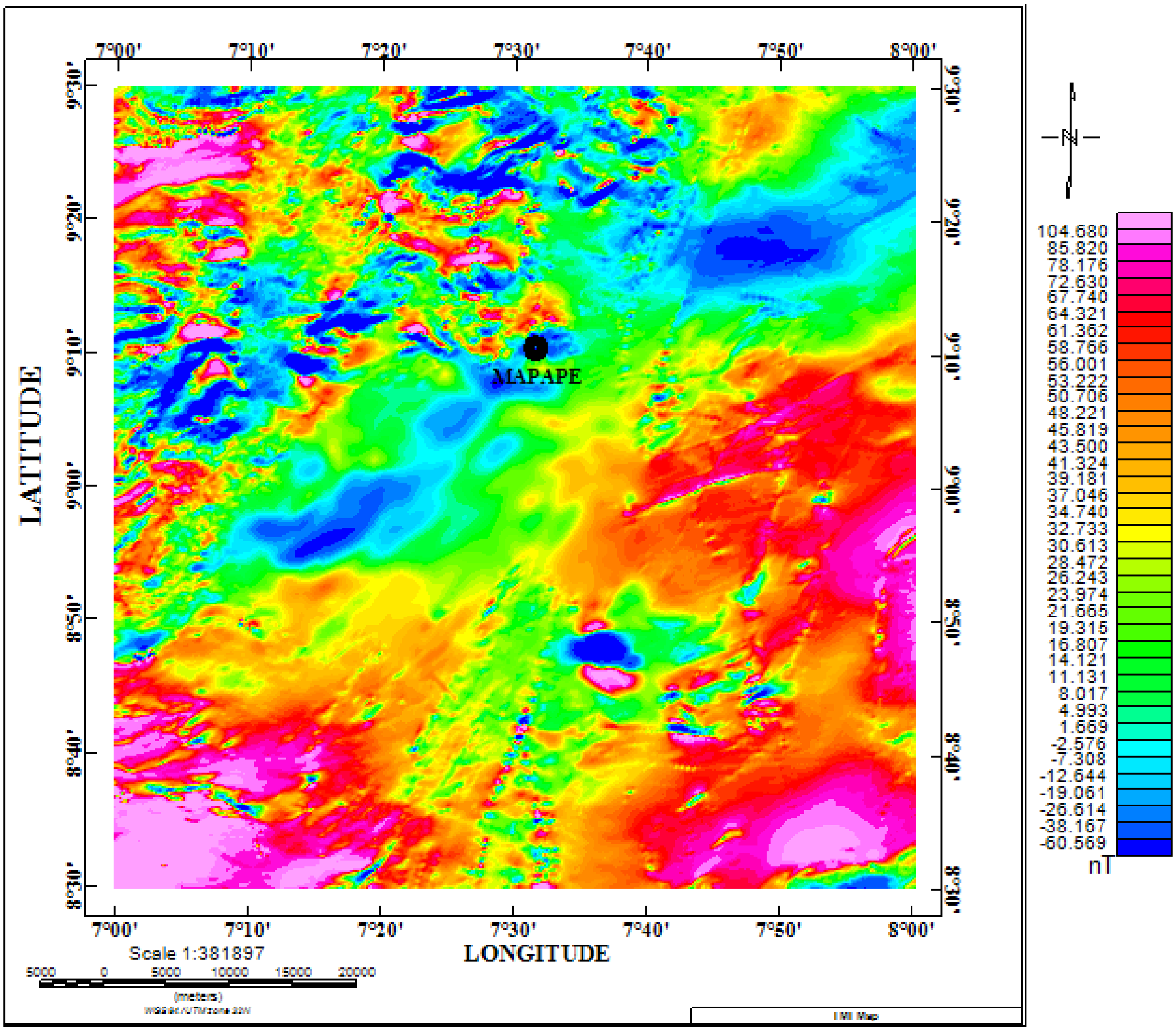

Figure 3: Total Magnetic Intensity of the Study Area and environs.

In order to have a meaningful interpretation, it was imperative to apply data reduction technique on the TMI. This will enable the residual and regional field data to be separated from the TMI. To achieve this, the Fast Fourier Transform was used for data conversion and reduction, which was used to produce the residual magnetic data of the study area. Figure 4 shows the residual map of the study area.

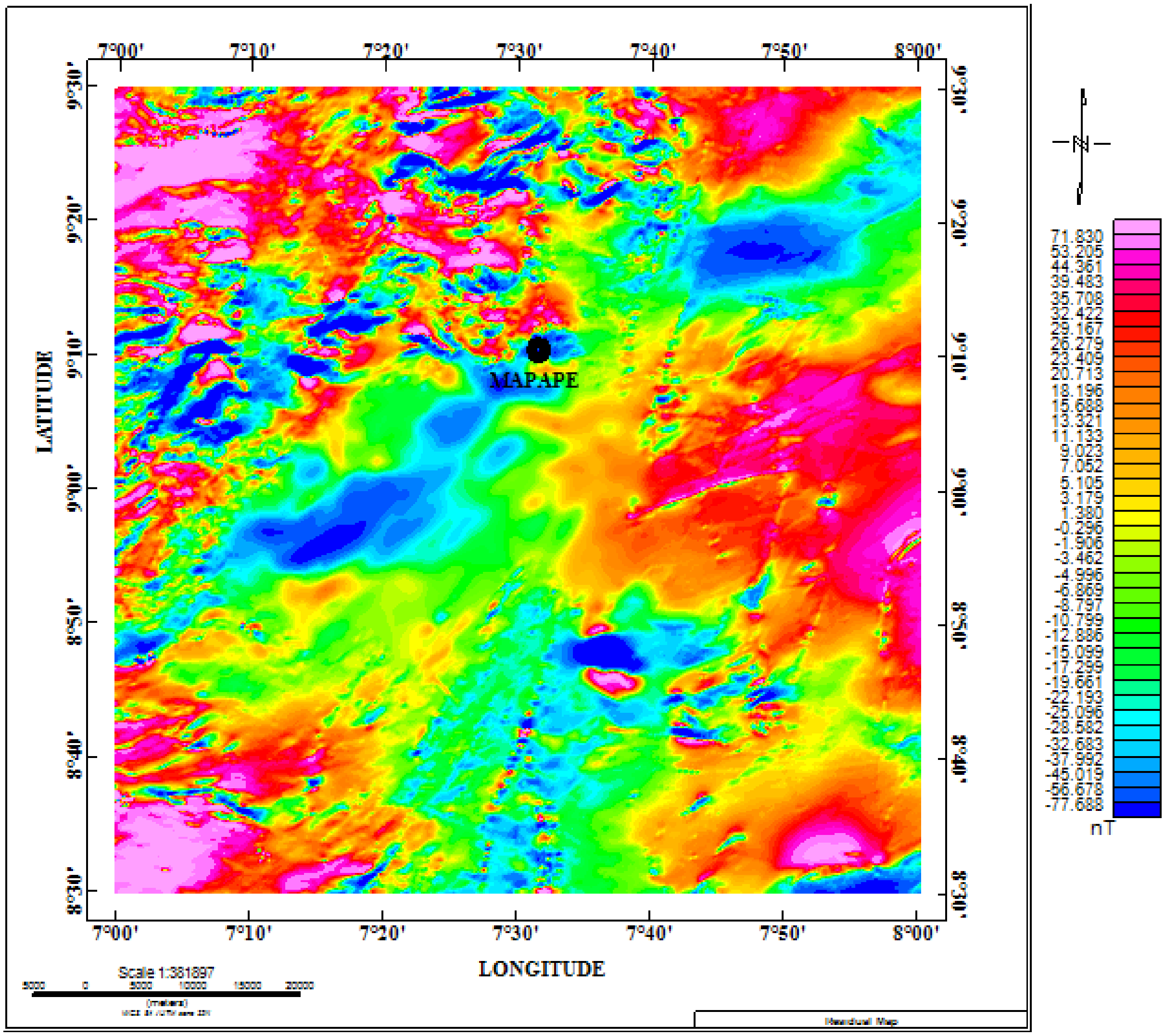

Figure 4: Residual Map of the study area and environs.

RESULTS AND DISCUSSION

Results

***Lineament Extraction*:** Lineaments are indicators of possible faulting or existence of other tectonic features. Lineament-enhancement technique were applied on the residual map in order to investigate the basic tectonic pattern of the study area. Figure 4 shows the lineament map, indicating possible fault lines all across the study area and environs. The lineaments seem to form a trend in the NE-SW direction, and the study area seem to reside on a fault line.

3D Euler Deconvolution: Thompson (1982) applied the 3D Euler technique to profile data, and this method was subsequently advanced to gridded data by Reid *et al.*, (1990). The 3D Euler process has been used to estimate the subsurface characteristics and depth location of features like; fault, geological contacts, lineaments, dykes, and sills.

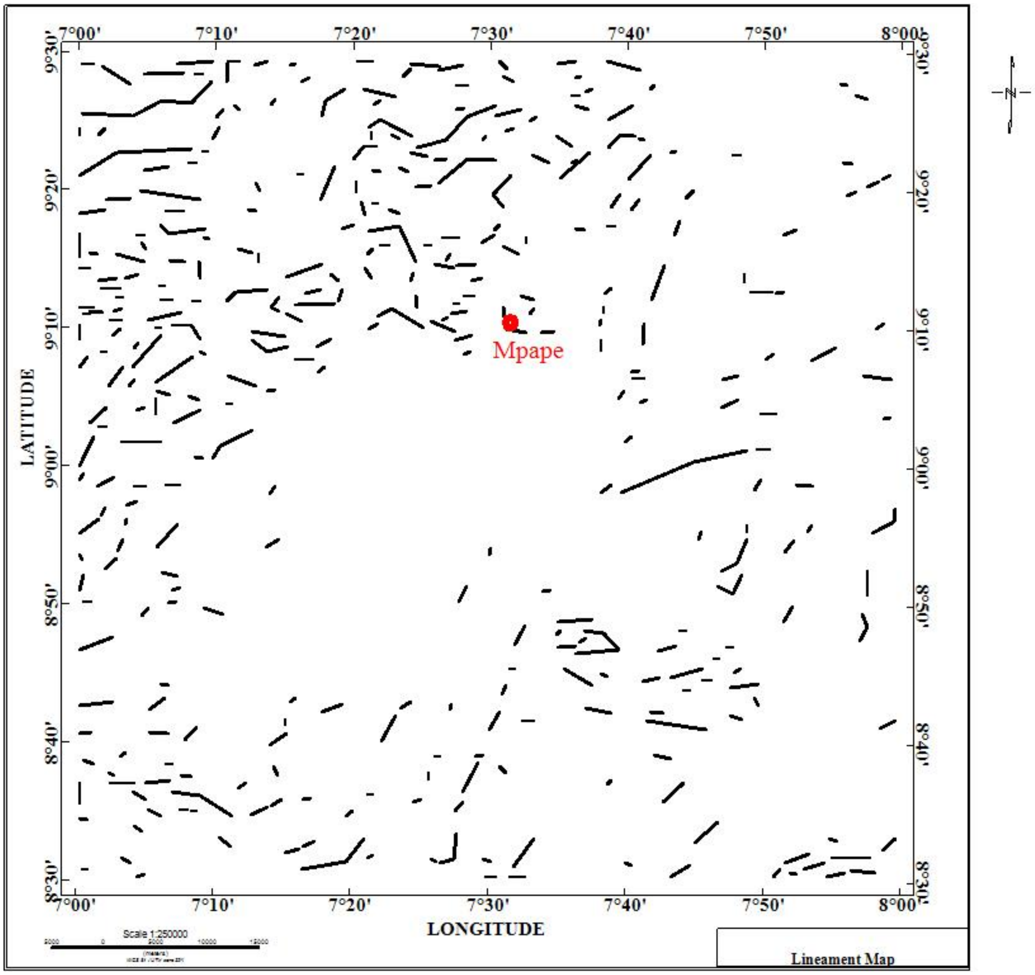

Figure 5: Lineaments extracted from the residual map of the study area and environs.

It requires information about causal bodies, which may be obtained by defining the structural index (SI) which is the rate of field change (Eweis *et al.*, 2021). The Euler's solutions were applied to the Shaded Residual aeromagnetic map shows the map in figure 6. A SI = 0.5 for the residual aeromagnetic map, gave good solutions for the lineaments, geological contacts, and faults. A solution shows a Geologic cluster around the region where the source bodies are located (Figure 6). The direction of primary trend can be seen to move in the NE–SW direction, and the depth of geologic structures associated as fault lines are in the range of 400 m-1500 m.

***H-gradient anomaly map*:** The H-gradient technique was used to interpret Residual aeromagnetic data. Figure 7 shows significant faults trending in the NE–SE directions.

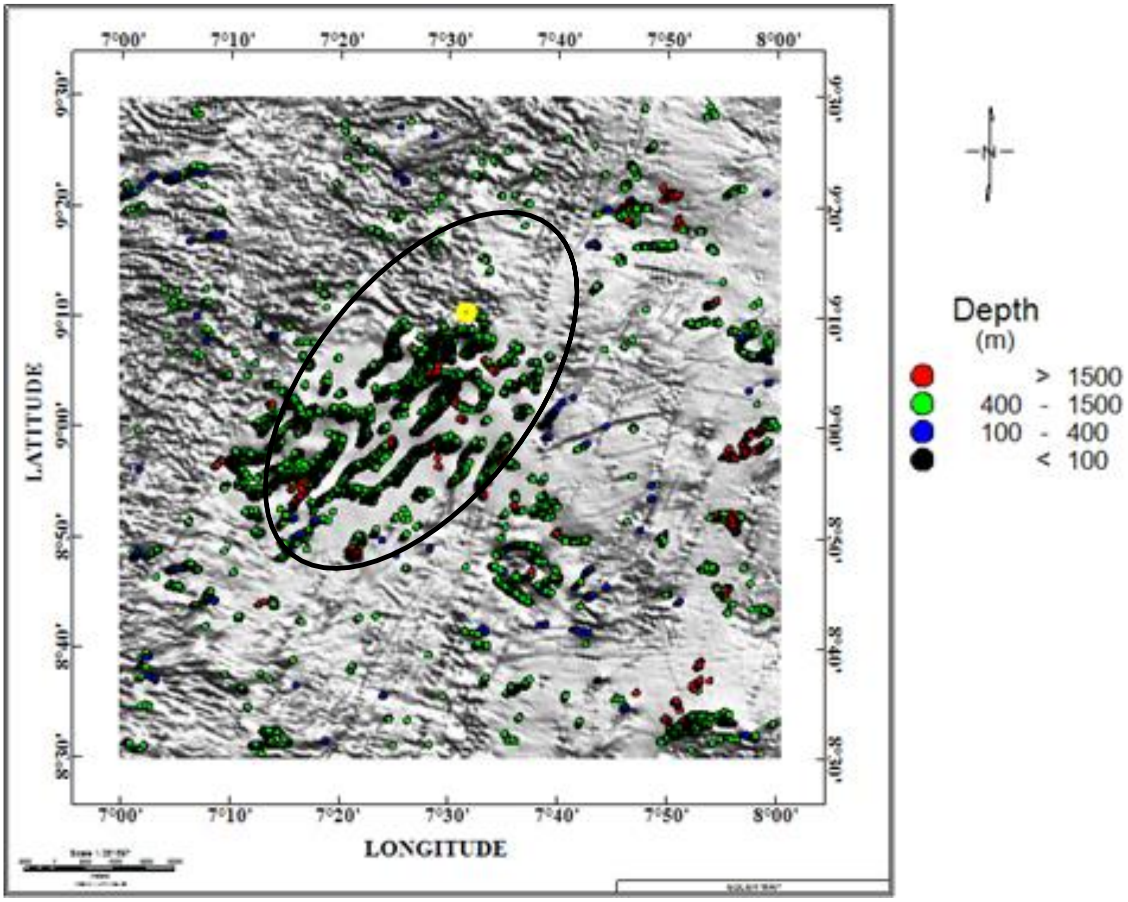

Figure 6: 3D Euler's solutions for residual aeromagnetic data with S.I = 0.5

It is also obvious that the locations of major faults are parallel to the geological and lithological boundaries of the Abuja region. Positive anomalies with values ranging from 0.004 – 0.024nT are noticed around the Mpape region. These anomalies could be traced to the crystalline basement complex and may be connected to the granite–gneiss intrusions within the region.

***Source Parameter Imaging*:** The Source Parameter Imaging (SPI), derived from the residual magnetic data was used to calculate the depth of magnetic sources. Figure 8 shows that the depth ranges from 150 m to 1,000 m but around the study area it ranges from 500-800 m.

Power Spectral Analysis: Two dimensional techniques for Spectral analysis of magnetic data have been described by several Authors (Ofoegbu *et al.,* 1992; Kolawole *et al.,* 2017). The average depth to magnetic sources of the block which made up the study area was computed. A cut-off wavenumber of 0.054 km^{-1} adopted from the point of change of the short and long

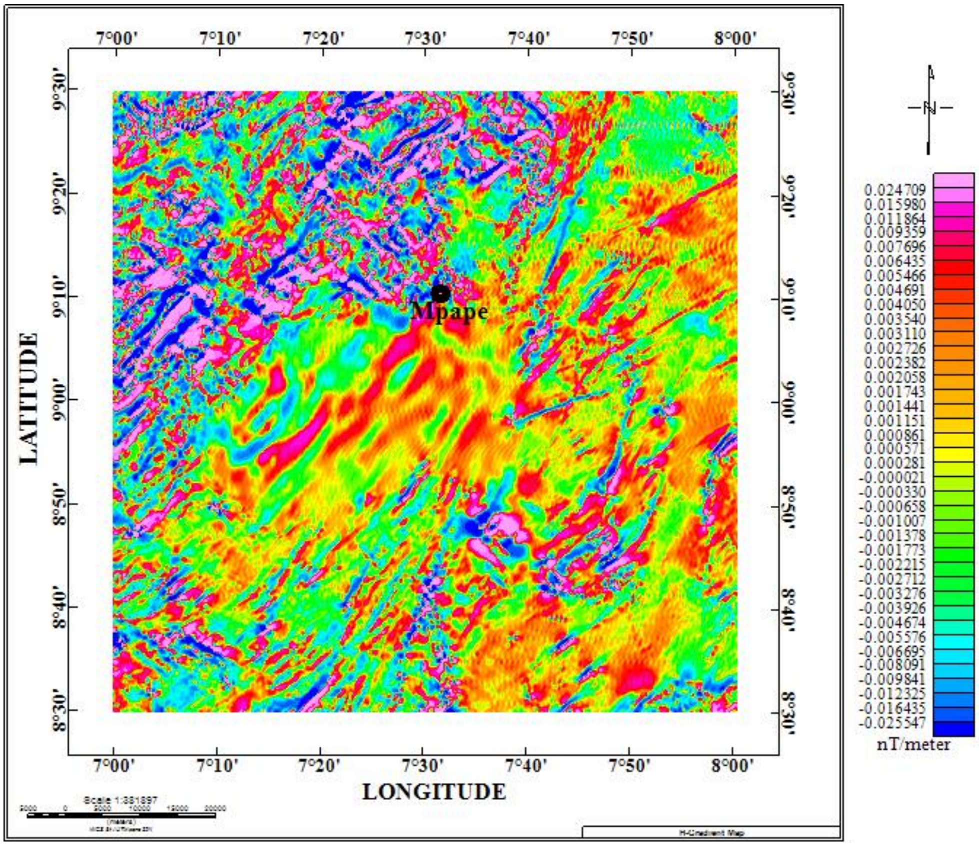

Figure 7: The H-gradient map for the residual aeromagnetic data.

Wavenumber segments of the power spectrum was used to correct for topography. The top-bound and centroid of magnetic source in the region are represented as Z_t and Z_0, respectively, and were calculated from the power spectrum of magnetic anomalies (figure 9). We utilized results from the evaluations to estimate the basal depth of the magnetic source Z_b, using the expression; $Z_b = 2Z_0 - Z_t$

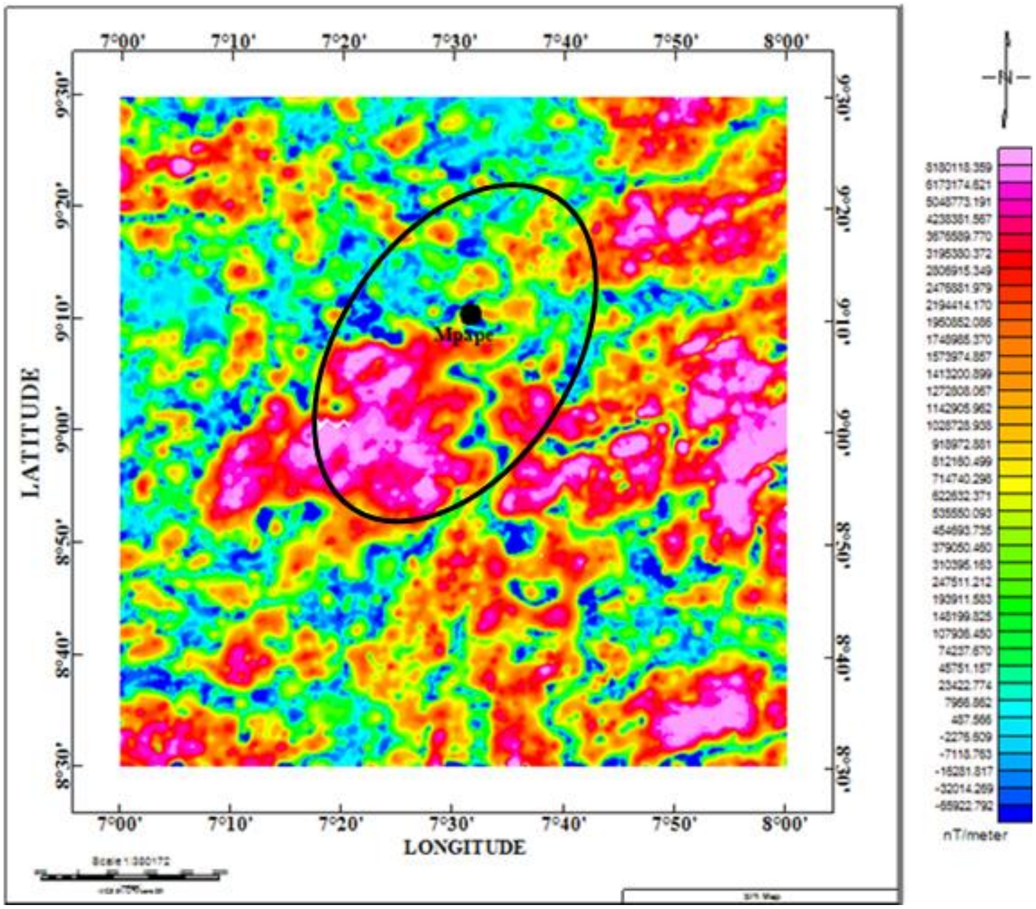

Figure 8: The SPI map for the residual aeromagnetic data.

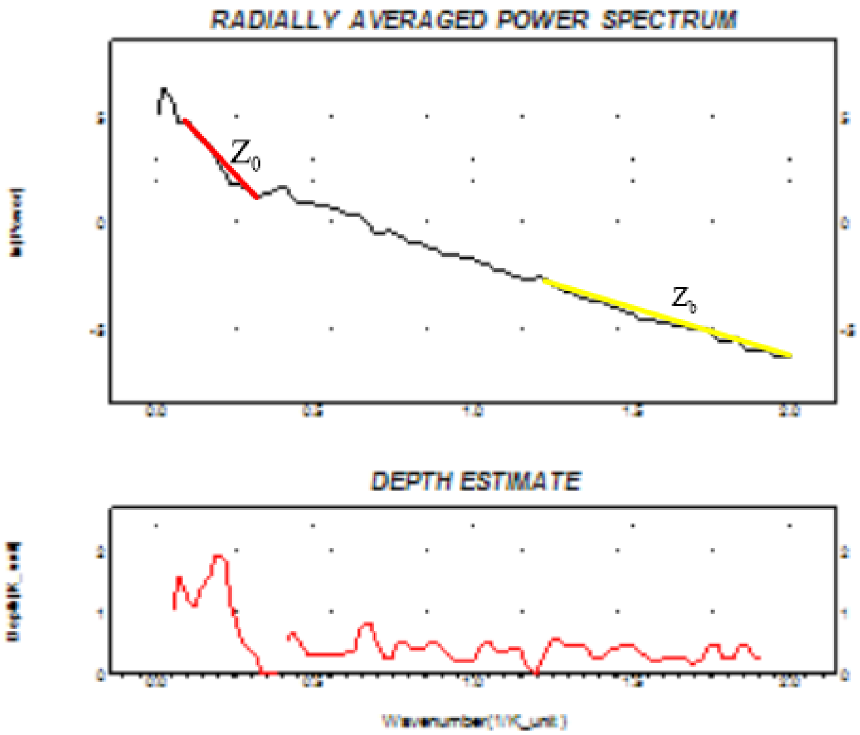

Figure 9: Radially power spectral analysis from residual aeromagnetic data.

Discussion

Ignoring earth tremor events in Nigeria would be a bad choice because they could be precursors to big earthquakes. Examining the Precambrian fractures and their extension into the Atlantic Ocean can assist us in understanding the mechanism causing this seismic activity. While the Ivory Coast fracture zone is thought to be linked to seismic activity near Abidjan (Burke, 1969), Francheteau and Le Pichon (1972) previously identified a link between the tremor-prone Akwapim fault near Accra, Ghana, and the Romanche fracture zone. Similar to this, seismic activity at Kribi, Cameroon, is thought to occur along the Ascension fracture zone's landward extension (Burke, 1969). The trends of the Atlantic fracture zones and the basement faults are similarly correlated in Sierra Leone. The destructive quake that struck Guinea in 1983, according to Kogbe and Delbos (1984), occurred along the suture zone between the West African craton and nearby upper Proterozoic metasediments, which is thought to represent the landward expansion of the Guinea fracture zone.

Since Nigeria lies on the same flank of the Atlantic Ocean as the countries mentioned earlier, similar features are expected. The presence of fracture zones which prominently traverse the western half of Nigeria had been pointed out by Ajakaiye et al (1987), Odeyemi (2006) and Elueze (2003). This megastructure named Ifewara-Zungeru fault is the longest linear feature within the Precambrian basement complex of Nigeria, and stretches from East of Ijebu-Ode in the South, through Ifewara, Iwaraja and Okemesi, to the basin of river Niger, South of Lafiagi to Zungeru and beyond to Kalangai in Northwestern Nigeria (Anifowose *et al.*, 2010). The reported occurrence of an earth tremor in Mpape which lies along the northward extension of this fault zone also supports the existence of this fault zone.

Our investigation of the location of a recent earth tremor in Nigeria's capital has given us significant information for comprehending the subsurface structures in this area. This investigation was required to calm anxiety, quell panic, and dispel rumors about what causes earth tremors while also examining how subterranean structures affect earthquake occurrences. The research area has seen tectonic activity, which has caused structural displacement of rocks in a way reminiscent of that seen during the Pan-African brittle deformation.

The aeromagnetic residual map shows low magnetic anomalies around the Mpape region. Given that this region is situated within the crystalline basement complex, the recorded lows, may show subsurface structural deformation in the region. A correlation of the residual aeromagnetic map with the geological map, places the crystalline basement complex as a region with lower positive magnetic anomalies and the sedimentary region with dominant higher magnetic anomalies. This observation may be attributed to the relatively low-susceptibility of granite, migmatite–gneiss, and schist rock composition of the crystalline complex against the basic shale and sandstone composition of the sedimentary terrain.

Considering the solutions generated from the Euler deconvolution technique, it was observed that the solutions clustered around the geologic structures associated with fault lines. These structures are situated around the study area, and they trend in the NE-SW direction at a depth ranging from 400 m- 1500 m. This result conforms Adepelumi *et al.*, (2008), who suggested that the causative mechanisms leading to the Abuja tremor were fault rupture along a NE–SW striking and NW dipping normal fault that ruptured at 15– 20 km depth.

Based on magnetic data, it has been found that the depth to the magnetic crust's base (basal depths) varies between 11.38 and 17.4 km, with an average of 15.26 0.40 km over the area covered by the coverage. At Mpape, the estimated basal depth averaged 12 km, this indicates a shallow depth to basement. The Mpape region's shallow basal depth is the result of subsurface intrusion, which also caused the region's significant subsurface faulting and fractures. The active crust in the Mpape region is located in the earth's top crust, according to Moho depth calculations.

CONCLUSION

For years, Nigeria was thought to be aseismic and this development made Nigerian geoscientists develop a lackadaisical attitude towards research into the occurrences of earthquakes in the country, hence, very little has been done before the 1984 event. The seismic events of 1984, 1990, 2000 and 2018 in the country aroused the consciousness of Nigerian geoscientists to the fact that the country might not be tectonically stable as earlier thought. This most recent event at Mpape has further triggered the need for National concern and the need to establish National structures that will provide adequate data for present and future study on Earthquakes in Nigeria. The aeromagnetic results has shown positive correlation with the geological structure of the study area, where low magnetic anomalies implies subsurface or surface deformation of the crystalline basement complex. The Euler solutions shows large clusters in the study area which also implies geological structures associated with fault lines. This can be obvious from the lineament trends NE-SW direction. Based on the magnetic informations of the study area, the basal depth varies from 11.38 km to 17.40 km (average 14.39 +/-0.40 km). this shows a shallow depth of the basement resulting from subsurface intrusion which are obvious cause of the region's significan subsurface faulting and fracture system forming weak zones and conduit path through which subsurface pressure can be released inform of tremors. The continuity of such activities can some day lead to larger tremor which forms and Earthquake. The active crust in the Mpape region is located in the earth's top crust, according to Moho depth calculations. We assume that this investigation will provide the necessary details on the subsurface structural configuration in charge of the recent earth earthquakes in the Mpape region. The outcomes might also direct the development of the region's infrastructure. This study could help identify areas that are more susceptible to earth tremors so that appropriate monitoring and evaluation systems could be quickly established. We wish to recommend that more Seismic stations be built all over the country to monitor the occurrence of this tremors to reduce future disasters.

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CONFLICT OF INTEREST
The authors wish to state that there are no conflict of interest in the work presented for review.

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