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Mineral Resource Exploration Potential in the Ado-Ekiti-Ilesa Region of Southwest, Nigeria using Aeromagnetic Survey

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ABSTRACT

This study investigates the mineral resource potential of the Ado-Ekiti and Ilesa regions in southwestern Nigeria using aeromagnetic data. These regions, located within the Precambrian Basement Complex and schist belts of Nigeria, are known for hosting significant mineral deposits, including gold, iron ore, and rare earth elements. However, limited geophysical exploration has constrained the full realization of their mineral potential. To address this, aeromagnetic data from sheets 243 (Ilesa) and 244 (Ado-Ekiti) were obtained from the Nigerian Geological Survey Agency and processed using advanced enhancement techniques to delineate geological structures and identify zones of mineralization. The study employed a suite of edge-detection filters, including Reduction to the Pole (RTP), Analytic Signal Amplitude (ASA), First Vertical Derivative (1VD), Tilt Derivative (TDR), and Total Horizontal Gradient (THG), to enhance the interpretation of magnetic anomalies. These filters improved the resolution of shallow and deep-seated features such as faults, shear zones, lithological boundaries, and dykes. Magnetic anomalies were classified into three litho-magnetic domains, corresponding to Older Granites and quartzites, undifferentiated metasediments, and mixed basement/metasedimentary sequences. Results reveal those high magnetic anomalies (65–251 nT) in areas like Ilesa and Osogbo are linked to magnetite-rich granitic and metamorphic rocks, indicative of iron ore and gold mineralization. Conversely, low anomalies (-12 to -174 nT) in regions such as Ifewara and Oriade correspond to quartzite and schist formations, potentially reflecting hydrothermal alteration zones or non-magnetic mineralization such as rare earth elements or hydrocarbons. Lineament analysis highlighted dominant NE–SW and N–S fault systems and NNW–SSE trending dykes, which are structurally significant for mineral deposition. The integration of aeromagnetic data with regional geological maps demonstrated a strong correlation between magnetic signatures and known lithological units. The methodology adopted allowed for the identification of both exposed and concealed mineral-bearing structures, providing a valuable tool for resource targeting. This study underscores the effectiveness of aeromagnetic surveys and data enhancement techniques in mapping subsurface geology and delineating mineral-rich zones in complex basement terrains. Ultimately, this work contributes to a geophysical framework for mineral exploration in southwestern Nigeria, promoting efficient resource allocation and supporting investment in the mining sector. The approach can be replicated in similar terrains across Nigeria to advance sustainable development through improved geological knowledge and exploration strategy.

Keywords:
Aeromagnetic survey,
Mineral exploration,
Magnetic anomalies,
Basement complex,
Ilesa schist belt,
Mineral-bearing structures.

INTRODUCTION

Aeromagnetic surveys have emerged as essential tools in geoscientific investigations, particularly in the search for subsurface geological structures and mineral resources. These surveys involve measuring variations in the Earth's magnetic field from an airborne platform, enabling the detection of magnetic anomalies associated with different rock types and geological formations. The interpretation of these anomalies offers insights into the distribution and concentration of magnetic and non-magnetic minerals, providing valuable data for mineral exploration, geothermal studies, and geological mapping (Gibson and Milligan, 2003; Phillips and Simpson, 2008).

In Nigeria, the integration of aeromagnetic and geological data has become increasingly significant in exploring the mineral potential of various terrains. The southwestern region, particularly areas such as AdoEkiti and Ilesa, is underlain by complex Precambrian basement rocks that are known to host economically viable minerals, including gold, iron ore, and rare earth elements. These areas fall within the schist belt of Nigeria, where previous studies have revealed the presence of extensive quartzite formations, shear zones, and lineaments that control mineral deposition (Sedara and Alabi, 2021; Lateef et al., 2021; Sedara, 2019).

The present study aims to utilize aeromagnetic data to map subsurface geological features, determine the magnetic susceptibility distribution, and identify potential zones of mineralization in Ado-Ekiti and Ilesa. By integrating advanced image enhancement techniques with geological mapping, this study provides a comprehensive geophysical model that can guide future exploration and attract investment in the mining sector of southwestern Nigeria. Despite the economic importance of mineral exploration in Nigeria, many mineral-rich areas remain underexplored due to limited use of advanced geophysical methods. The traditional reliance on field-based geological mapping is often constrained by accessibility issues and dense vegetation. Aeromagnetic surveys offer a non-invasive and cost-effective alternative, capable of detecting both exposed and concealed structures (Lateef et al., 2019; Sedara, 2019). However, while some areas of Osun and Ekiti States have been surveyed, a detailed integration of aeromagnetic data and geological interpretation to delineate economically viable zones remains insufficient, particularly in Ilesa and Ado-Ekiti. This study addresses this gap by applying advanced aeromagnetic techniques to reveal hidden structures and lithologies with mineral potential. Nigeria's economy stands to benefit from expanding the mining sector, which requires systematic exploration of untapped regions. Ado-Ekiti and Ilesa are strategically located within geologically favorable terrains yet lack detailed, modern geophysical investigations. This study employs aeromagnetic surveys enhanced by advanced processing tools to fill that knowledge gap, supporting efficient resource allocation, sustainable development, and informed decision-making for exploration ventures.

Geology of the Study Area

Regional Geological, Structural and Mineralization Setting

The Nigerian Basement Complex forms part of the Pan-African mobile belt, a geological province that extends across large portions of West Africa. It comprises ancient crystalline rocks, primarily of Precambrian age, and includes three major lithological groups (Rahaman, 1988): The migmatite–gneiss–quartzite complex, slightly migmatized to non-migmatized metasedimentary and meta-igneous rocks and the Older Granite suite. Ado-Ekiti and Ilesa fall within this complex, particularly within the Ilesa schist belt and the Effon Psammite Formation. The dominant rock types include: Quartzite (massive and fissile), Quartz schists and mica schists, Granulites and migmatites and Older Granites and pegmatites (Oyawoye, 1976; Caby et al., 1981; Caby and Boesse, 2001; Oyinloye, 2011). These rocks exhibit variable deformation, metamorphism, and intrusive relationships indicative of a complex tectonic history. The terrain is dissected by NE–SW and NW–SE trending faults and shear zones, which play a critical role in localizing mineral deposits. These structures serve as pathways for hydrothermal fluids and influence the emplacement of mineralized veins. Fractures are prominent along ridges and stream valleys, although many are concealed under thick vegetation. The study area is rich in both magnetic and non-magnetic mineral deposits. Gold mineralization is particularly associated with quartz veins and sheared schists in the Ilesa region. Iron ore, rare earth elements, and possibly hydrocarbons are inferred from magnetic anomalies and geochemical trends. The integration of structural and lithological data improves the understanding of ore control mechanisms. The geological map used for the study area is shown in figure 1.

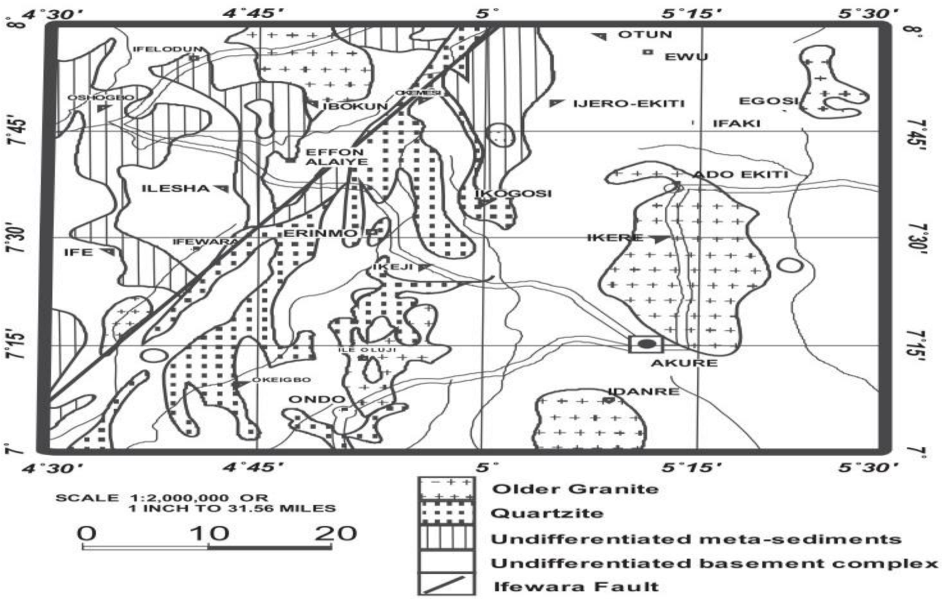

Figure 1: Geological Map of the Study Area and Surrounding Areas (After Abraham Et Al., 2014)

MATERIALS AND METHODS

Geophysical Dataset

The aeromagnetic data used in this study were originally obtained as two separate sheets i.e Sheet 243 (Ilesha) and Sheet 244 (Ado-Ekiti) from the Nigeria Geological Survey Agency (NGSA) which was acquired between 2004 and 2008 at a scale of 1:100,000. These datasets were merged for enhanced accessibility and data continuity. Initial processing steps included the generation of residual magnetic intensity (RMI) data, followed by conversion into total field anomaly data, gridded at a 0.5 km interval. Magnetic field analysis was carried out on the reduced-to-the-pole (RTP) dataset, assuming a magnetic declination of –3° and an inclination of –10°, based on the RTP correction method of Silva (1986). The dataset, attached as a GRD file, presents a gridded image of the combined aeromagnetic sheets and serves as the basis for investigating mineral resource potential in the region.

Further data enhancement was performed using OASIS Montaj (Geosoft, 2011), facilitating the identification of geologic and hydrogeologic anomalies. Additional filtering techniques were applied to the RMI data, producing several derived images useful for detailed structural and lithological characterization of the study area and delineating zones of mineralization. Figures 4–9 display the anomaly field maps after removal of the regional geomagnetic field and diurnal magnetic effects. Mapping magnetic susceptibility variations within crustal rocks significantly aids geological interpretation (Schetselaar & Ryan, 2009) and mineral exploration (Herbert et al., 2014), particularly in regions with sparse outcrop exposure (Bahiru, 2011; Herbert et al., 2014). Magnetization in metamorphic terrains depends heavily on the nature of the source rocks. For instance, pelitic metasediments (derived from fine-grained sedimentary rocks) tend to be more magnetic than psammites (Grant, 1985). Other influencing factors include thermal alteration, multiple metamorphic events, low-temperature alteration, and granitization (Grant, 1985). Guided by the geological map from Abraham et al. (2014), the aeromagnetic dataset was carefully interpreted to delineate lithological boundaries and structural features associated with mineralization processes. The complete workflowfrom data acquisition to interpretation is illustrated in Figure 2.

Magnetic Data Acquisition and Processing

The magnetic data underwent a series of filtering processes to generate and interpret various geophysical maps. Magnetic anomalies associated with geological structures such as shear zones and faults originate from multiple sources. When these sources are located in close proximity, their anomalies can overlap and interfere with one another. Furthermore, overlapping sources at varying depths can give rise to both weak and strong anomalies within the same region (Nasuti et al., 2019). To enhance structural discontinuities in the total magnetic intensity (TMI) image (Figure 4) and improve the delineation of subsurface features, several edge enhancement techniques were applied. These include: Analytic Signal Amplitude (ASA) transform (Rajagopalan, 2003), First Vertical Derivative (1VD) filter (Cooper and Cowan, 2004), Tilt Derivative (TDR**)** transform (Miller and Singh, 1994), and TAHG transform, which incorporates the Total Horizontal Gradient Magnitude into the TDR equation (Ferreira et al., 2013). In regions near the magnetic equator where inclinations fall within 20°

magnetic anomalies tend to exhibit an asymmetric shape due to the dipolar nature of Earth's magnetic field. This asymmetry causes a horizontal displacement between the observed anomaly and its actual source (Rajagopalan, 2003).

The Reduction to the Pole (RTP) transformation corrects for the inclination and declination of the Earth's magnetic field, effectively repositioning anomalies directly over their causative bodies. For this study area, a magnetic inclination of -10° and a declination of -3° were used based on regional geomagnetic field characteristics (Figure 5). The First Vertical Derivative (1VD) filter enhances shallow magnetic features by emphasizing short-wavelength anomalies while attenuating the effects of deep-seated sources. It is especially useful for mapping surface or near-surface geological contacts and faults (Figure 6). The Analytical Signal Amplitude (ASA) technique combines the horizontal and vertical gradients of the magnetic field, allowing the amplitude of magnetic anomalies to be localized directly above their sources. It is particularly useful for identifying dykes, faults, and intrusive bodies (Figure 7). The Tilt Derivative helps delineate weak and subtle magnetic boundaries. It normalizes the magnetic field, making it easier to identify both strong and weak source bodies (Figure 8). The Horizontal Gradient (HG) filter highlights the edges of magnetic anomalies, useful for interpreting lithological boundaries and structural discontinuities such as shear zones and fault contacts (Figure 9). The Analytic Signal Amplitude (ASA) filter (Figure 7), which is not affected by the direction of magnetization, was applied to the Total Magnetic Intensity (TMI) data to center anomalies directly over their sources and enhance features such as north–south (N–S) trending dykes in the study area. The First Vertical Derivative (1VD) filter was used to suppress long-wavelength components in the TMI image, thereby improving the resolution of linear northeast (NE) trending anomalies associated with structural zones (Figure 4). In this regard, it provided better delineation than the ASA filter. The Tilt Derivative (TDR) filter (Figure 8) was employed to accentuate both the amplitude and discontinuities of TMI anomalies, proving particularly effective for mapping N- to north-northeast (NNE) striking faults and N–S trending dykes. The Total Amplitude of Horizontal Gradient (TAHG) filter (Figure 9) was applied to the TMI data to identify the centers and edges of magnetic anomalies associated with the study zones. For structural and lithological interpretation using the enhanced magnetic maps, the following key steps were undertaken: identification of distinct magnetic domains, correlation of magnetic anomalies with known geological formations using existing geologic maps, classification of anomalies based on their shape, wavelength, amplitude, and spatial distribution, and lineament analysis to trace subsurface faults and fractures. These magnetic transformation techniques applied to the Residual Magnetic Intensity (RMI) dataset were essential in improving geological interpretation and are further discussed in subsequent sections.

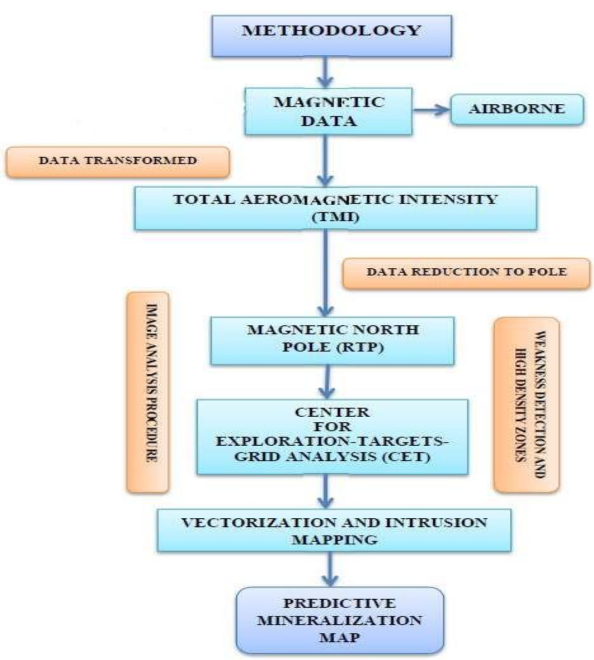

Figure 2: Flow Chart for the Methodology

RESULTS AND DISCUSSION

Magnetic Anomaly Distribution and Litho-Magnetic Domain Classification

The study area displays a wide range of magnetic intensities, from highly positive anomalies (65 to 251 nT) in areas such as Ilesa, Oshogbo, and Okemesi, to negative anomalies (-12 to -174 nT) in Ifewara, Erinmo, and Oriade. These patterns reflect the magnetic signatures of different rock types and structural elements. The positive anomalies are associated with the Older Granite complex and magnetite-rich formations while the negative anomalies correlate with quartzites and schists of the Ife-Ilesa schist belt, which typically have low magnetic susceptibility. For the structural interpretation, the lineament analysis revealed predominant NE–SW and N–S trending faults, evidence of NNW–SSE and NW–SE trending dykes and zones of magnetic discontinuity suggestive of fracture zones or lithological contacts. These structural features align with regional tectonic trends and are consistent with previous studies (Caby et al., 1981; Odeyemi, 1993). They are likely to have influenced mineral emplacement and rock deformation in the region. Based on RTP and gradient maps, three major litho-magnetic domains were identified which are Domain I with high magnetic amplitude and short-wavelength anomalies, corresponding to Proterozoic granites and quartzites. The Domain II are broad and low-amplitude anomalies, indicative of deeply buried metasedimentary sequences and Domain III with very low magnetic response, possibly reflecting thick sediment cover or highly weathered basement.

General Regional Magnetic Feature and Mineral Potential Zones

From the anomaly interpretation the Ilesa and Ado-Ekiti exhibit strong magnetic responses, suggesting zones enriched in magnetite-bearing rocks, possibly associated with iron ore and gold deposits. Also the Ifewara and Oriade show lower magnetic intensities, potentially linked to hydrothermal alteration zones or nonmagnetic mineralization (e.g., phosphate, hydrocarbon indicators) while areas with very high anomalies may also indicate rare earth elements, especially in granitic intrusions and pegmatitic veins. The several transformation contributed unique insights like the RTP which repositioned anomalies for more accurate location mapping while the 1VD highlighted shallow structures such as quartz veins, near-surface dykes, and altered zones. The ASA centralized anomalies above causative bodies and aided in delineating N–S trending features and the Tilt Derivative and HG identified deep-seated contacts and lithological boundaries. These results validate the effectiveness of advanced aeromagnetic data processing in structural and lithological mapping for mineral exploration.

The magnetic and geologic maps demonstrate a strong correlation between exposed rock units and their corresponding magnetic signatures. The significant variability in magnetic intensity across the area reflects a diverse range of magnetic properties within the subsurface lithologies. Prominent positive anomalies, ranging from 52 to 112 nT, are observed in Oshogbo, Okemesi, and Ilesha (Figure 3). These high-intensity zones correspond with exposed undifferentiated metasedimentary units in those locations. Moderate positive anomalies, ranging from 20 to 50 nT, are also recorded around Ijero-Ekiti and Aramoko, likely originating from similar undifferentiated metasediments. In the towns of Ado-Ekiti and Ikere, positive anomalies between 50 and 70 nT are attributed to the presence of Older Granites exposed in the area.

In contrast, negative magnetic anomalies ranging from –11 to –66 nT are evident in the regions around Erinmo, Ifewara, Oriade, and Okeigbo. These zones correspond to belts composed of quartzite, quartz-mica schist, and granulitic migmatites, which are part of the Okemesi Quartzite Member of the Effon Psammite Formation. This formation, located east of Ilesha, belongs to the Ife-Ilesha Schist Belt within Nigeria's Precambrian Basement Complex (Loehnert, 1985; Adegbuyi et al., 1996). Additionally, the study area exhibits magnetic lows ranging from –0.46 to –43 nT extending westward, associated with fractured quartzite units within the same formation. The complex shapes of magnetic anomalies observed across the area are primarily due to variations in Earth's magnetic field at the measurement locations. To simplify and accurately position these anomalies over their causative sources, the Total Magnetic Intensity (TMI) data were reduced to the pole (RTP). This transformation enhances interpretability by relocating magnetic anomalies more directly above the geological structures that generate them.

The enhanced Reduced-to-Pole (RTP) image of the study area (Figure 4) displays magnetic field amplitudes reaching approximately 250 nT, reflecting variations in magnetic intensity likely caused by lithological differences or topographic changes. The Analytical Signal (AS) was computed for the area (Figure 6) to position anomalies directly above their causative bodies by combining both the vertical and horizontal derivatives of the magnetic field. This method is advantageous because it eliminates dipolar effects, resulting in centrally located peaks even for small-scale bodies, thus offering a clearer representation of subsurface sources (Alsaud, 2008). Also, applying the First Vertical Derivative (1VD) to the AS image further sharpens and more precisely positions anomalies compared to the original AS output. The Tilt Derivative (Figure 7), when applied to the RTP data, enhances short-wavelength anomalies and proves effective in tracing anomalies along their structural strike direction (Alsaud, 2008).

A Horizontal Gradient (HG) image was also derived from the RTP data, and upward continuation to 1 km was conducted to highlight deeper-seated magnetic features and delineate edges of magnetic basement blocks, faults, or other subsurface structures. This approach emphasizes linear features corresponding to geologic contacts. The 1VD image enhances high-frequency, shallow-source magnetic structures by effectively removing regional trends, making it particularly useful for delineating near-surface lithological boundaries. To improve structural interpretation, various illumination angles were applied to AS, RTP, and Tilt Derivative images, producing shaded relief maps that emphasize different structural trends. In interpreting crustal domains, key characteristics of magnetic anomalies such as direction, relative amplitude, and wavelength were evaluated (Porwal et al., 2006). Based on the RTP data, three litho-magnetic domains exhibiting consistent magnetic signatures were identified (Figure 4), and these domains align well with regional stratigraphic units previously mapped by Reece (1961). The work identified three domains where **d**omain I is **l**ocated in the south and east, comprises Proterozoic basement rocks (Older Granite and Quartzite) with high-amplitude, short-wavelength anomalies while **d**omain II **o**ccupies the central and northern sections, consisting mainly of sedimentary rocks with low-amplitude, broad, long-wavelength anomalies, indicative of a deeper basement and composed of undifferentiated metasediments and **d**omain III encompasses areas with mixed Proterozoic basement and metasedimentary rocks, characterized by very low magnetic responses possibly due to thick rift sediments and westward-deepening Proterozoic layers.

The RTP image generally attenuates shallow-source anomalies, thereby revealing deeper magnetic sources more effectively than other datasets. In contrast, the Analytical Signal (Figure 6) displays both shallow and deep-seated anomalies and outlines numerous bounding bodies along which contacts were interpreted based on their strike directions. High-magnitude, closely spaced, and short-wavelength anomalies were prominent in the southern zone underlain by pelitic schist and gneissic terrain, as well as in the northeastern and northwestern regions containing undifferentiated gneiss, granite, and Pleistocene volcanic and sedimentary cover. Moreover, two prominent dykes trending north-northwest (NNW) and northwest (NW) were identified from the analytical signal data. The Tilt Derivative image (Figure 7) also revealed sharp, closely spaced, short-wavelength anomalies beneath various lithologies, facilitating the delineation of lithological contacts, particularly between pelites and underlying schist/gneiss terrains. The Horizontal Gradient (Figure 8), which emphasizes deeper anomalies, effectively highlighted dominant magnetic signatures underlying the Proterozoic basement.

Finally, the Magnetic Image Map by Abraham et al. (2014) (Figure 3) was compared with the study's TMI map (Figure 4) to refine the differentiation and interpretation of key geologic features across the study area.

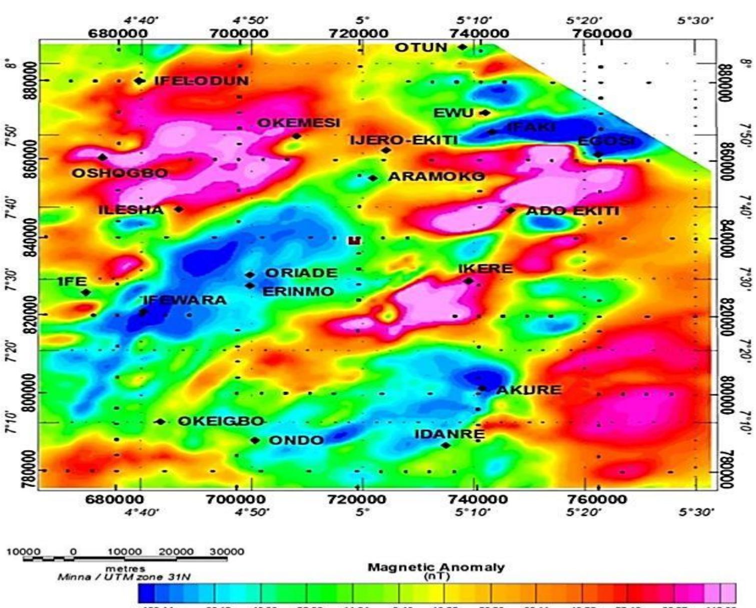

Figure 3: Magnetic Anomaly Field Map of the Study Area and Surrounding Areas (After Abraham Et Al., 2014)

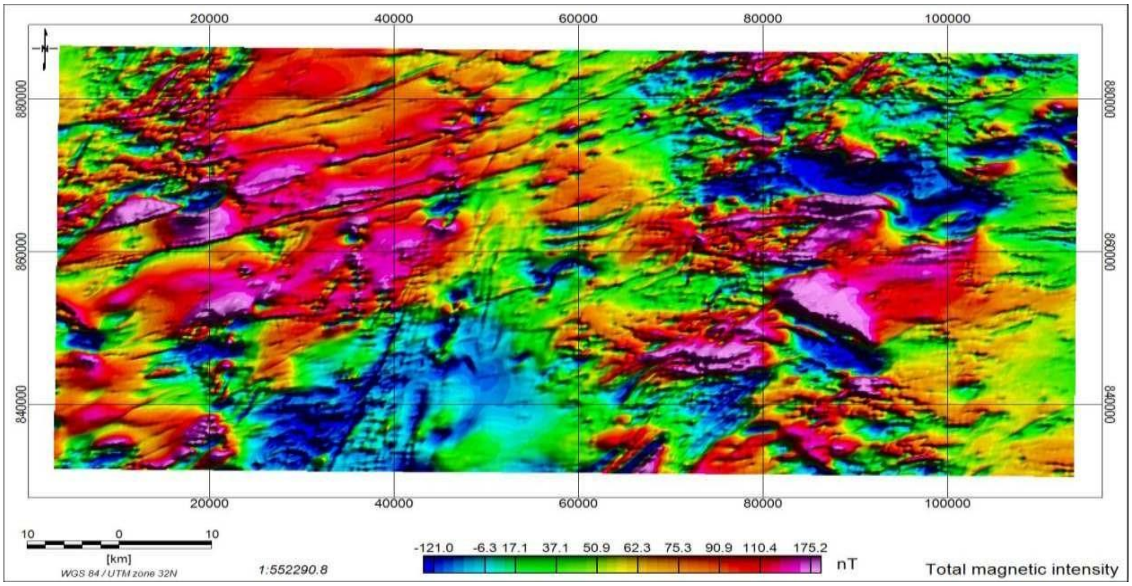

Figure 4: Total Magnetic Intensity (TMI) Image Map of the Study Area

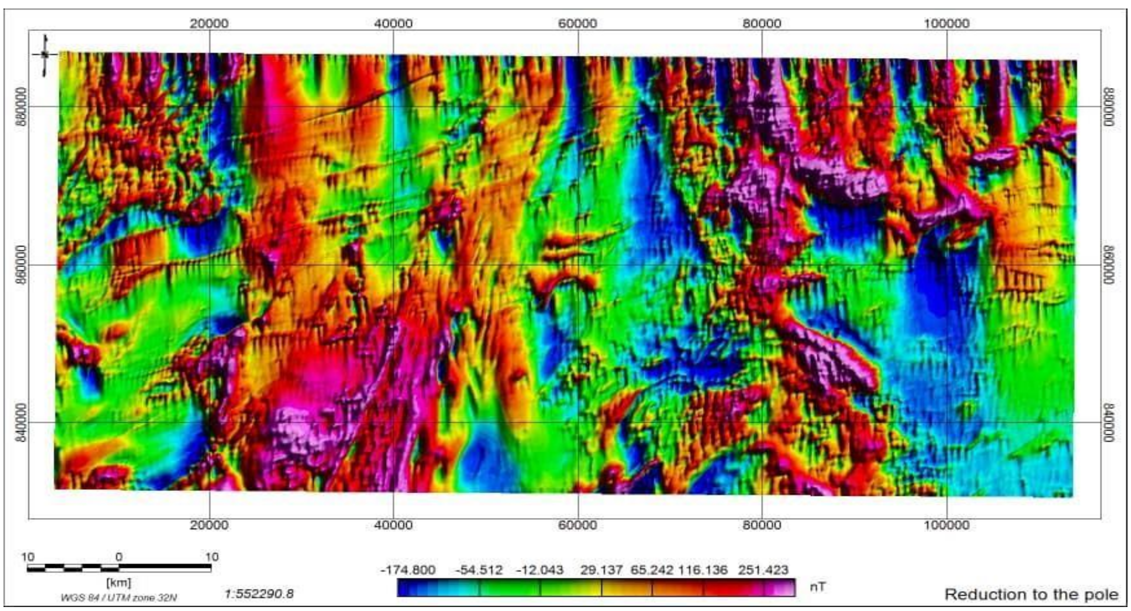

Figure 5: Reduction to Pole (RTP) Image Map of the Study Area

The magnetic data were reduced to the pole (RTP) using a regional declination of –3° and an inclination of –10°, aligning anomalies more directly over their causative bodies for more accurate interpretation. Prominent positive magnetic anomalies, with amplitudes ranging from 65 to 251 nT, are observed around Oshogbo, Okemesi, and Ilesha, indicating the presence of highly magnetic subsurface materials in these areas. Moderate positive anomalies, between 29 and 65 nT, are also recorded within the town of Ado-Ekiti.

Conversely, significant negative anomalies are observed across the southeastern, southwestern, and central parts of the study area—particularly around towns such as Ifaki, Ifewara, Erinmo, and Oriade. These negative anomalies range from –12 to –174 nT and may reflect the presence of less magnetic or demagnetized lithologies, structural depressions, or deeper basement configurations.

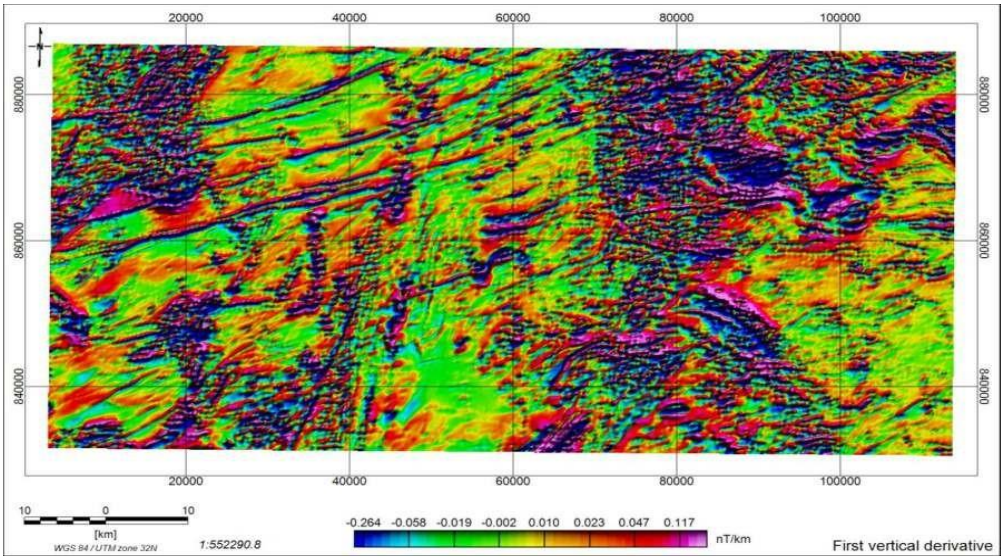

Figure 6: First Vertical Derivative (1VD) Image Map of the Study Area

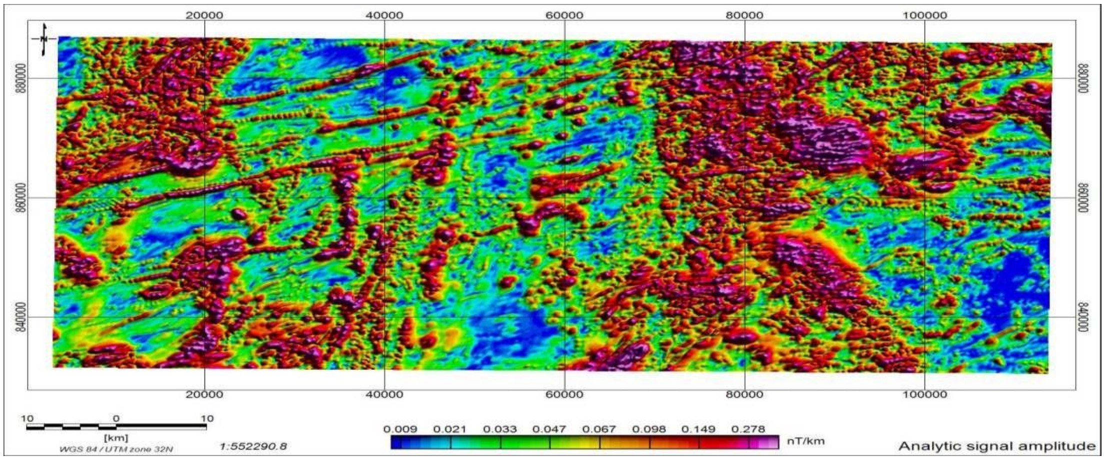

Figure 7: Analytical Signal Amplitude (ASA) Image Map of the Study Area

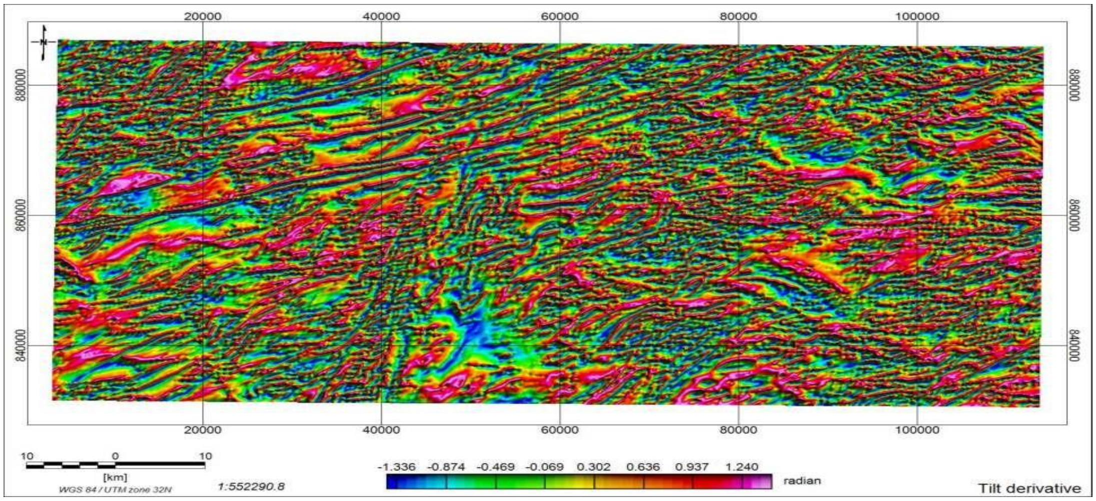

Figure 8: Tilt Derivative (TDR) Image Map of the Study Area

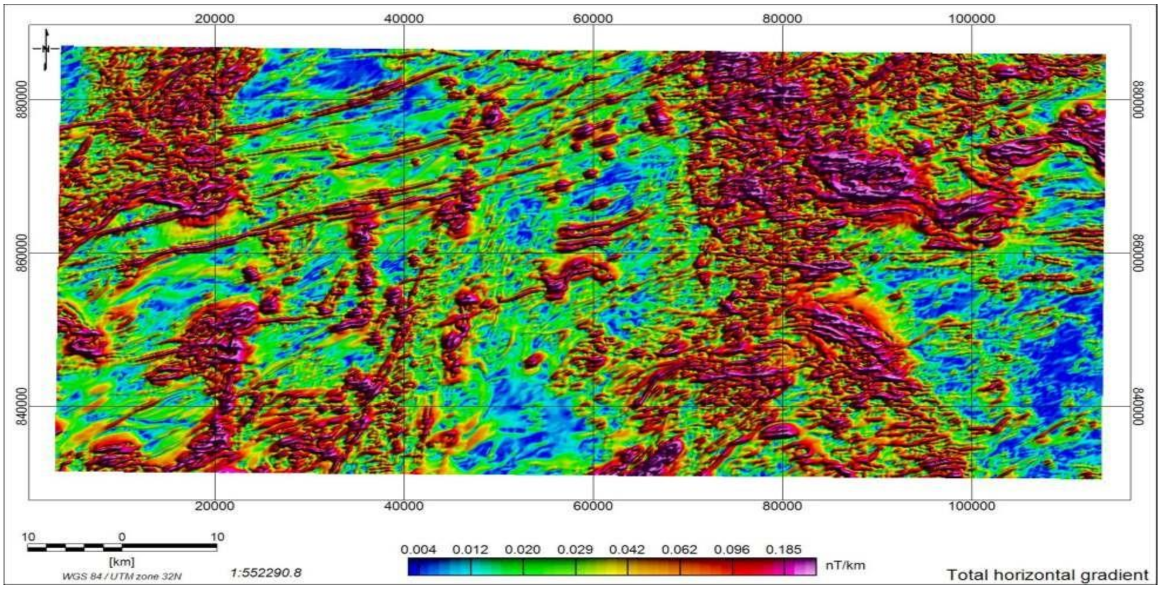

Figure 9: Total Horizontal Gradient (TAHG) Image Map of the Study Area

CONCLUSION

This study demonstrated the practical application of aeromagnetic data in delineating geological structures and assessing mineral potential in Ado-Ekiti and Ilesa, with key findings. The region is structurally complex with prominent NE–SW and N–S trending faults and dykes. Magnetic anomaly patterns correlate with major lithological units, validating their use in mapping subsurface geology. Aeromagnetic data reveal the presence of both magnetic and non-magnetic mineralization zones, with strong potential for gold, iron ore, rare earth elements, and possibly hydrocarbons. Enhanced interpretation techniques such as RTP, ASA, and 1VD significantly improve anomaly resolution and target identification. This study provided a geophysical foundation for understanding the subsurface geology of Ado-Ekiti and Ilesa, helping narrow down prospective zones for further exploration. The integration of modern enhancement techniques and geophysical modeling contributes a replicable framework for similar studies across Nigeria and beyond.

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