https://dx.doi.org/10.4314/dujopas.v9i4a.18
ISSN (Print): 2476-8316
ISSN (Online): 2635-3490
Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 9 No. 4a December 2023*

Subsurface Qualitative Investigation for Mineral Exploration using Aeromagnetic Data

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Abstract
This research investigated the subsurface qualitative investigation for mineral exploration of Ibadan Southwest Nigeria, using high resolution aeromagnetic data. The data acquired from Nigeria Geological Survey Agency (NGSA) were subjected to different filtering processing techniques to produce magnetic anomaly maps which were analyzed to detect the subsurface geologic features that are indicative of the potential mineral deposits in the study area. The processing techniques applied in this study to delineate the magnetically active regions were Total Horizontal Derivative (THD), Analytic Signal Amplitude (ASA) and Upward Continuation (UP) method at 150 m and 250m. The results obtained show THD values ranged between 0.002 nT and 0.039 nT connoting regions between non-magnetic body region and high magnetic anomaly regions. The ASA technique revealed susceptibility contrast region between 0.0022 and 0.1472 nT/m; these depict region of geologic body housing the mineralized zones. Thus, there is potential for mineral exploration in the study area.

Keywords: aeromagnetic, mineral, anomaly, susceptibility, subsurface

INTRODUCTION
The aim of a magnetic measurement is to identify and describe regions of the Earth's crust that have unusual (anomalous) magnetizations related to the local mineralization that is potentially of commercial interest. It is carried out with the objective of locating the concentration magnetic minerals or determining the depth to magnetic basement. The better depth penetration, capability to acquire data in region that are impossible to cover by ground survey, systematic and extensive area coverage make aeromagnetic surveys attractive, where the main objective has been to assist in searching for minerals (Macnae, 1979; Keating, 1995,

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Power, et al. 2004), oil (Nabighian *et al.,* 2005), archaeological (Tsokas and Papazachos, 1992) research and for searching hazardous waste (Smith *et al.,* 2000). Thus, comparing the aeromagnetic data with other geophysical data, the potentialities of aeromagnetic data are readily available (Nasir *et al.,* 2011). The aeromagnetic method is also widely used in additional application such as water-resources assessment (Smith and Pratt, 2003; Blakely *et al.,* 2000a), Seismic hazards (Blakely *et al.,* 2000b; Saltus *et al.,* 2001), geothermal resources (Smith *et al.,* 2002), volcano-related landslide hazard (Finn *et al.,* 2001), regional and local geologic mapping (Finn, 2002), mapping of unexploded ordinances (Butler, 2001), locating buried pipelines (McConnell *et al.,* 1999) which can be of economic interest (Mazur *et al.,* 2000).

There are several geophysical researches carried out around Ibadan and its environment in the area of aeromagnetic surveying. Among them are Oladejo et al., 2019 who investigated the subsurface stability of Ibadan against occurrence of tremor and was able to identified three different set of dextral faults trends which could be responsible for tremor occurrence in Ibadan many years ago. The report of Sunmonu et al., (2013) on interpretation of aeromagnetic data of Ibadan for geo-structural analysis also revealed the presence of some element of subsurface structures in the area, however only few has been done in the area of mineral exploration around the study area. The Nigeria Geological Survey Agency (NGSA) were recently cited in Ibadan Oyo state carrying out aeromagnetic survey for the acquisition of aeromagnetic data suspected for establishing some solid mineral deposition in Ibadan axis. The purpose of this research is to investigate the subsurface structure for mineral prospecting using aeromagnetic data, and also produce reliable information about the basement structures which can also serve as a pilot investigation for the agency (NGSA).

MATERIALS AND METHODS

Geology of the Study Area

The presence of varieties of rocks in Ibadan southwest Nigeria associating with different types of minerals are of high economic values (Ahmed, 2018). It has attracted different researchers to carries out various geophysical studies in the region, some of these researchers are Kolawole *et al.,* 2023; Egbeyale *et al.,* 2022; Oladejo *et al.,* 2019; among others. According to these previous researchers, the geology of study area (Ibadan) is located with the Pre-Cambrian basement rock (figure 1). The nature of these rocks are either metamorphic or crystalline (granite gneiss, hornblende granite, Schistamphibolites, xenoliths and aplites). Earlier discoveries in Ibadan shows the presence of gemstone, Talc and granite, also Ayinla (2014) identified some of the metallic minerals present in Ibadan in commercial quantity (Gold, Aquamarine, Amethyst, Tourmaline, sillimante and Tantalite.

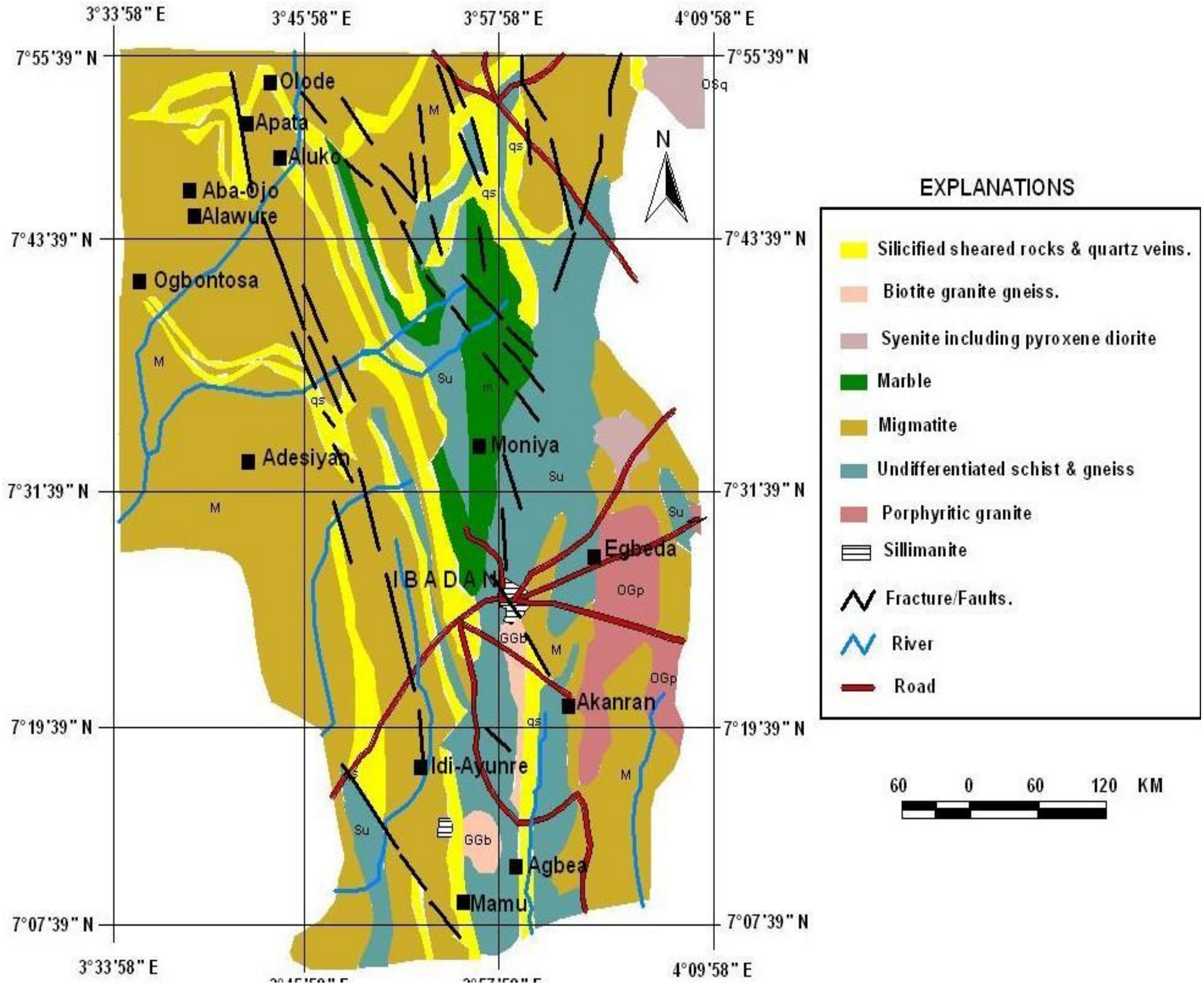


Figure 1: Geology of Ibadan and its environs (Adetoyinbo *et al.*, 2010)

METHODOLOGY

Aeromagnetic data of Ibadan and its environs was acquired from Nigeria Geological Survey Agency (NGSA) in an excel format of x, y, and z corresponding to the longitudes, latitudes and their Total Magnetic Field Intensities respectively. Oasis Montaj software database was used in obtaining the Total Magnetic Field Intensity (TMFI), IGRF correction was carried out and Total Magnetic Field Anomaly map were produced (figure 2). The acquired aeromagnetic data required proper filtering and enhancement through various filtering applications in order to accentuate important diagnostic features (anomaly), and display better information from the dataset for both qualitative and quantitative interpretations. Reduction to Magnetic Equator (RTME), Total Horizontal Derivatives (THD), Analytic Signal Amplitude (ASA) and Upward Continuation (UC) are the filtering and enhancement techniques used in this study. RTME was carried out on the Total Magnetic Field Intensity data to allow the anomalies directly above the causative bodies. UC process was further carried out to improve the magnetic signal and also remove the shallow noise effect. The anomalous of geological interest (residual magnetic map) were then generated by removing the regional field from reduction to magnetic equator field. Enhancement process (THD and ASA) were further carried out on the residual magnetic anomaly data. The reason for the enhancement was to further produce a clearer image of the magnetic sources, fractures, faults and lithological boundaries (Akeredolu *et al.*, 2022).

Analytic Signal Amplitude (ASA)

The Analytic Signal Amplitude is a perimeter used in analytic signal method, it peaks over the isolated magnetic contacts and does not depend on the direction of both the magnetization and magnetic field of the earth (Li, 2006; Roest *et al.,* 1992). ASA is ALSO defined as the square-root of the combination of the derivatives (vertical and horizontal) of the magnetic field. The mathematical expression for analytic signal amplitude is given as:

$$\mathrm{ASA}(x,y,z) = \left[\left(\frac{\partial T_z(x,y)}{\partial x}\right)^2 + \left(\frac{\partial T_z(x,y)}{\partial y}\right)^2 + \left(\frac{\partial T_z(x,y)}{\partial z}\right)^2\right]^{\frac{1}{2}} \quad (1)$$

where $\left(\frac{\partial T_z(x,y)}{\partial x}\right)^2$ and $\left(\frac{\partial T_z(x,y)}{\partial y}\right)^2$ are horizontal derivatives of the magnetic field in the direction of x and y. $\left(\frac{\partial T_z(x,y)}{\partial z}\right)^2$ is the vertical derivative of the magnetic anomaly.

There were plethora of literature on the successful utilization of analytic signal method in locating dike bodies (Aoud *et al.,* 2003; Nabighian, 1972, 1984). Roest *et al.,* in 1992 developed the ASA method and the improvements were presented by Hsu et al. in 1996 and 1998. This method utilized fourier transforms in computing the vertical derivative thereby increasing its noise susceptibility.

Total Horizontal Derivatives (THD)

Total horizontal derivative (THD) is often used in determining the location of magnetic source's edge (Cordel and Grauch, 1985) and in delineating deep or shallow magnetic sources (Mekkawi, 2012). This derivative only involve first order derivative (horizontal) thereby making it relatively less sensitive to noise in the magnetic dataset (Cordel and Grauch, 1985). The amplitude of THD is mathematically expressed as:

$$\mathrm{THD}(x,y) = \left[\left(\frac{\partial T_z(x,y)}{\partial x}\right)^2 + \left(\frac{\partial T_z(x,y)}{\partial y}\right)^2\right]^{\frac{1}{2}} \quad 2$$

Where T is the potential field anomaly, $\frac{\partial T_z(x,y)}{\partial x}$ and $\frac{\partial T_z(x,y)}{\partial y}$ are the horizontal derivatives of the magnetic fields in the direction of x and y.

RESULTS AND DISCUSSION

Total Magnetic Field Intensity (TMFI) Map

The total Magnetic Field anomaly map of the study area is shown in Figure 2. This map displayed total magnetic intensity pattern due to the variations in lithology and magnetic susceptibilities with magnetic field intensity values of the study area ranges from -111.3 nT (minimum) to 148.0 nT (maximum). The areas with high magnetic intensity values (orange – violet color) ranges from 44.4 to 148.0 nT is most dominant in northwestern part of the study area. The high magnetic effects of geologic structures are due to the presence of minerals (e.g. banded-gneiss, migmatite) with high magnetic susceptibilities and strength (Usman *et al.,* 2018; Abubakar and Mohammed, 2022). The positive magnetic anomalies are an indication of the presence of magmatite and gneisses in the area. However low magnetic intensity locations vary from -111.3 to 35.7 nT (blue to orange color) are displayed in northeastern, southeastern and southwestern part of the area. The negative anomaly values may be attributed to low magnetic rocks such as amphibolites and schist.

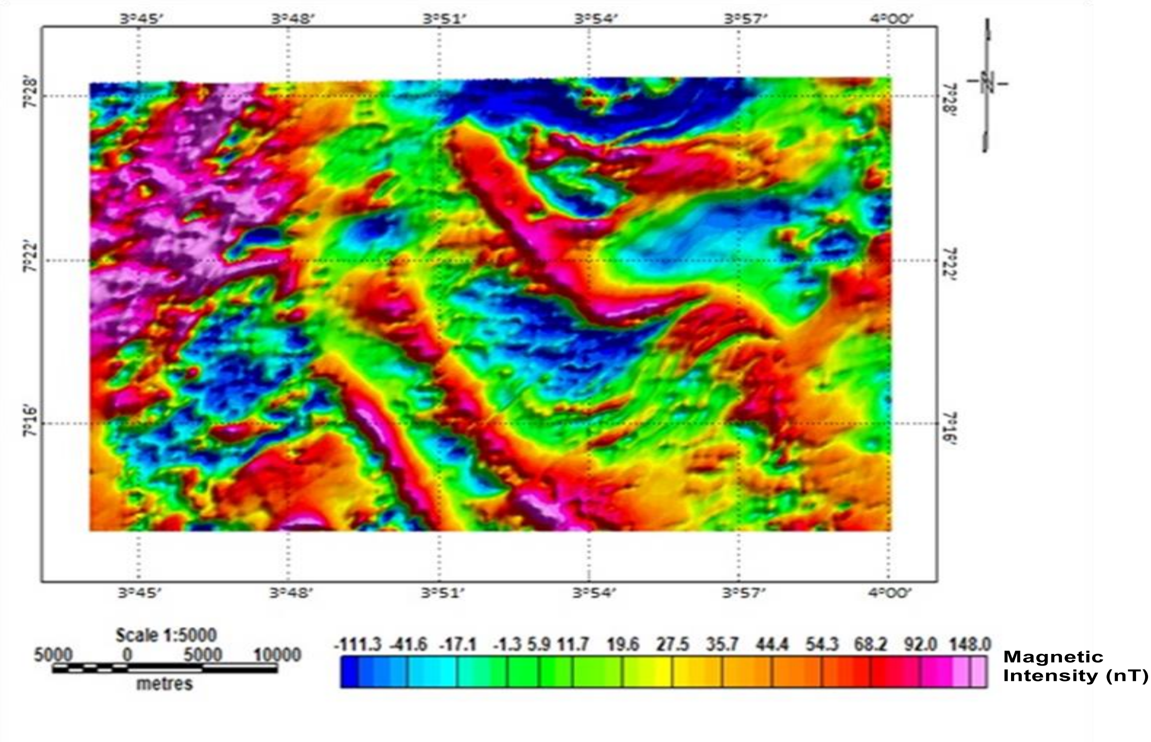


Figure 2: Total Magnetic Field Intensity (TMFI) anomaly Map of study area

Residual Anomaly Map (RAP)

The residual anomaly map (Figure 3) is generated by deducting a long wavelength anomalies detected (a computed regional anomaly data) from the Total Magnetic Field Anomaly (Pitcher, 1994). This drastically reduce the Total Magnetic Field Intensity (TMFI) data because unwanted noises has been filtered off. The result in Figure 3 shows dominant of high magnetic anomaly trends in some pockets of locations such as northeast, northwest and southwestern direction with magnetic values ranges between 7.9 nT and 48.1 nT., These magnetic highs are associated with rocks possessing higher magnetic susceptibility since the coordinate of the area is of lower magnetic latitude.

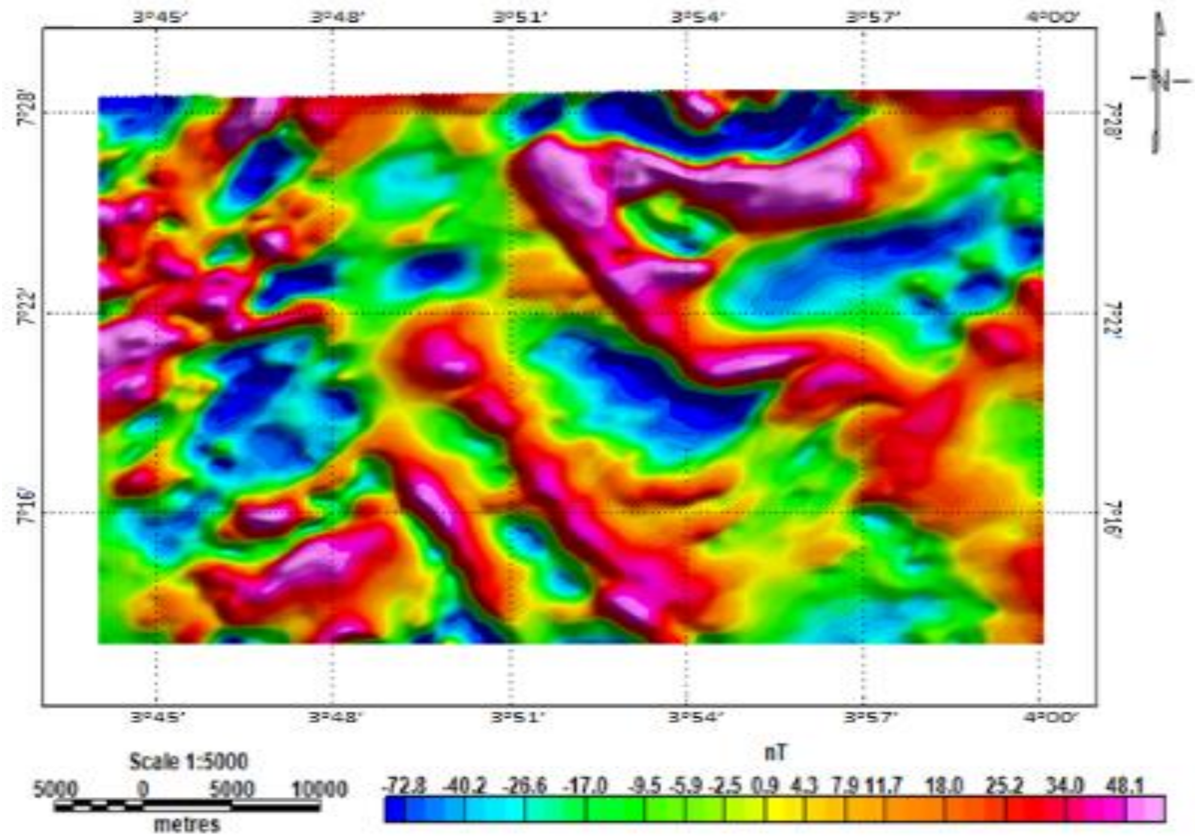


Figure 3: Residual Anomaly map of study area

Reduction to Magnetic Equator (RTME)
The intensity of magnetic field of the earth is reduced from the earth's poles to the magnetic equator, which allows the orientation of magnetic anomaly (peak of the signals) over the sources to be changed. Hence the correction of the asymmetries of the magnetic intensity anomalies can be done for meaningful interpretation using reduction to magnetic equator (RMTE) as the filtering technique. The purpose of these techniques were to center the magnetic anomalies over the magnetic signatures (i.e to accentuate the noise in the horizontal direction). The reduction to magnetic equator (RTME) over the study area in figure 4 represents two domain anomalies namely high magnetic amplitude (H) and low magnetic amplitude (L). The high magnetic amplitude ranged from 32.6 nT to 109.1 nT is dominant majorly in N-W and some pocket of locations in S-E and S-W. These magnetic values is characterized with geological structures consisting high magnetic contents which can serve as magnetic mineral accumulation. However low magnetic amplitude ranged from 32.6 nT to -83.6 nT is dominant majorly in Northeastern part of the study area

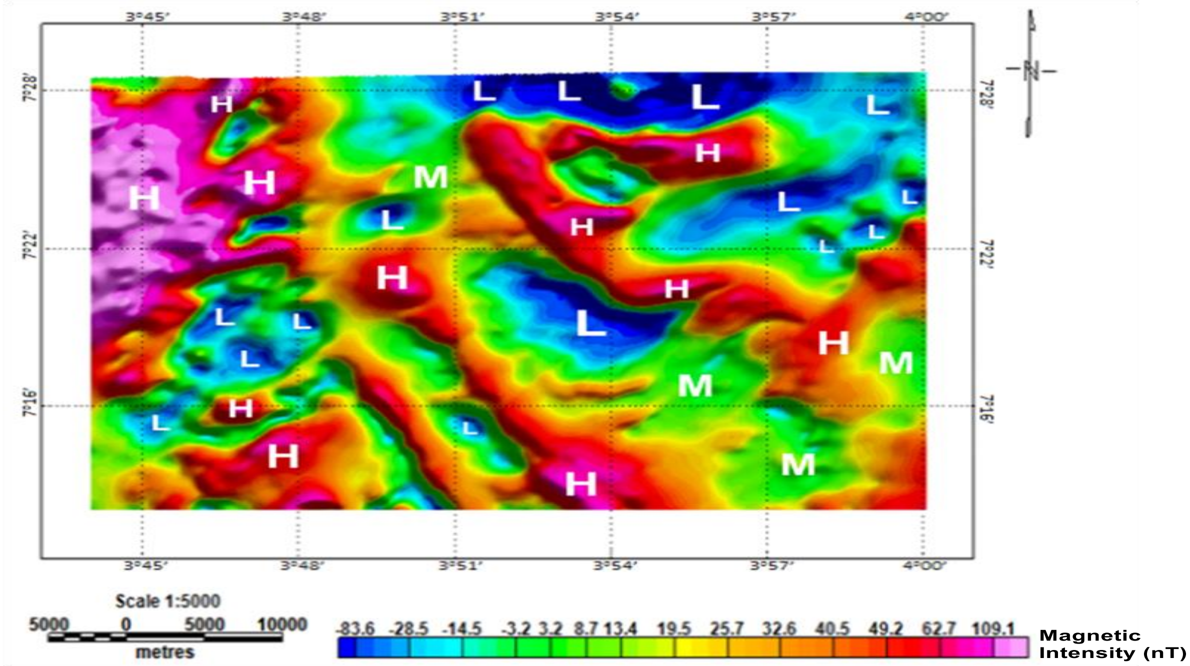
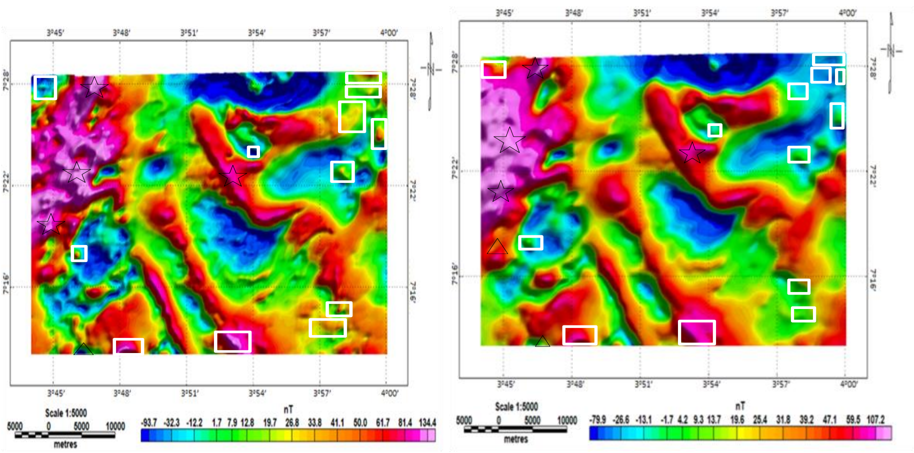


Figure 4: Reduction to Equator Map of the study area

Upward Continuation

Figure 5a and 5b shows the upward continuation of Total Magnetic Field Intensity Reduced to Magnetic Equator (RTE-TMI map) at 150 m and 250 m deep. The pattern of magnetic anomalous signature observed in these maps depicts the variations in the magnetic properties of the geologic structures in the study area. At 250 m, upward continuation appearance of some anomalies were observed. By visual observations all the smaller, thinning and narrower geologic structures in 150 m (figure 5a) deep continuum disappeared progressively in 250 m (figure 5b) deep continuum because increase in upward continuation decreases the effect of smaller magnetic bodies (Okpoli and Akinbulejo 2022). More negative anomalies appeared in the northeastern region but disappeared in the northwestern region. The boundary of the negative anomalies is appeared to be well defined at the central region. The traces of blue anomalies disappeared more in the southern region. The violet anomalies became more prominent in the northwest while the red anomaly is well defined across the study area (figure 5b).



(a) (b)

Figure 5: Upward Continuation of the study area at depth (a) 150 m; and (b) 250 m

Total Horizontal Derivative (THD)

The results of the total horizontal derivative (THD) of the study area generated from the residual magnetic intensity data is presented in figure 6. The total horizontal derivative values ranged between 0.002 (blue) to 0.039 nT (violet). The regions from 0.016 nT (orange) to 0.002 nT (blue) connotes low non-magnetic bodies suggested to be sedimentary rocks of the study area. These quantum of non-magnetic materials are majorly dominant in southwest and some pocket of places in northwestern part of the study area. The non-magnetic body can be interpreted as felsic and schist materials hosting the magnetic bodies. However, the regions from 0.016 nT (orange color) to 0.039 nT (violet color) dominant in the northeastern and northeastern part of the study area highlight areas of high magnetic anomaly (intensity) regions representing the mineralized zones. These zones are contained in the lineaments that determines the mineral content of the basement rocks (Solomon, 2004; Abubakar, and Mohammed, 2022). The mineral zones may represent the basement rocks in the form of metallic mineral deposit in majorly northeastern and northwestern part of the study area.

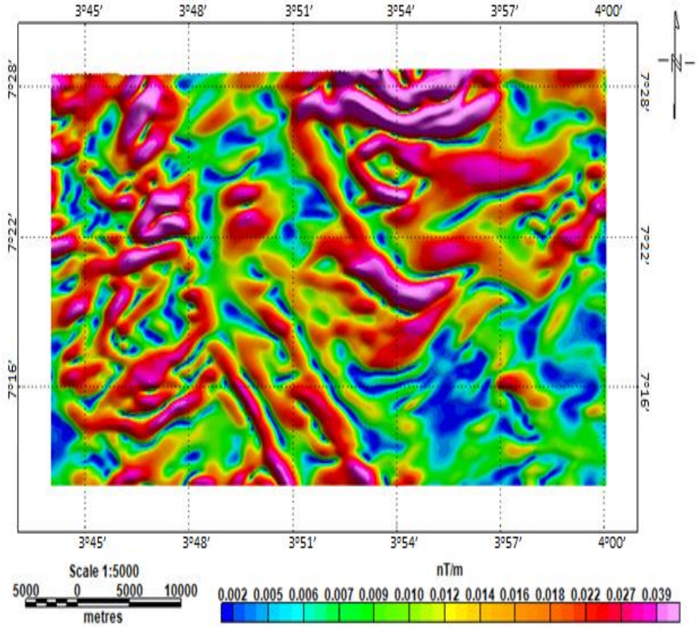


Figure 6: Total Horizontal Derivative of the study area

Analytic Signal Amplitude (ASA)

The residual magnetic data was used in generating the analytic signal amplitude map of the study area (figure 7). The susceptibility contrast of the magnetic structure generated from Analytic Signal Amplitude ranged from 0.007 to 0.110 nT. The region from 0.035 (orange color) to 0.110 nT (violet color) depict high amplitude region of geologic bodies housing the mineralized zones like granite gneiss in the basement region (Udensi, and Osazuwa, 2002; Biswas et al. 2014). This region is dominant in the northern region and NW region of the study area. However regions from 0.035 nT (orange color) to 0.007 nT (blue color) is a region low amplitude geologic bodies with low susceptibility contrast which can be interpreted as non-metallic mineral regions (Okunlola, 2008; Tawey et al., 2020; Abubakar and Mohammed, 2022)

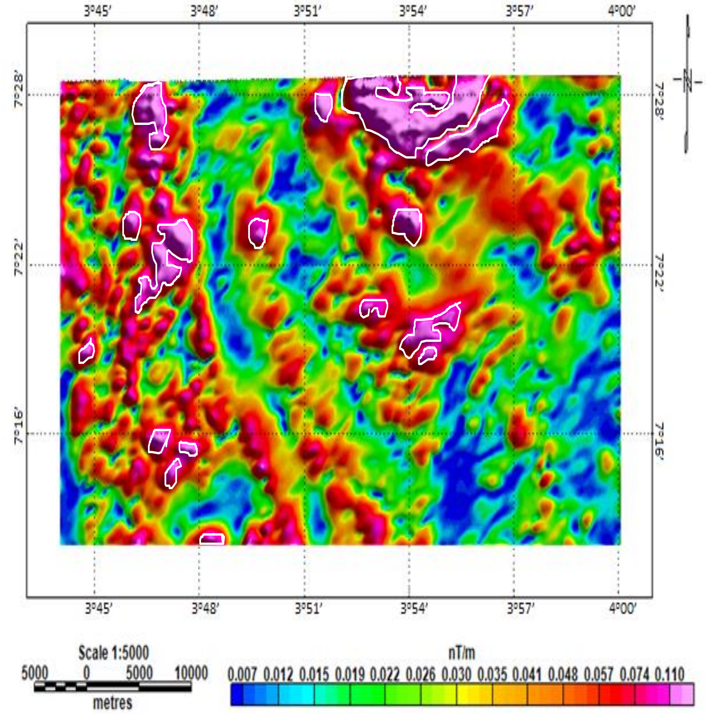


Figure 7: Analytic Signal Amplitude Map of the study area.

CONCLUSION

Qualitative investigation of subsurface of Ibadan and its environs were carried out using aeromagnetic data. The aeromagnetic data of the area was reduced to magnetic equator and residual magnetic data generated were enhanced using techniques including total horizontal derivative (THD), analytic signal amplitude (ASA) and upward continuation. Two regions of magnetic anomalies were delineated as it was also reported by Oladejo et.al., 2019 who carried out research on structural analysis using aeromagnetic data of Ibadan. From total horizontal derivative; High magnetic anomaly region (from 0.016 – orange to 0.039 nT – violet color) and low non-magnetic regions (from 0.016 nT – orange to 0.002 nT – blue color) were delineated, they are due to magnetic intrusions into the host with magnetic structures. From analytic signal amplitude, the susceptibility contrast region ranged from 0.035 nT (orange color) to 0.110 nT (violet color) depicts high amplitude region of geologic structures housing the mineralized zones. The region from 0.035 nT (orange color) to 0.007 nT (blue color) depicts low amplitude region. The upward continuum at 250 m deep reflects significant basement anomalies and the boundary of the regional signature became well defined. The results also revealed the mineral potential zones which is pronounced within the northern and western part of the study area, some of the suspected mineral in these zones are biotite hornblende granite and amphibolites.

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