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Aeromagnetic Method in the Ilesha Schist Belt, Nigeria: A Synthesis of Subsurface Applications, Structural Evolution, and Resource Exploration

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Abstract: The Ilesha Schist Belt is an important gold-bearing zone of the Nigerian Basement Complex. It is characterized by a complex structural framework due to deep weathering profiles and dense vegetation. This paper synthesises and evaluates the last three decades of aeromagnetic investigations conducted across the schist belt and analogous Pan-African terrains. The aim is to provide a comprehensive overview of the application of aeromagnetic data on the belt's structural evolution, lithological mapping, and mineral exploration potential. We review the efficacy of the techniques such as Reduction to the Pole (RTP) and First Vertical Derivative (FVD) for sharpening near-surface magnetic responses and litho-structural mapping, and the quantitative methods like Analytic Signal (AS) and Euler Deconvolution for depth estimation. Major findings from this synthesis confirm a dominant NE-SW Pan-African trend in the region. The collective data confirms a bimodal depth distribution of magnetic sources, reflecting shallow lithologic contacts and deeper basement. This synthesis provides a critical benchmark, identifies current research gaps in high-resolution 3D modelling, and outlines future geophysical strategies needed for sustainable resource management and guiding the next generation of gold exploration in the Ilesha Schist Belt.

Keywords: *Aeromagnetic; Ilesha Area; Mineral; Structural Delineation; Pan-African Orogeny*

Introduction: Ilesha area is situated within the crystalline basement complex. It holds considerable geological and economic importance in Osun, Southwestern Nigeria. It is part of the Ife-Ilesha Schist Belt that is distinguished by its rich mineral resources (gold) and its structural designs formed by multiple geological occurrences within the Pan-African Orogeny [1-3]. The characterisation of the subsurface geology in Ilesha is vital for mineral exploration, groundwater resources processing, and effective assessment of geohazards. Geophysics investigations are frequently hindered by dense vegetation, which restricts the possibility of direct geological mapping. Consequently, it is essential to integrate geophysical surveys with remote sensing techniques to achieve comprehensive subsurface characterisation [4]. The aeromagnetic method is a geophysical technique used to delineate the complex subsurface geology of the Ilesha Schist Belt, Nigeria [5,6]. The survey provides essential data on the distribution of magnetic minerals, structural features, and the depths of magnetic sources through the analysis of spatial variations in the Earth's magnetic field [7,8]. Its non-invasive nature, cost-efficiency, and ability to cover extensive areas make the method a preferred geophysical technique for regional geological mapping, structural interpretation, and resource exploration in this region [5,6,7]. This review aims to serve as a valuable reference for researchers, particularly those developing thesis frameworks related to the geophysical investigation in the Ilesha area. It also offers a solid foundation to understand the role and significance of the aeromagnetic method in this geological region. It offers a comprehensive overview of the application of the aeromagnetic method in the Ilesha Schist Belt areas [9,10].

Geological Setting of the Ilesha Area: The Ilesha area is within the Precambrian Basement Complex of Southwestern Nigeria, and it forms part of the West African Craton. The geology of this region is primarily characterised by migmatite-gneiss complexes, metasediments, and metavolcanics, intruded by various granitoid formations [11,12,13,14]. This area constitutes the Ife-Ilesha Schist Belt, one of Nigeria's several north-south oriented schist belts. The belt is the remnants of supracrustal rocks that formed the older migmatite-gneiss complex during the Pan-African Orogeny [12,11,14]. This orogeny produced intense folding, faulting, and metamorphism. leading to structural patterns that influence the distribution of mineral resources [13,15].

The primary rocks found in the Ilesha (Figure 1) area include gneisses, Porphyritic granite, migmatite gneiss, amphibolites, quartzites, schists (such as mica schist and talc schist), and pegmatites [13,16,17]. The schist belts carry significant gold deposits that are typically linked to quartz veins and shear zones. The dominant structural trend in the area is NE-SW, indicating the Pan-African Orogeny's influence.

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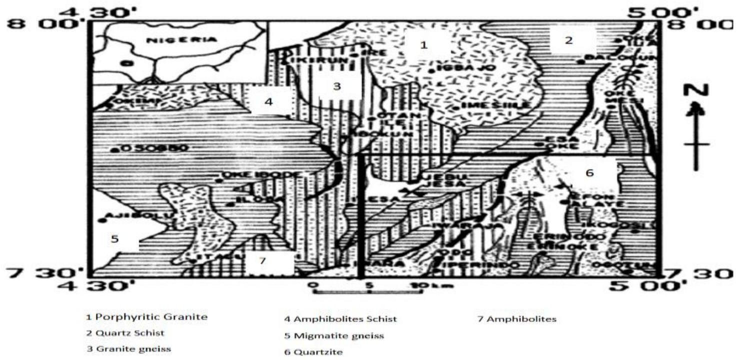

Fig. 1: Geology map of the Ilesha area.

Principles of the Aeromagnetic Method: The aeromagnetic method is a passive geophysical technique that measures the variations in the Earth's magnetic field caused by the differing magnetic properties of subsurface rocks. These variations, referred to as magnetic anomalies, are generated by magnetometers towed by an aircraft, usually at a constant height above the ground [5,9]. The core principle of this method is based on the fact that different rock types display different concentrations of magnetic minerals, predominantly magnetite, which affects their magnetic susceptibility. As a result, geological formations with varying magnetic susceptibilities result in measurable anomalies in the Earth's magnetic field [18,19].

Magnetic Properties of Rocks: The magnetic characteristics of rocks are determined by the presence and concentration of ferromagnetic minerals such as magnetite (Fe_3O_4), maghemite, hematite, and pyrrhotite. The magnetic susceptibility of any rock indicates its capacity to become magnetised in an external magnetic field. Generally, igneous and metamorphic rocks that are rich in mafic minerals tend to have higher magnetic susceptibilities compared to sedimentary rocks. For instance, basalts and gabbros exhibit strong magnetic responses, whereas limestones and sandstones are typically weakly magnetic. Variations in magnetic susceptibility underground create anomalies that can be detected and mapped by aeromagnetic survey [18].

Data Acquisition and Processing: The acquisition of aeromagnetic data involves flying an aircraft equipped with a magnetometer over a grid of parallel survey lines, with perpendicular tie-lines flown for quality control and levelling [9,19,20,21]. The data can also be acquired from any national agency like the Nigerian Geological Survey Agency (NGSA). The collected Total Magnetic Intensity (TMI) data then undergoes different steps of geophysical processing steps to isolate magnetic anomalies that represent variations in subsurface geology. These steps include diurnal correction to compensate for temporal fluctuations [22] International Geomagnetic Reference Field (IGRF) Removal to remove regional magnetic field from geological sources leaving only the residual anomalies [3]; and levelling to correct for variations in the aircraft's altitude along the observation lines [20]. Processes like Reduction to the Pole (RTP) or Reduction to the Equator (RTE) are applied to transform the magnetic anomalies. This process positions the anomalies directly over their causative sources, especially in regions like Nigeria with significant magnetic inclination [21,23,24].

Interpretation Techniques: Interpreting aeromagnetic data can generally be divided into qualitative and quantitative methods: Qualitative Interpretation involves reviewing magnetic anomaly maps to detect patterns, trends, and features which correspond to geological structures. Linear anomalies may indicate faults, dykes, or lithological contacts, while circular or elliptical anomalies might suggest the presence of intrusive bodies or domes. The shape, amplitude, and gradient of anomalies can reveal information about the causative sources' characteristics and depths [22,24]. Quantitative Interpretation employs mathematical and computational techniques to extract specific data regarding subsurface sources. Common quantitative methods include:

Analytical Signal Method **ASM):** The Analytical Signal method (ASM) is a powerful technique for locating the edges and depths of magnetic sources. It was introduced by [19]. The main advantage of this method is that its amplitude does not depend on the direction of the Earth's magnetic field and the source's magnetisation. This enables effective interpretation in areas with low magnetic latitudes. The ASM is defined using equation ne below:

$$\mathrm{ASM} = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2 + \left(\frac{\partial M}{\partial z}\right)^2} \qquad \text{eq.1}$$

The peaks of the Analytical Signal amplitude mostly occur directly over the edges of magnetic sources which aid in the delineation of magnetic boundaries like faults or contacts [19].

Total Horizontal Derivative (THDR) and First Vertical Derivative (FVD): The Total Horizontal Derivative (THDR), often referred to as the Horizontal Gradient Magnitude (HGM), is an effective edge-detection technique which highlights the horizontal rate of change in the magnetic field. This method was introduced by [22] and it is expressed as:

$$\mathrm{THDR} = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2} \qquad \text{eq.2}$$

Like the Analytical Signal, the peaks of the THDR are typically located over the edges of magnetic bodies which provide a clear indication of their lateral extent. In contrast, the First Vertical Derivative (FVD), as discussed by [20], is a high-pass filter that effectively improves shallow features and sharpens magnetic anomalies. By emphasizing the rapid changes in the magnetic field closer to the surface, the FVD refine the resolution of geological structures hidden by deeper magnetic responses. The two derivatives are important for promoting the visual and quantitative interpretation of source geometry.

Euler Deconvolution: Euler Deconvolution, a technique introduced by [20] and [25], is a semi-automatic method for estimating the location and depth of magnetic sources. The method is based on Euler's Homogeneity Equation, which relates the magnetic field M and its derivatives to the source position (x_o, y_o, z_o):

$$(x - x_o)\frac{\partial M}{\partial x} + (y - y_o)\frac{\partial M}{\partial y} + (z - z_o)\frac{\partial M}{\partial z} = N(B - M) \qquad \text{eq. 3}$$

B represent the regional magnetic field, and N is the Structural Index (SI). The SI relates the magnetic field decay rate to the geometry of the source (e.g.,)

$N = 0$ for a contact, $N = 1$ for a dike/pipe, $N = 2$ for a cylinder, $N = 3$ for a sphere). Using this equation over a grid with a moving window, a cluster of solutions with the depth to the magnetic source is produced.

Source Parameter Imaging (SPI): This method provides estimates of depth to magnetic sources through the analysis of the local wavenumber of the magnetic field:

$$k = \sqrt{\left(\frac{\partial M}{\partial x}\frac{\partial^2 M}{\partial x \partial z} + \frac{\partial M}{\partial y}\frac{\partial^2 M}{\partial y \partial z} + \frac{\partial M}{\partial z}\frac{\partial^2 M}{\partial z^2}\right)} \Bigg/ \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2 + \left(\frac{\partial M}{\partial z}\right)^2} \qquad \text{eq. 4}$$

For a thin sheet magnetic source, the depth h is given as:

$$h = \frac{1}{k_{max}} \qquad \text{eq. 5}$$

where k_{max} is the maximum value of the local wavenumber.

Radially Averaged Power Spectrum: The Radially Averaged Power Spectrum method is a frequency domain technique introduced by. It is used to determine average depths to magnetic sources, often distinguishing between shallow and deep sources [26]. The power spectrum of the magnetic field is related to the depth of the sources via a relationship where the log of the power spectrum is plotted against the radial wavenumber. The slope of the straight-line segments on this plot is proportional to the depth of magnetic sources:

$$\ln(E(k)) = \ln A - 2hk \qquad eq. 6$$

Here, E(k) is the power spectrum at wavenumber k, A is a constant, and h is the average depth. Distinct linear segments often correspond to different source layers and allow the researcher to differentiate between shallow and deep sources, hence providing a crucial regional depth control.

Peters' Half-Slope Method: Peters' Half-Slope Method, introduced by [27], is a graphical technique for estimating the depth to the top of a magnetic body from a profile plot of the magnetic anomaly. It is based on the assumption that the magnetic body can be approximated as a vertical step or a thin dike. Peters' Half-Slope involves fitting straight lines to the steepest parts of the magnetic anomaly profile. The distance between the points on the profile where the magnetic field intensity is one-half of the maximum slope is taken to be the depth to the top of the magnetic source.

When these interpretation techniques are systematically applied, they provide geophysicists with detailed information about the subsurface, geological structures are defined, and potential targets for geophysical exploration are identified [5]. The progress of these methods has improved the precision and reliability of aeromagnetic interpretations in the geological environment especially in the Ilesha area [24,28].

Structural Delineation and Tectonic Framework: The structural delineation of the subsurface has been a fundamental aspect of aeromagnetic studies in the Ilesha area. Initial investigations largely focused on identifying significant linear features to identify faults, fractures, and lithological contacts through qualitative interpretations of magnetic anomaly maps. As data processing methods evolved, further geophysical techniques, such as the analytical signal method, total horizontal derivative, and first vertical derivative, became standard for enhancing and delineating these geological structures [29]. The introduction of 3D Euler deconvolution further improved structural mapping by providing depth estimates for these features, facilitating a more thorough understanding of the subsurface geometry.

The findings show that research consistently indicates a dominant NE-SW structural trend, characteristic of the Pan-African Orogeny that shaped the regional geology [30]. These structures are significant as they often act as pathways for mineralising fluids and govern the position of various rock zones. Some studies also recognise E-W and NNE-SSW trends, indicating secondary structural modifications or specific shear zones like the Ifewara shear zone [31]. The capacity to map these hidden features provides invaluable insights into Ilesha's tectonic history and crustal framework. This further contributes to a better understanding of geodynamic processes and potential geohazards such as earthquakes.

Mineral Exploration and Prospectivity Mapping: The Ilesha area has seen extensive use of aeromagnetic investigation for mineral exploration due to its gold availability. This aeromagnetic survey has focused on identifying magnetic highs or lows amplitudes with known mineral occurrences or host rocks [32]. Over time, the methodology has evolved to integrate aeromagnetic data with complementary geophysical data like electrical resistivity and radiometric data. it enhanced the development of more accurate mineral prospectivity maps [33]. Further advancements include the application of sophisticated modelling techniques like multi-criteria decision Analysis which incorporate diverse geological and geophysical parameters to systematically classify regions into zones of varying mineralisation potential [34].

Aeromagnetic data has proven highly effective in delineating magnetic anomalies associated with mineralised zones and structural controls on mineralisation. The integration of aeromagnetic data with radiometric and remote sensing data significantly enhances the identification of hydrothermally altered zones and are key indicator of gold mineralisation [35]. Validation efforts using known mining sites and geochemical analyses have demonstrated the robustness of these prospectivity models, with high success rates in predicting high-potential gold exploration targets [36], thereby reinforcing the reliability of aeromagnetic methods in mineral exploration.

Depth Estimation of Magnetic Sources: Estimating the depth to magnetic sources and basement topography is critical for understanding the subsurface architecture of the Ilesha area. However, the use of Euler deconvolution and spectral analysis has considerably enhanced the accuracy and dependability of depth estimates, thereby revealing the thermal structures and geothermal potential. These techniques are capable of determining the depths to the top of magnetic sources, including the crystalline basement and various geological interfaces, thus offering a three-dimensional perspective on the subsurface.

Recent research employs advanced methods like source parameter imaging (SPI) and 3D Euler deconvolution to estimate depths ranging from 0.3 to 5.48 km, indicating both shallow and deep magnetic sources [20,37]. These advancements have improved the resolution of basement topography models [20,25]. Observations from studies in the Ilesha area describe a range of depths to magnetic sources, reflecting the varying depths of geological features. For example, depths to sources located within shear zones have been estimated between 90 m and 200 m, while overall magnetic source depths can range from as shallow as 12.6 m to as deep as 600 m for geological contacts. These depth variations are influenced by the specific geological features studied and the resolution of the data [20]. The consistent application of these methods has resulted in a clearer representation of subsurface geometry, aiding in the identification of shallow, accessible mineral targets and mapping deeper basement structures [25,37].

Groundwater Potential Assessment: Although groundwater is not the primary focus, aeromagnetic data have become increasingly helpful for their indirect contributions to groundwater exploration. The evolution in this area involves connecting magnetic patterns to features that control groundwater movement, such as fractured zones and weathered basement. Recent studies underscore the importance of integrating aeromagnetic methods with direct electrical methods to validate groundwater potential [38]. Additionally, spectral analysis of aeromagnetic data has identified Curie point depths (e.g., 15.1 km at Ikogosi Warm Spring), suggesting geothermal potential generating radioactive heat [39].

Findings show that Aeromagnetic surveys can efficiently outline structural discontinuities like faults and fractures, which often serve as key channels and reservoirs for groundwater. The NE-SW trending lineaments associated with the Pan-African Orogeny have been suggested to correlate with areas of high-yield groundwater aquifers. However, it is consistently recommended that these findings be confirmed and further explored through electrical methods to determine the exact groundwater potential and the stability of the underlying basement.

Case Studies: This section provides a detailed overview of significant studies that have utilized the aeromagnetic method in conjunction with other geophysical techniques to investigate the Ilesha area. Table 1 below further summarizes and compares the objectives, methods, and key findings of the case studies identified.

Akinlalu et al. (2024): [40] employed the stepwise weight assessment ratio analysis model for mapping the prospective gold area in parts of the Ilesa Schist belt. They utilized aeromagnetic, aero-radiometric, and remote sensing datasets. Data enhancement techniques were applied to aeromagnetic data to produce lineament maps, and analyses of radiometric and ASTER data delineated hydrothermally altered zones. The study identified lithology, lineament density, hydrothermal alteration, and slope as major factors that influence gold mineralization, with hydrothermal alteration being the most important. They confirmed that NE-SW trending structures facilitate the transportation of hydrothermal and mineralizing fluids, and gold mineralization is primarily associated with granitoids. The produced gold potential map classified the study area into five potential zones, with high to very high potential in the southern, western, and northwestern axes. Qualitative and quantitative validations showed high success rates (73 and 74 % respectively), substantiating the model's reliability [40]. These studies collectively demonstrate the versatility of the aeromagnetic method in understanding the complex geology and resource potential of the Ilesha area. They highlight a clear trend towards integrated approaches, advanced data processing, and quantitative modelling to address various geological and economic questions.

Olafisoye et al. (2022): [41] interpreted the aeromagnetic data of Ilesha to reveal possible future earthquake hazards and establish groundwater potential. They applied various edge detection methods, including analytical signal amplitude, total horizontal derivative (TDR), first vertical derivative (FVD), and 3D Euler deconvolution (ED), residual magnetic anomalies to identify linear structural discontinuities. Upward continuation filtering and depth estimation procedures (Source Parameter Imaging and radially averaged power spectrum) were also used to map geological structures and determine the depth to crystalline basement rocks. The study found that lineaments of the study area are in the direction of NE-SW, depicting the Pan-African Orogeny, suggesting possible groundwater aquifer zones in the area. Deep-lying faults extending beyond 2 km were identified. 3D Euler deconvolution and spectral analysis revealed magnetic source depths ranging from 55 m to 345 m and 13 m to 250 m, respectively. The delineated structural discontinuities exhibited a stress history similar to that of the Ifewara-Zungeru fault network, suggesting potential future earthquake occurrences.

Salawu et al. (2021): [2] provided new insights into the Ife-Ilesha schist belt by integrating satellite, aeromagnetic, and radiometric datasets. The objective was to evaluate structural features and identify potential mineral zones. They enhanced shuttle radar topographic digital elevation data using hill-shading and superimposed total gradient lineaments on a 3-D Euler deconvolution map. The study revealed major structural trends including NE− SW, NNE− SSW, E− W, and minor N− S directions, with the Ifewara shear zone trending NNE− SSW. Depths to the top of magnetic sources were estimated to vary from 90 m to 200 m. Complementary analysis of airborne radiometric data showed that the Ifewara shear zone is characterised by radiometric anomalies, indicating regional mineralisation alteration zones. The study concluded that there is a strong correlation between the satellite, radiometric, and aeromagnetic maps, providing valuable insights and re-evaluation of structural features relevant to gold mineralisation.

Olomo et al. (2021): [42] investigated the mode of occurrence of mineral deposits in Iperindo and its environs in the Ilesha area using magnetic and electrical resistivity methods. For the magnetic data, the total magnetic intensity map was enhanced using reduction to the equator, magnetic susceptibility, and analytic signal filters to suppress noise and accentuate magnetic bodies. 3-D Euler deconvolution and radial spectral analysis were applied to locate and estimate the depth to magnetic anomalies suspected to host mineral deposits. The study found that magnetic deposits have varying depths from 20 m to 300 m. Delineated magnetic anomalies predominantly trend in the NE-SW direction. It implies that geological structures formed during the Pan-African orogeny are often impregnated with mineralised bodies. The integration with electrical resistivity and induced polarisation data further highlighted areas with disseminated mineral deposits within fault/fracture zones.

Akinlalu et al. (2021): [43] focused on assessing the mineralisation potential in part of the Ilesha Schist belt using aeromagnetic, electrical resistivity, and geological data for subsurface investigation of a gold deposit. Three parameters identified were lineament density, lithology, and electrically derived coefficient of anisotropy. Geophysical techniques, including total horizontal derivative, 3-D Euler deconvolution, and source edge detection, were applied to aeromagnetic data to produce a lineament map. The aeromagnetic results showed predominantly NE-SW trending structures, characteristic of the Pan-African orogenic events, with some E-W trending lineaments indicating secondary alteration. Euler deconvolution solutions estimated geological contacts at depths of 94-600 m. The study successfully developed a reliable mineralisation potential zone with high validation success rates, confirming the importance of integrated geophysical and geological parameters for gold exploration.

Olurin (2017): [44] specifically focused on the interpretation of high-resolution airborne magnetic data (HRAMD) of Ilesha and its environs. The study area, delimited by geographic latitudes 7°30′-8°00′N and longitudes 4°30′-5°00′E, falls within the basement complex of Southwestern Nigeria. The digitised data were obtained from the Nigerian Geological Survey Agency (NGSA). Olurin (2017) applied Euler deconvolution on filtered and enhanced magnetic data to delineate geological structures and estimate depths. The total magnetic intensity distribution ranged from -77.7 nT to 60.9 nT. The residual magnetic intensity map revealed distinct magnetic highs and low values that indicate variations in magnetic susceptibilities. A significant finding was that the depths to magnetic sources from Euler deconvolution varied from 12.6 m to 110.7 m. The study also identified predominant structural trends in the NE-SW and NW-SE directions, consistent with the regional Pan-African orogeny. The study further emphasised the effectiveness of HRAMD and Euler deconvolution in mapping complex geological structures for mineral exploration.

Kayode et al. (2013): [45] provide fundamental insights into magnetic data interpretation applicable to aeromagnetic studies. The research focused on the eastern part of Ilesa town, aiming to delineate subsurface geological structures for mineral potential. They employed a proton precision magnetometer to record total field magnetic data along fifteen traverses. Qualitative and quantitative interpretations were carried out. Major findings include residual magnetic values ranging from 80 nT to -330 nT. The Peters half-slope method was used to estimate the maximum depth to the basement at approximately 160 m. The analytical signal was utilised to estimate the lateral extent of interpreted lithologies. The study concluded that the maps produced were effective in delineating geological structures and identifying areas with potential mineral zones [45]. They further highlight the uses of magnetic methods in mapping subsurface features and estimating depths, which are directly applicable to aeromagnetic data analysis.

Other important studies include [38], who integrated aeromagnetic and vertical electrical sounding data to assess groundwater potential around Ijano, identifying fractured zones with NE-SW trends as favourable for groundwater exploration. [42] combined aeromagnetic and radiometric data to map mesothermal alteration zones in the western Ilesha Schist Belt, finding that potassium-enriched zones correlate with gold deposits, as validated by existing mining pits. [46] applied variogram and kriging to aeromagnetic data to show that kriging enhances the delineation of magnetic anomalies for mineral exploration, particularly in identifying potential mineral zones. [32] investigated the petrology and gold mineralisation of the Ilesha Schist Belt. Aeromagnetic data were used to identify potential mineral zones with NE-SW trending shear zones and magnetic anomalies associated with amphibolite belts. [30] analysed the Ifewara Fault Zone's relationship with regional fracture systems through aeromagnetic profiles, concluding that the fault zone serves as a major structural control influencing both mineralisation and seismic activity.

Table 1. Comparative table of geophysical case studies in the Ilesha area.

Sources	Methods	Objectives	Finding
[45]	Ground Magnetic Survey (Proton Precision Magnetometer)	Delineate subsurface geological structures and identify mineral potential.	Effective delineation of geological structures; utility of magnetic methods in mapping subsurface features and estimating depths.
[44]	High-Resolution Airborne Magnetic Data (HRAMD), Euler Deconvolution.	Delineate geological structures and estimate depths.	Effectiveness of HRAMD and Euler deconvolution in mapping complex geological structures for mineral exploration. Variations in magnetic susceptibilities revealed.
[2]	Integrated: Satellite (SRTM), Aeromagnetic, Radiometric Data, 3-D Euler Deconvolution.	Evaluate structural features and identify potential economic mineral zones.	Strong correlation between data sets; radiometric anomalies indicate regional mineralisation alteration zones. Valuable re-evaluation of structural features for gold mineralisation.
[42]	Integrated: Magnetic and Electrical Methods, 3-D Euler Deconvolution, Radial Spectral Analysis.	Investigate the mode of occurrence of mineral deposits (Iperindo and environs).	Delineated magnetic anomalies trend NE-SW, implying structures from the Pan-African orogeny are often impregnated with mineralised bodies. Integration highlights disseminated mineral deposits in fault/fracture zones.
[43]	Aeromagnetic, Electrical Resistivity, Geological Data, Multi-Criteria Decision Analysis (MCDA), 3-D Euler Deconvolution.	Assess mineralisation potential (gold) in part of the Ilesha Schist belt.	Developed a reliable Mineralisation Potential Model (MPM); NE-SW structures characteristic of the Pan-African orogenic events are important.
[41]	Aeromagnetic Data, Analytical Signal, Total Horizontal Derivative, 3D Euler Deconvolution, Source Parameter Imaging (SPI), Spectral Analysis.	Reveal possible future earthquake hazards and establish groundwater potential.	Lineaments (NE-SW) suggest possible high-yield groundwater aquifer zones. Identified deep faults and a stress history similar to the Ifewara-Zungeru fault network, suggesting potential future earthquake occurrences.
[40]	Integrated: Aeromagnetic, Aero-radiometric, ASTER (Remote Sensing), Stepwise Weight Assessment Ratio Analysis (SWARA).	Gold prospectivity mapping in parts of the Ilesa Schist belt.	Hydrothermal alteration is the most important factor for gold mineralisation. Gold is associated with granitoids. Produced a reliable gold mineralisation map with high success rates.

Conflicting Viewpoints or Ongoing Debates: While the body of researchers on the aeromagnetic method in the Ilesha area generally converges on several key understandings, certain aspects present subtle differences, varying interpretations, or areas that warrant further discussion and potential debate. These points often arise from the inherent complexities of geophysical data interpretation, the use of diverse methodologies, and the multifaceted nature of the geological subsurface.

Variability in Depth Estimates: One of the most notable areas of variation among studies is the reported range of depths to magnetic sources and geological contacts. For instance, [44] reported depths to magnetic sources ranging from 12.6 m to 110.7 m using Euler deconvolution. [41] found magnetic source depths ranging from 13 m to 345 m (from spectral analysis) and 55 m to 345 m (from D Euler deconvolution). [42] estimated depths to magnetic anomalous bodies between 20 m and 300 m. [38] estimated fracture depths of 6–38 m using Euler deconvolution, while [46] reported deeper sources (0.478–5.48 km) using horizontal gradient and local wavenumber methods. [43] reported estimated depths of geological contacts ranging from 94 m to 600 m using Euler deconvolution solutions. These differences can be attributed to several factors.

Different studies may be targeting different types of magnetic sources (e.g., shallow mineralisation, deep basement structures, or specific lithological contacts), each with its characteristic depth range.

a. The resolution of the aeromagnetic data (e.g., flight height, line spacing) can significantly influence the accurate depth estimation of magnetic sources. Higher resolution data may resolve shallower, more subtle features, while lower resolution data may only capture deeper, larger anomalies.
b. The specific interpretation algorithms and their parameters (e.g., structural index in Euler deconvolution) can yield different results. Finally, the inherent assumptions of each depth estimation technique play a role; for example, spectral analysis provides average depths over a broader area, while Euler deconvolution provides point-by-point estimates. A direct comparative study systematically applying various depth estimation techniques to the same high-resolution data, coupled with ground-truthing (e.g., borehole data), could help reconcile these differences and provide a more unified understanding of the subsurface depth architecture.

Relative Importance and Interplay of Structural Trends: Based on several reports, there is a consensus that NE-SW trending structures are dominant in the Ilesha area, reflecting the influence of the Pan-African Orogeny [2,29,40,42,43]. However, the emphasis and interpretation of other structural trends sometimes vary. [43] noted the presence of E-W trending lineaments as imprints of secondary structural alteration, distinct from the dominant NE-SW trends. [2] highlighted NNE-SSW trends, particularly associated with the Ifewara shear zone, alongside NE-SW and E-W trends. [34] and [4] also identified NW-SE trends as characteristic of the Pan-African orogeny.

Integration of Methods vs. Single-method Aeromagnetic Interpretation: The increasing integration of aeromagnetic data with other geophysical methods and remote sensing datasets reflects a paradigm shift toward subsurface evaluations [2,40,42,43]. While aeromagnetic surveys provide valuable structural and lithological insights, their limitations in characterising certain geological features like conductive mineralisation or fluid-bearing structures necessitate complementary approaches. For example, [41] identified groundwater potential zones using aeromagnetics but emphasized the need for electrical resistivity verification, while [36] demonstrated superior capability of electrical resistivity tomography in delineating gold-associated sulfide minerals.

Future studies should quantitatively evaluate the improvements presented by combined methods compared to aeromagnetic interpretations only, particularly in complex terrains like the Ilesha Schist Belt. Such analyses would provide empirical guidelines for balancing geological resolution with cost-effectiveness, addressing a critical gap in exploration geophysics. The challenge remains in developing standardised frameworks to assess when multi-method approaches are justified versus when aeromagnetics alone may suffice, ensuring both scientific rigour and economic viability in resource exploration.

Detailed Petrophysical Characterization of Rock Units: While studies interpret magnetic anomalies based on inferred lithologies and structures, there is a general lack of detailed petrophysical characterisation of the various rock units in the Ilesha area. Understanding the precise magnetic susceptibility, density, and other physical properties of different rock types (e.g., gneisses, schists, granitoids, mineralised zones) through laboratory measurements on representative rock samples is crucial. Such data would significantly improve the accuracy of quantitative interpretations of aeromagnetic data, allowing for more precise lithological mapping of magnetic sources. Without robust petrophysical constraints, interpretations often rely on generalised assumptions, which can introduce ambiguities.

Quantitative Assessment of Groundwater Potential: While aeromagnetic data have been very useful in identifying structural features hosting groundwater potential, there is still a significant gap in the quantitative assessment of groundwater potential. For effective groundwater exploration, it is crucial to quantify aquifer parameters such as transmissivity, storage coefficient, and hydraulic conductivity. This would require integrating geophysical methods with hydrogeological investigations, including pumping tests, borehole logging, and more extensive electrical resistivity or electromagnetic methods specifically designed for hydrogeological characterization [41]. Developing integrated geophysical and hydrogeological models would provide a more robust framework for sustainable groundwater exploitation.

Environmental Impact Assessment of Mining Activities: The Ilesha area has a long history of mining, including significant artisanal and illegal small-scale mining activities [47]. Despite this, there is a notable gap in studies that integrate aeromagnetic data with environmental geophysics to assess the impact of these mining activities on the subsurface and groundwater systems. Aeromagnetic data, combined with other geophysical methods, could be used to map subsurface disturbances, delineate contaminant plumes, and monitor changes in groundwater levels or quality. Such research is vital for addressing environmental concerns, land degradation, and public health issues associated with mining [48].

Application of 3D Inversion Techniques: While Euler deconvolution and spectral analysis are widely applied for depth estimation and structural interpretation, the literature shows limited application of 3D inversion techniques to aeromagnetic data in the Ilesha area. A 3D inversion can provide more accurate and detailed subsurface models, especially in areas with complex geological structures and overlapping anomalies [49,50]. These techniques can resolve ambiguities inherent in 2D methods by simultaneously fitting the observed magnetic field to a 3-dimensional distribution of magnetic susceptibility. Implementing such advanced techniques could lead to a more precise understanding of the geometry and distribution of magnetic sources, improving targeting for exploration [51].

Suggestions for Future Research: Building upon the identified gaps in the current literature, the following suggestions outline opportunities for future research utilising the aeromagnetic method in the Ilesha area, Southwestern Nigeria. This involves integrating high-resolution aeromagnetic data with other complementary datasets, such as:

Seismic Data: While challenging in basement terrains, targeted seismic reflection or refraction surveys could provide high-resolution structural information, especially on deeper crustal features and fault geometries, which can constrain aeromagnetic interpretations.

Electrical Resistivity and Electromagnetic (EM) Data: As highlighted by [36] and [42], electrical methods are crucial for delineating conductive features associated with mineralisation (e.g., sulfides, graphite) and groundwater. Integrating these with aeromagnetic data in a 3D modelling environment would provide a more complete picture of subsurface conductivity and magnetic susceptibility distributions.

Borehole and Well Data: Existing and future borehole logs, core samples, and well completion reports provide invaluable ground-truth information on lithology, alteration, and fluid presence. Incorporating these into 3D models would significantly reduce ambiguity in geophysical interpretations.

Geological Mapping and Remote Sensing: Detailed geological maps, structural measurements, and advanced remote sensing products (e.g., hyperspectral data for alteration mapping) should be integrated to provide surface constraints and validate subsurface models. The work by [2] and [40] demonstrates the power of such integration.

Environmental Geophysics and Mining Impact Assessment: Given the prevalence of mining activities in the Ilesha area, future research should focus on the environmental applications of aeromagnetic and integrated geophysical methods:

Mapping Subsurface Contamination: Investigate the use of aeromagnetic data, possibly in conjunction with electrical resistivity or electromagnetic methods, to map subsurface contamination plumes associated with mining activities, especially if these plumes contain or react with magnetic minerals.

Assessing Ground Stability: Utilise geophysical methods to assess ground stability in areas affected by mining, identifying potential subsidence zones or unstable ground conditions.

Groundwater Monitoring: Implement time-lapse geophysical surveys to monitor changes in groundwater levels and quality in response to mining operations, providing crucial data for environmental management and remediation efforts.

Conclusion: The aeromagnetic method has become indispensable in deciphering the geological framework and resource potential of the Ilesha area, Southwestern Nigeria. This review consolidates findings from multiple peer-reviewed studies, highlighting the method's efficacy in mapping subsurface structures such as faults, shear zones, and mineralised corridors, particularly for gold exploration, despite challenges posed by dense vegetation and thick overburden. Beyond structural delineation, aeromagnetic surveys have enabled depth to source estimations, groundwater prospectivity assessments, and preliminary geohazard evaluations, offering a foundational understanding of the region's subsurface architecture. Recent research in Ilesha has reflected a transition from qualitative interpretations to advanced quantitative analyses and integrated multi-geophysical approaches, as demonstrated by studies that combine aeromagnetic, radiometric, and remote sensing data. Despite progress, gaps persist in petrophysical characterisation, structural evolution, and environmental impact studies related to mining. Future efforts should prioritise 3D geophysical modelling, machine learning-enhanced interpretations, and environmental geophysics to refine resource targeting and promote sustainable exploration practices in this geologically complex region.

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