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Utilizing Magnetic Signatures to Investigate Geologic Strength Using Computer Software in Parts of Ibadan, Nigeria

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Abstract

In light of earthquake activity and its consequences for civil engineering construction, this study explores the subsurface stability of Ibadan, Nigeria. The study uses high-resolution aeromagnetic data to perform a thorough structural analysis, with an emphasis on the identification of fault systems and their possible relationship to seismic activity. It does this by using Geosoft Oasis Montaj 6.4.2 data processing and analysis software. Numerous crystalline rocks, such as the gneiss-migmatite complex, quartz, pegmatite, amphibolites, xenoliths, and aplites, compose the geological framework of Ibadan. The study area is 55 by 55 km in size and is situated in the southwest of Nigeria. Its latitudes are 3° 30' to 4° 00' east and 7° 00' to 7° 30' north. The total magnetic intensity (TMI) data that Fugro Airborne Survey Limited gathered between 2003 and 2009 served as the foundation for the aeromagnetic study. The collected data was carefully processed, going through stages like leveling, gridding, correction for the International Geomagnetic Reference Field, and de-cultivation. To extract meaningful information, reduction techniques were used, such as the Total Horizontal Derivative (THDR) and the Reduction to Magnetic Equator (RTE). Based on magnetic lineament analysis, the results show three prominent fault trends: ENE-WSW, NW-SE, and NE-SW. The possible seismic significance of these fault trends is highlighted by the structural analysis, which includes a superimposition of magnetic faults on the updated geological map. There is a correlation between the observed tremors in Ogun State and Ibadan and historical earthquake events, specifically the NE-SW and ENE-WSW fault sets. Insights from this study are very helpful for Ibadan's construction planning and earthquake risk assessment. The detected fault systems emphasize how crucial it is to take seismic hazards into account when planning urban development projects, particularly the NE-SW and ENE-WSW trends. A solid basis for well-informed decision-making is provided by the software-enabled analysis, which improves the area's earthquake readiness and helps to build resilient infrastructure.

Keywords: Geologic strength, Structural analysis, aeromagnetic data, Ibadan, Tremor

Introduction

Nwankwoala and Orji (2018) have demonstrated that an earthquake occurs when there is sufficient energy to drive fracture propagation along a fault plane. Over a period of approximately 85 years, 39 tremors have been recorded in Nigeria (Nwankwoala & Orji, 2018; Ofonime et al., 2010; Eze et al., 2011; Nwankwoala, 2018). While other microseismic activity has been felt in the city without a credible account of it happening, seven of the total events have been reported about Ibadan (Nwankwoala & Orji, 2018). A few of the early warning signs of earthquakes that have not been proven by science include flavor changes in groundwater, unusual behaviors of animals, tilting or bulging of the Earth's surface, gas discharges from below, color changes in the sky, and the occurrence of foreshocks (Cicerone et al.,2009). The African continent is composed of stable Pre-Cambrian basement rocks (Adagunodo et al., 2018a). These rocks can be classified as igneous, meta-igneous, or meta-sedimentary based on their composition. Above the basement rocks are a variety of geologic features, such as sedimentary, volcanic, and unconsolidated structures. Situated on the remobilized portion of West African basement rocks, Nigeria is one of the most important countries in Africa, and it has been plagued by a number of small earthquakes, also known as tremors, since 1933. It was previously believed that these rocks were not seismic. Earth's surface vibrates and produces tremors when energy is abruptly released from the lithosphere (Nwankwoala & Orji, 2018). A structural analysis of Ibadan's subsurface

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structures is necessary to ascertain the strength of the underlying bedrock for the construction of civil engineering structures. Ibadan is a major town in southwest Nigeria. In order to prevent physical structures like dams, bridges, highways, and buildings from constantly breaking down and collapsing, subsurface mapping is essential for evaluating whether a structure is appropriate for civil engineering (Hammed et al., 2018). The continuous collapse of physical structures has placed the lives and property of Nigerians residing in the vicinity of these areas in grave danger. In Nigeria, geophysicists are now expected to conduct pre- and post-foundation studies, especially in a number of megacities where state governments are initiating "Urban Renewal Projects." This will contribute to reducing the probability of structural breakdowns in the country. Civil engineers can use near-surface feature information from foundation studies using geophysical methods when designing the foundation for their projects (Adagunodo et al., 2017). It is also a more economical approach than the geotechnical method in terms of expenses and the area inspected during site inspection (Adagunodo et al., 2015c). Many authors have demonstrated the usefulness of geophysical techniques in civil engineering (Ozcep & Ozcep, 2011; Oyeyemi et al., 2017). According to Adagunodo et al. (2015e), these methods include seismic refraction, electrical resistivity, electromagnetic and magnetic approaches, and gravity. The current study used the magnetic approach to investigate the subsurface stability in Ibadan, Nigeria, in order to aid construction engineers in understanding the geo-structural settings of this study region.

There are currently three primary types of magnetic surveys that are available: aeromagnetic, marine, and ground magnetic. All these types of surveys have been discussed (Adagunodo et al., 2015c). Of the three magnetic method types, aeromagnetic survey is thought to be the most effective for regional studies due to its speed, ability to cover a large area quickly, and lack of obstacles like water, mountains, forests, sacred locations, and vegetation (Okpoli & Eyitoyo, 2016). This benefit has come from the structural analysis of Ibadan, southwest Nigeria, using high-resolution aeromagnetic data. Aeromagnetic data analysis has proven useful in the interpretation of buried characteristics found in Pre-Cambrian basement rocks and sedimentary landscapes. These characteristics include the locations of lineaments and structures that may host resources such as minerals, hydrocarbons, and groundwater (Oladunjoye et al., 2016; Okpoli & Ekere, 2017). Igneous rocks, metamorphic rocks, and related structures have also been mapped using this method because of their higher magnetization than other rocks (Reynolds et al. 1990). Aeromagnetic survey has revealed the geographical distribution and trend of magnetic and nonmagnetic materials in the upper part of the crust (possibly up to 10 km) (Gunn, 1975). A few of the earlier works on the topic are listed in the references (Sunmonu et al., 2013; Okpoli & Ekere, 2017; Badmus et al., 2013; Ganiyu et al., 2018).

The various series of units that comprise the crystalline rocks of Ibadan include the gneiss-migmatite complex, quartz, pegmatite, amphibolites, xenoliths, and aplites. The southwest part of Nigeria is home to Ibadan, the capital of Oyo state. Its borders are Kwara state to the north, Osun state to the east, Ogun state to the south, and the Republic of Benin to the west (Fig. 1). The study area is the largest indigenous city in West Africa, spanning 55 by 55 km, with a total area of 3023 km^2. It lies in the latitude range of 3° 30' to 4° 00' east and 7° 00' to 7° 30' north. Ibadan's geology is found in the Basement complex rocks of southwestern (SW) Nigeria, which are thought to be Pre-Cambrian in age.

Materials and Methods

Fugro Airborne Survey Limited gathered the TMI data from 2003 to 2009 as a component of the well-known geophysical campaign conducted by the Nigerian Geological Survey Agency (Adagunodo et al., 2018e). The aeromagnetic Total Magnetic Intensity (TMI) data from Ibadan, southwest Nigeria, were used in this study. The data collection strategy used in the field campaign and any required data revisions comply with the NGSA standard for the acquisition of aeromagnetic data (Nigerian Geological Survey Agency, 2008) (Adagunodo et al., 2018d). In order to mitigate latitudinal effects and enhance signal-to-noise ratio, the acquired data underwent de-cultivation, leveling, International Geomagnetic Reference Field correction, and gridding (Patterson & Reeves, 1985).

For the TMI to be interpreted meaningfully, data reduction techniques must be applied (McEnroe et al., 2004). As a result, the residual data and regional field data from the TMI can be extracted. To do this, the Fast Fourier Transform which was also used for data conversion and reduction was used to generate the remaining magnetic data from the research area. The Reduction to Magnetic Equator (RTE) technique was selected due to the study's proximity to the Equator. This approach is in line with the tactics used by Okpoli and Ekere (2017) and Adagunodo et al. (2018d). When working with shallow magnetic sources and rock types that exhibit significant variations in magnetism, data reduction and processing become essential (Gunn & Dentith, 1997). The beauty of aeromagnetic data is that residual data can be meaningfully interpreted by comparing it to the geological map of the area. To improve the strength of the magnetic source edges, Total Horizontal Derivative was applied. The boundaries of intrusive bodies (Gunn & Dentith,

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1997), faults, and other lateral variations are defined by the THDR based on the detection technique. The theoretical foundations of this enhancement strategy have been studied by Blakely (1996).

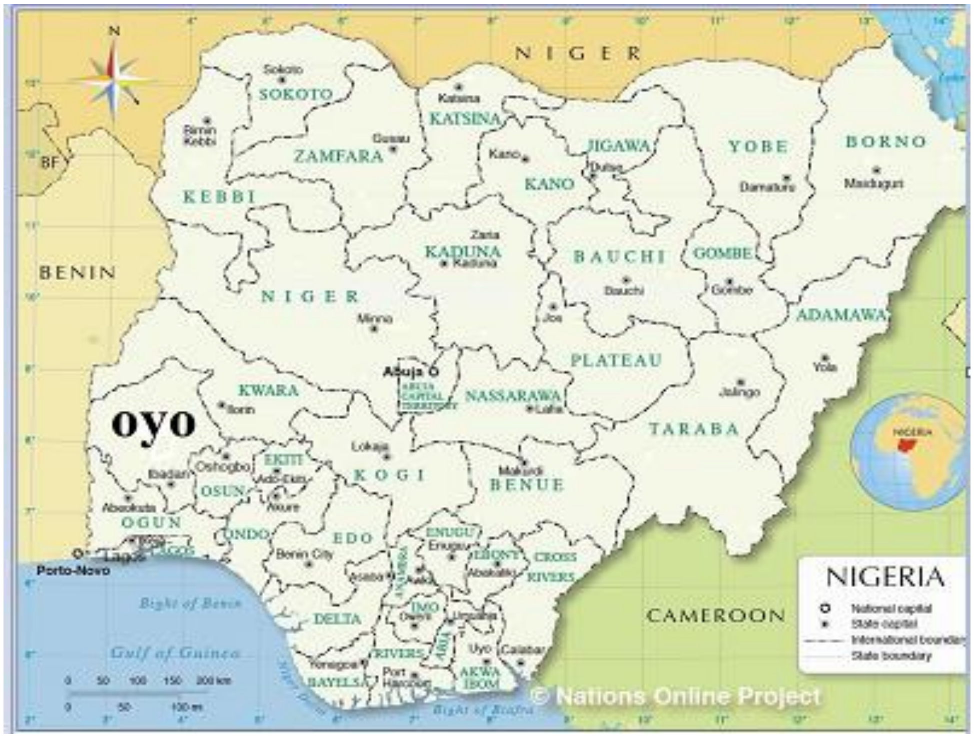

Fig. 1: Map of Nigeria showing the study area – the capital of Oyo state.

Results

The TMI, regional, and RTE residual maps are shown in Figs. 2–4. After the regional field has been eliminated from the TMI, it is demonstrated that there is no discernible change in the pattern of magnetic anomalies generated on either the RTE residual map (Fig. 4) or the TMI (Fig. 2). As seen in Fig. 4, the research area displays magnetic anomalies of high (H), middle (MED), and low (L) magnitudes. The high magnitude magnetic anomaly signals, represented by the red and pink colors, had magnetic field intensities ranging from 19.5 to 109.1 nT. Two parallel ridges that stretch from northwest to southeast are formed by their dispersion throughout Ibadan (Wynn, 2002). As seen in Fig. 3, these sites are lithologically consistent with granite gneiss, migmatite, and banded gneiss, three contrasting basement rocks found in Ibadan (Adagunodo et al., 2018a). These zones are thought to be comparatively shallow in relation to magnetic sources, per Hubbard's definition from 1975. The intermediate magnetic anomalies signature, represented by the green color, had a magnetic susceptibility ranging from 3.2 to 19.5 nT. Northwest to southeast is their primary direction. These signatures are separated by depression and uplift and located between two parallel NW-SE magnetic high ridges. These regions correlate lithologically with quartzite/quartz-schist and quartzite, and are thought to be medium depths to the magnetic source (Fig. 3). It is known that quartzite and quartz-schist have intermediate magnetic susceptibilities (Adagunodo et al., 2018e).

The blue-colored low magnetic anomalies had magnetic field strengths between -83.6 and -3.2 nT. They appear as depressions in the west-southwestern, central, and north-central sections of Ibadan, but they are most noticeable in the northern and eastern sections where they form a recumbent fold-like structure. As an illustration of how they frequently result from granitic intrusion in basement complex (Nwankwoala & Orji, 2018), which represents areas of deep depth to the magnetic source (Ganiyu et al., 2018), consider the intrusion of quartzite/quartz-schist by migmatite and banded gneiss on the geologic map (Fig. 3) of Ibadan.

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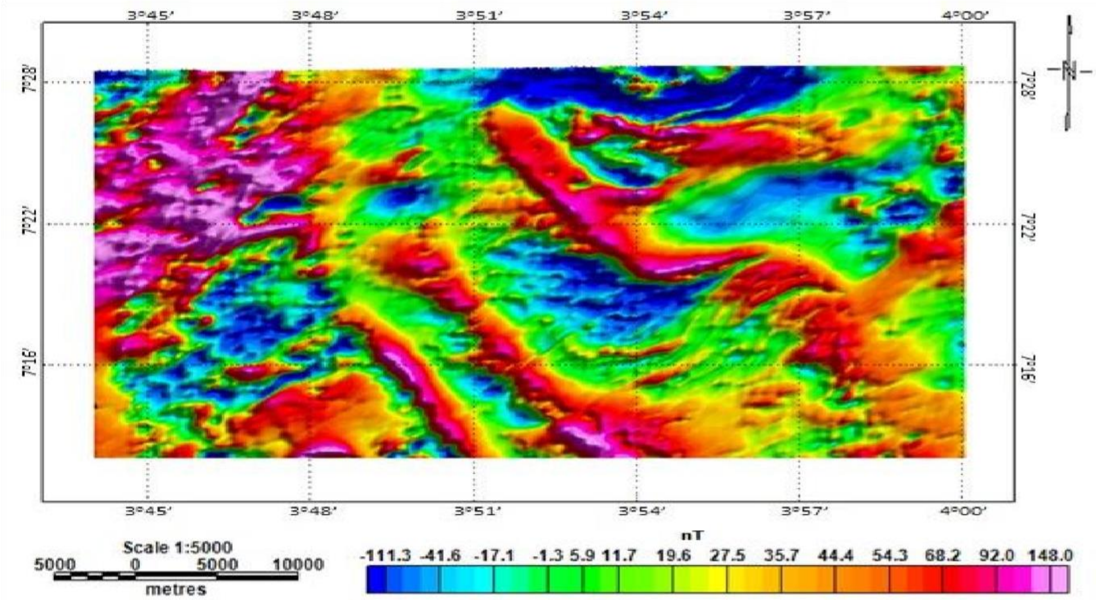

Fig. 2**:** TMI map of the study area.

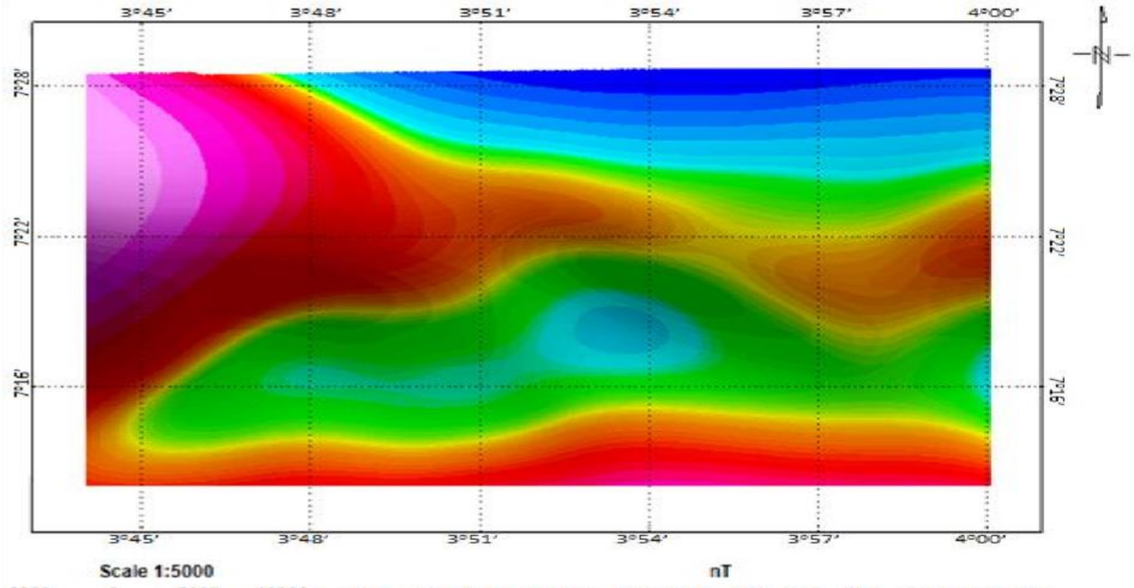

Fig. 3: Regional magnetic field of the study area.

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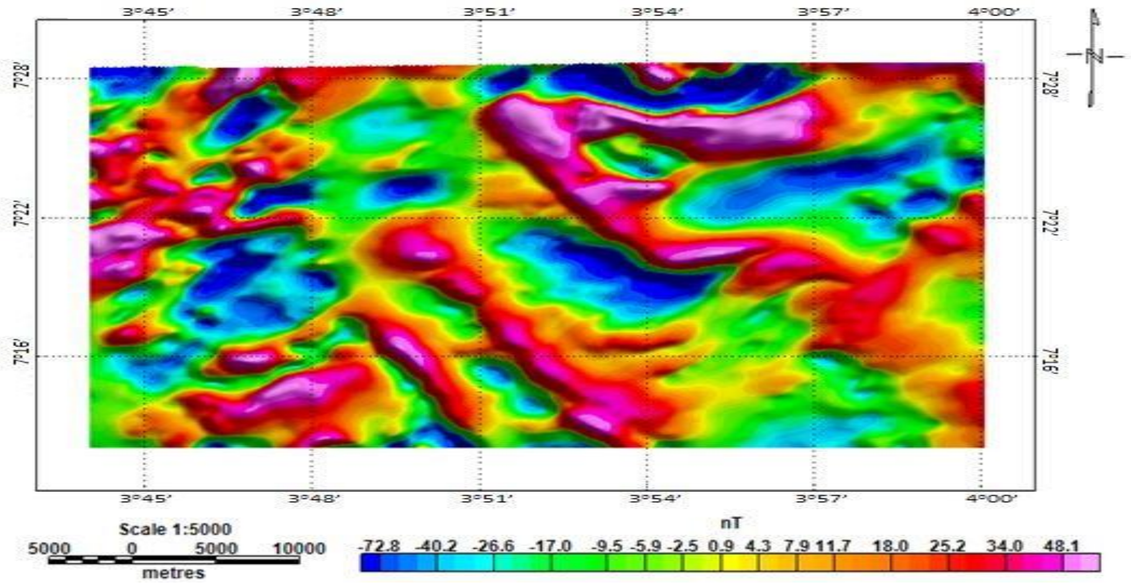

Fig. 4: RTE residual map of the study area.

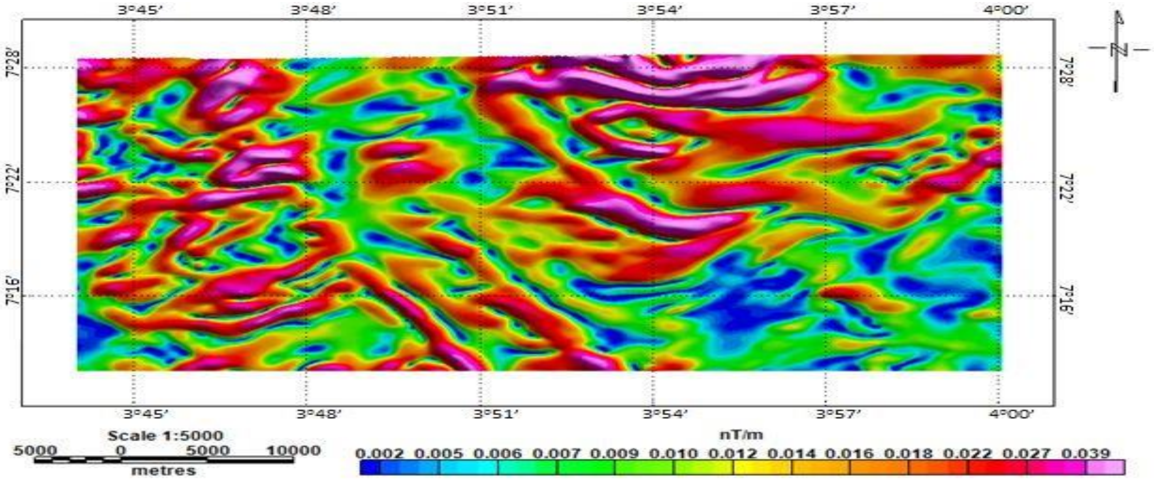

Fig. 5**:** The THDR Map showing the locations of Magnetic contacts as Peak Amplitude of the study area.

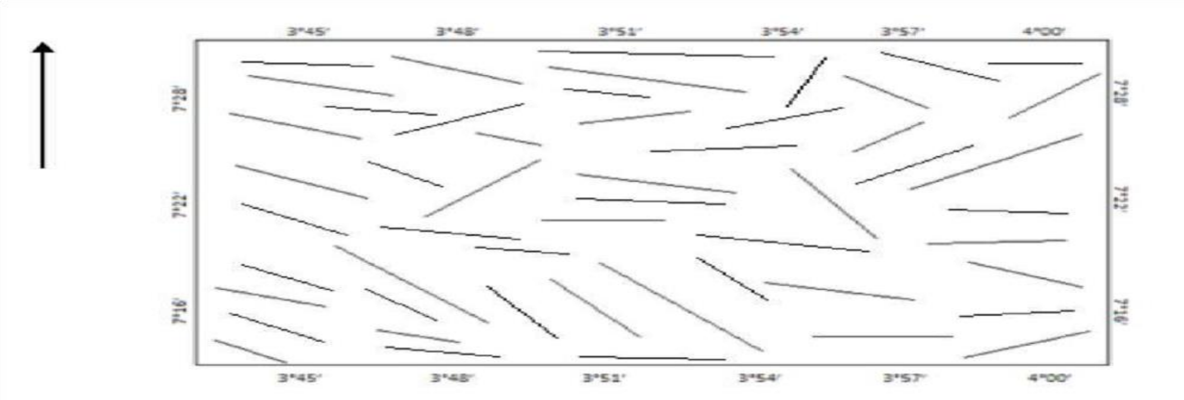

Fig 6: Magnetic lineaments map extracted from the THDR signatures

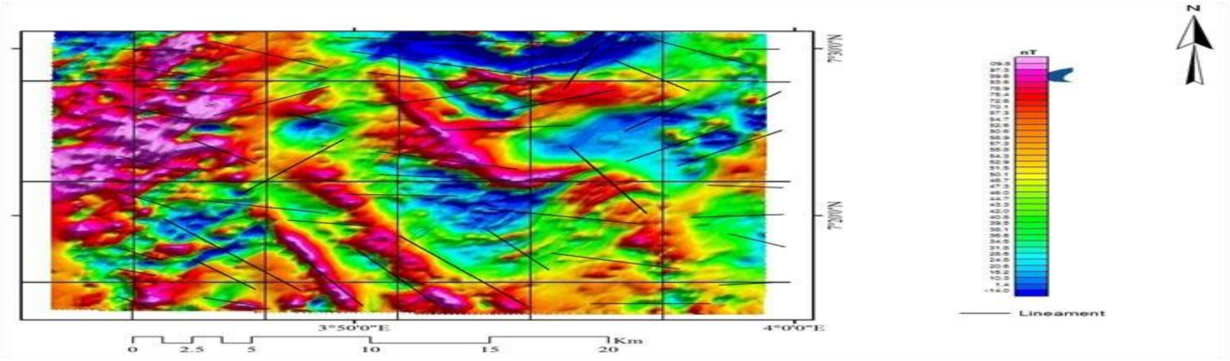

Fig. 7: Superimposition of the lineaments on the RTE residual map

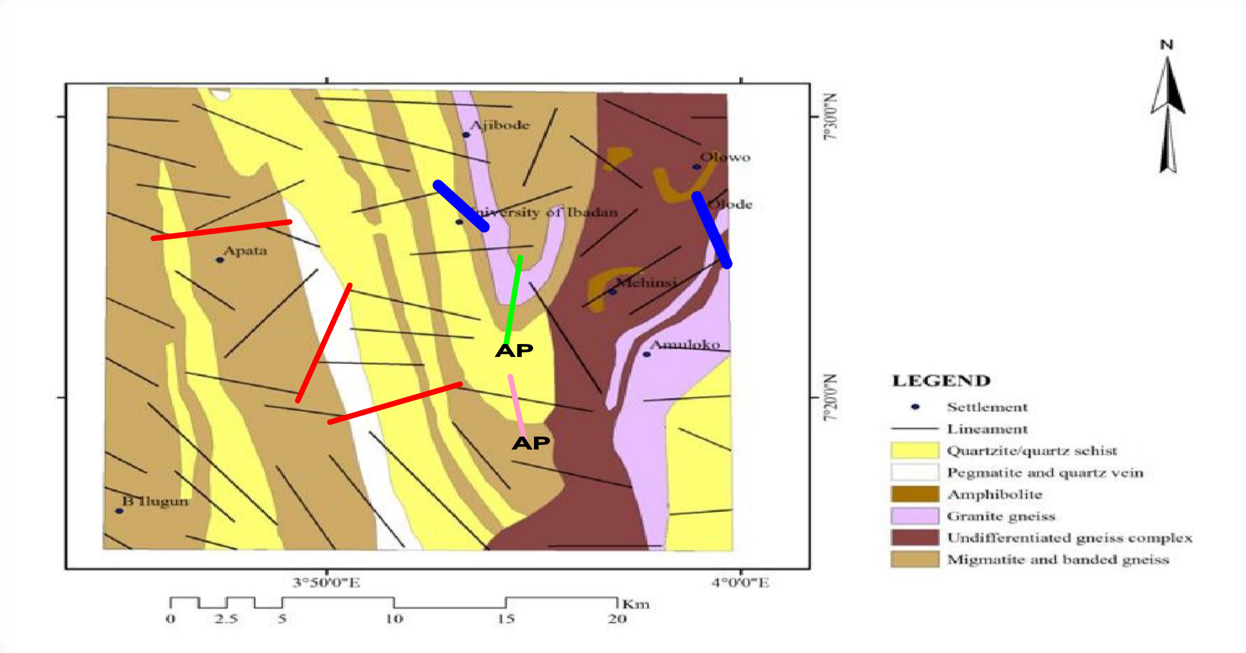

Fig. 8: Composite map of the study area

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Discussion

Fig. 5 displays the THDR map that was produced using the RTE residual magnetic map (Fig. 4). Changes in the inferred contact patterns (e.g., general direction and spacing) could identify two distinct structural domains within the research area. The main directions of orientation on the THDR map of Ibadan are east, west, and south. The amplitude of the gradient ranges from 0.02 to 0.039 nT/m. The THDR map is used to extract lines for use in magnetic lineaments analysis. Figure 6 shows the extracted lineaments map. Out of the 53 line segments that were recovered from the THDR of Ibadan, NE-SW accounted for 50% of the distribution and is the most dominant, exposing 17% of the distribution, while E-W is the least prevalent.

A magnetic fault map produced by superimposing the lineaments recovered from the THDR map (Fig. 7) and the modified geologic map of Ibadan (Fig. 8) were used in the structural framework analysis of the research area, which was carried out using ArcGIS 10.3 software. Reddish-purple and blue in color, magnetic faults are caused by the offset of magnetic gradients or domains (Adagunodo et al., 2018a; Gunn & Dentith, 1997). Ibadan is home to three distinct sets of sinistral and dextral faults that are oriented differently, with some of the more notable ones being NE-SW, NW-SE, and ENE-WSW.

Due to the possibility that they are the cause of the tremors felt in Ogun state and Ibadan, the presence of the NE-SW and ENE-WSW fault sets in the region is noteworthy. According to Adetoyinbo et al. (2014), this observation is consistent with the September 11, 2009, earthquake, which had a magnitude of 4.4 and an epicenter close to Allada in the Republic of Benin, 128 kilometers west of Lagos, Nigeria. With a distinct NE-SW fault trend, the presence of significant faults close to the University of Ibadan's (UI) southwest and south is especially noteworthy. According to Hubbard (1975), and Burke et al. (1977), this fault may be a Kibaran age suture and be connected to the Zungeru-Ifewara fault or its synthetic counterpart. It is also possible to view the NW-SE fault at UI as an antithetic fault (Gunn & Dentith, 1997). The orientations of the fault systems in Ibadan and their possible effects on seismic activity in the area are clarified by this structural analysis, which offers insightful information.

Conclusion

With a focus on earthquake occurrence and safe locations for civil engineering construction, the investigation of subsurface stability in Ibadan has been made easier by the use of Geosoft Oasis Montaj 6.4.2 data processing and analysis software. By overlaying lineaments from the Total Horizontal Derivative Residual (THDR) map onto the geological map, multiple sets of sinistral and dextral faults have been identified within the Ibadan region through the analysis of high-resolution aeromagnetic data. ENEWSW, NW-SE, and NE-SW are the three distinct fault trends that have surfaced. According to this observation, the NE-SW and ENE-WSW fault sets may be to blame for the tremors felt in Ogun State and Ibadan. According to Adetoyinbo et al. (2014), there is a noteworthy coincidence between these fault trends and the earthquake that struck on September 11, 2009, with a magnitude of 4.4 and an epicenter close to Allada in the Republic of Benin (128 km west of Lagos, Nigeria).

It is thought that the NE-SW fault-set found close to Ibadan is an extension of a NE-SW trending fracture, potentially linked to a section of the NE-SW Zungeru-Ifewara fault that rises in the Atlantic Ocean. Nigerian earthquake activity has been linked to the Zungeru-Ifewara fault. The synthetic magnetic faults located south and southwest of the University of Ibadan (UI) have the potential to become synthetic to the Ifewara-Zungeru fault upon tectonic activation. Ibadan might be vulnerable to at least small earthquakes or earth tremors, according to this analysis. The software-enabled analysis has provided important new information for future construction and earthquake risk assessment by shedding light on Ibadan's structural features and the possible seismic hazards connected to particular fault trends.

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