Integration of Aeromagnetic and Radiometric Studies to Delineate Hydrothermal Alteration and Mineralized Zones in Effon-Alaaye and Its Environs, Southwestern Nigeria

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ABSTRACT

Basement terrains of southwestern Nigeria host structurally controlled hydrothermal mineralization, but delineating alteration zones and prospective targets remains challenging due to limited surface exposure and complex deformation history. This study integrates aeromagnetic and radiometric datasets to delineate hydrothermal alteration zones and assess the mineralization potentials of Effon-Alaaye and its environs within the Nigerian Basement Complex. High-resolution airborne aeromagnetic and gamma-ray spectrometric data covering the Ado-Ekiti Sheet 244 were acquired by the Nigerian Geological Survey Agency in 2006 and processed using Geosoft Oasis Montaj 8.4 (HJ). Aeromagnetic analysis included Total Magnetic Anomaly (TMA), Reduction to the Equator (RTE), First Vertical Derivative (FVD), Analytic Signal (AS), residual magnetic separation, Euler deconvolution, and lineament extraction to map subsurface structures and lithological contrasts. Radiometric processing involved potassium (K), thorium (Th), uranium (U), potassium deviation (KD), and ternary (K–Th–U) mapping to identify lithological variations and hydrothermal alteration signatures. Integrated interpretation established spatial relationships between structures, alteration zones, and mineralization. Results reveal a structurally complex basement dominated by NNE–SSW to NE–SW trends consistent with African-wide tectonics. Magnetic lineaments, low-magnetic corridors, and clustered Euler depth solutions delineate shear zones, faults, and lithological contacts that likely acted as conduits for hydrothermal fluids. Radiometric maps highlight potassic alteration zones characterized by elevated K and KD anomalies that correlate strongly with magnetic structures. Thorium data discriminate felsic intrusions from schist belt host rocks, while uranium maps delineate a uranium-enriched zone in the northeastern sector (Alawaye–Ojejelu–Itawure axis), suggesting hydrothermal uranium mineralization. Integrated results indicate that the highest mineralization potential occurs where shear zones intersect secondary structures and coincide with radiometric alteration signatures. Consequently, Iwaiji, Ipole, Agopoti, Alawaye, Ojejelu, and Itawure are identified as priority targets for orogenic gold, uranium, and associated polymetallic mineralization.

Key words: Effon-Alaaye, Polymetallic Mineralization, Basement Complex, Hydrothermal Alteration

INTRODUCTION

Effon-Alaaye and its environs (Long. 4°53′–5°00′ E; Lat. 7°30′–7°45′ N) lie within the Precambrian Nigerian Basement Complex, a segment of the African-wide orogeny mobile belt marked by intense tectono-metamorphic evolution. The terrain comprises migmatite–gneiss complexes, schist belts, quartz veins, and African-wide orogeny granitoids that have experienced multiple deformation and magmatic events [1-2]. These lithologies, together with pervasive fractures, shear zones, and faults, provide conduits for fluid circulation and hydrothermal alteration, creating favourable conditions for metallic mineralization within quartz veins, pegmatites, and potassic-altered zones [3-4]. Despite these favourable geological indicators, Effon-Alaaye remains largely underexplored using integrated aerogeophysical methods. Existing studies in the area rely mainly on surface geological mapping and remote sensing [5]. Identified key lithologies and structural trends, but their work lacked the subsurface resolution necessary to detect deeper alteration systems. In contrast, research across analogous

Basement Complex terrains demonstrates the effectiveness of combining aeromagnetic and radiometric datasets for subsurface exploration. While [6] mapped concealed shear zones and lithological boundaries in the Ilesha area using aero-geophysical methods. Recent developments in airborne radiometry have highlighted the usefulness of radioelement ratios, such as K/Th, K/eTh, eU/K, and Th/U, for identifying hydrothermal alteration, metasomatism, and potassium enrichment. Studies within the Nigerian Basement Complex [7-9] confirm that integrating radiometric ratios with magnetic structural interpretation enhances the delineation of alteration zones. International works [10] also show that magnetic–radiometric synergy improves the detection of lithological contacts, lineaments, and alteration footprints associated with mineralization. Although Effon-Alaaye lies close to major mineralized belts, including the Iwaraja–Ifewara shear zone and Ilesha schist belt [11-12], no comprehensive aeromagnetic–radiometric study has been conducted in the area. This creates a significant knowledge gap regarding the subsurface structural configuration and its influence on hydrothermal alteration and mineralization. This study, therefore, integrates aeromagnetic and radiometric datasets to delineate alteration zones and assess the mineralization potential of Effon-Alaaye and its surroundings. By analysing magnetic structures, depth-to-source estimates, radiometric anomalies, and alteration-sensitive ratios, the study aims to generate a detailed geophysical interpretation that will guide further geological and geochemical investigations and contribute to improved mineral exploration strategies within the southwestern Nigerian Basement Complex.

Location and physiography of the study area

The study area, Effon Alaaye and its environs, lies in southwestern Nigeria between latitudes 7°30′–7°45′ N and longitudes 4°53′–5°00′ E. It is part of the Precambrian Nigerian Basement Complex, specifically associated with the Ilesha Schist Belt. The physiography is characterized by undulating terrain, moderate to steep hills, and narrow valleys, shaped by differential weathering of migmatites, quartz-schists, and granitic intrusions. The regional tropical climate, characterized by distinct wet and dry seasons, significantly influences weathering, landscape development, and surface drainage patterns. Similar lithological and structural features have been documented in the Basement Complex rocks of southwestern Nigeria, including quartzites, schists, and migmatitic gneisses exposed in neighboring parts of the Ilesha Schist Belt as part of the Pan-African orogenic framework [13, 5]. Geologically, the basement succession in southwestern Nigeria comprises three major lithologic-petrotectonic units: the Migmatite–Gneiss–Quartzite Complex, meta-sedimentary/metavolcanic schist belts (such as the Ilesha Schist Belt), and Pan-African granitoids/older granites. These units form the framework for understanding the structural and mineralization controls in the region [1]. The Ilesha Schist Belt contains a variety of metasedimentary and metavolcanic rocks, including schists, quartzites, phyllites, amphibolites, banded iron formations, and subordinate granitic/pegmatitic intrusions [9, 6]. The lithological complexity and repeated folding produce rugged terrain, with ridges on competent rocks and valleys on more weatherable lithologies. Structurally, portions of the schist belt record multiple deformational events tied to the Pan-African orogeny and earlier tectono-metamorphic cycles. Studies integrating field mapping, remote sensing, and aerogeophysical data have revealed fold axes and shear zones trending NE–SW, NNE–SSW, and other orientations, reflecting ductile and brittle deformation phases [10]. These structural fabrics, including fold limbs and hinge zones, control fluid pathways, hydrothermal alteration, and the localization of mineralized veins, making them key targets for mineral exploration. Given this geological and structural context, Effon Alaaye's topography, lithology, and structural fabric likely predispose the area to hydrothermal alteration and metal mineralization, making it a promising target for integrated geophysical (aeromagnetic and radiometric) studies and follow-up geological and geochemical investigations.

Geological setting

Effon-Alaaye lies within the Precambrian crystalline Basement Complex of southwestern Nigeria, part of the African-wide mobile belt that separates the West African and Congo cratons. The basement of this region is polycyclic in origin and records multiple tectono-metamorphic events that produced a heterogeneous assemblage of high-grade metamorphic and intrusive rocks. Field and petrographic studies across Ekiti and neighbouring areas show that the dominant lithologies comprise migmatite–gneiss complexes, banded and granite-gneisses, with subordinate schists, quartzite bands, and variably intruded bodies (granites, charnockites, pegmatites, and aplites). These rock types reflect high-grade amphibolite–to–granulite–facies metamorphism and crustal reworking during Proterozoic African-wide tectonism [14]. Structurally, the area is characterized by pervasive foliation and gneissic banding, with brittle-ductile shear zones, faults, and fracture networks that locally control

lithological contacts and the emplacement of intrusive bodies. Detailed mapping and structural analyses in nearby Ekiti localities record alternating leucosome-melanosome fabrics, abundant quartz veins, and late brittle reactivation, signatures of syn-tectonic magmatism followed by later brittle deformation [15, 16]. These structural fabrics are important because they create permeability contrasts and pathway networks for hydrothermal fluids and metasomatic processes. Petrographic and geochemical investigations from neighbouring outcrops (e.g., Ora-Ekiti and Ila-Orangun areas) indicate mineral assemblages dominated by quartz, K-feldspar and plagioclase, biotite ± muscovite and accessory opaques (magnetite, ilmenite), implying felsic to intermediate protoliths that have experienced anatexis and magmatic differentiation. Geochemical classifications of these rocks commonly span calc-alkaline to peraluminous signatures, consistent with crustal melting and fractional crystallization in a convergent-margin to collisional tectonic setting [14]. The combination of (1) a migmatite–gneiss country rock that records partial melting and crustal reworking, (2) multiple intrusive events (granitoids and charnockites), and (3) an extensive network of structural discontinuities creates a favourable geological framework for hydrothermal alteration and basement-hosted mineralization. Recent work across southwestern Nigerian basement terrains emphasizes that hydrothermal alteration and mineralization commonly concentrate along structural corridors, contact zones between intrusions and country rocks, and sites of enhanced permeability produced by brittle reactivation [14]. Weathering and regolith development in the tropical climate further modify primary signatures, producing near-surface geochemical dispersion patterns that must be considered during exploration. The geology of Effon-Alaaye and its environs, high-grade migmatite–gneiss basement, emplacement of felsic to intermediate intrusions, and structurally controlled fluid pathways, provides a robust geological rationale for integrated radiometric, geochemical, and mapping studies aimed at delineating hydrothermal alteration zones and assessing mineralization potential in the area.

Aeromagnetic data acquisition and processing workflow

The aeromagnetic dataset used in Effon-Alaaye was clipped from the high-resolution airborne magnetic survey of the Ado-Ekiti Map Sheet 244 (1:100,000), acquired by the Nigerian Geological Survey Agency [17]. The survey was designed to map subsurface structures, lithological boundaries, and potential mineralization indicators within the Nigerian Basement Complex. The workflow adopted in this study involves the following major stages:

1. Data acquisition

• Aeromagnetic data were collected at a nominal flight altitude of 50 m with 150 m flight-line spacing in NW–SE direction and NE–SW tie lines for navigational control (NGSA, 2006).

• Measurements were acquired as Total Magnetic Anomaly (TMA), capturing magnetic responses related to variations in basement lithology and structural zones associated with hydrothermal alteration and mineralization.

2. Data preparation and processing

• The TMA dataset was supplied as a gridded file and imported into Geosoft Oasis Montaj™ 8.4 (HJ) for processing.

• Initial processing included clipping, gridding, and inspection of noise levels.

• The TMA grid was resampled to ensure a uniform 5000 m cell size for interpretational consistency.

• Diurnal variations and non-geological noise were minimized to enhance the clarity of subsurface magnetic responses.

3. Aeromagnetic enhancement

• Several non-linear filtering algorithms were applied to enhance magnetic signatures linked to structural features and mineralized zones:

- Reduction to the Equator (RTE) to reposition anomalies directly over their causative bodies due to Nigeria's low magnetic latitude.

- First Vertical Derivative (FVD) to highlight shallow-seated magnetic sources and better define geological contacts.

- Analytic Signal (AS) to delineate boundaries of magnetic bodies independent of magnetization direction.

- These enhancement techniques follow established procedures used in the structural interpretation of basement terrains in Nigeria 18

4. Interpretation

- High-amplitude magnetic anomalies were interpreted as magnetite-rich and structurally competent lithologies.

- Linear anomalies and low-magnetic zones were associated with faults, fractures, and shear zones, serving as preferential fluid conduits for hydrothermal processes.

Radiometric data acquisition and processing workflow

The radiometric dataset for Effon-Alaaye was obtained from high-resolution airborne geophysical surveys extracted from the Ado-Ekiti Map Sheet 244 (1:100,000). The survey, conducted in 2006 by the Nigerian Geological Survey Agency (NGSA), aimed to map lithological variations and delineate hydrothermal alteration zones within the Nigerian Basement Complex. The main steps involved are summarized below:

1. Data acquisition

- Airborne surveys were flown at a 50 m altitude with 150 m flight line spacing oriented NW–SE, complemented by NE–SW tie lines for positional control.

- Natural gamma-ray emissions of potassium (K), uranium (U), and thorium (Th) were measured. Variations in these radioelements indicate lithology, weathering intensity, and hydrothermal alteration associated with mineralization.

2. Data preparation and processing

- Raw datasets were supplied in Geosoft-compatible grids and processed using Oasis Montaj™ 8.4 HJ.

- Processing included clipping, gridding, and corrections for diurnal and cosmic background effects.

3. Radiometric enhancement and mapping

- Color composite images were produced for K, Th, U, and potassium deviation (KD) anomalies.

- A ternary K–Th–U map assigned red, green, and blue channels to visualize lithological contrasts and alteration patterns.

- KD maps were generated to highlight areas enriched in potassium due to hydrothermal fluids, distinguishing them from unaltered lithologies using the K–Th baseline ratio.

4. Interpretation

- Areas with high K but low Th and U were interpreted as hydrothermally altered zones, while high Th and U indicated less altered lithologies.

- This workflow follows established methods for Nigerian basement terrains [19-21], providing a robust framework for mapping hydrothermal alteration zones and assessing mineralization potential.

KD Calculation:

$$KD_1 = \frac{K}{Th} \qquad \text{and} \qquad K_n = \left(\overline{K/Th}\right) Th, \qquad KD_2 = \frac{K - K_n}{K_n}$$

Where K is a measure of Potassium (e.g, wt% or ppm), Th is equivalent to thorium (ppm), and K/Th is the regional background of the K/Th ratio [22]. Potassic alteration (KD) is a key indicator in many ore systems (e.g., porphyry Cu ± Mo ± Au, high-sulfidation, mesothermal).

AEROMAGNETIC DATA SET RESULTS AND DISCUSSION

Total magnetic intensity anomaly map

The Total Magnetic Intensity (TMA) anomaly map (Fig 1) displays variations in the Earth's magnetic field after removal of the regional International Geomagnetic Reference Field (IGRF), highlighting contrasts in subsurface magnetic susceptibility typically related to rock type and structure, such as magnetite content. In crystalline terrains like the Ilesha Schist Belt, these magnetic signatures help delineate lithological units, identify faults and shear zones, and highlight hydrothermal alteration zones, which are critical for orogenic gold mineralization [23-24] Warm colors (red/pink/yellow) on the TMI map typically indicate high magnetic anomalies, associated with rocks rich in magnetite, such as basic intrusives or iron-rich metamorphics [24] In contrast, cool colors (blue/green) cor respond to low magnetic anomalies, often marking metasedimentary schists and quartzites with low susceptibility or hydrothermally altered zones where magnetite has been destroyed, providing important proxies for gold exploration [24-25]. Linear anomaly trends, dominantly NE–SW to NNE–SSW, align with major fault and shear systems formed during the African-wide orogeny. These structures act as conduits for mineralizing fluids and define corridors of deformation where gold mineralization is most likely. Sharp transitions between high and low magnetic zones highlight fault contacts and deformation zones, consistent with derivative and lineament analyses [23, 25]. Towns such as Iwaiji, Ipole, and Agopoti coincide with broad low magnetic zones bordered by high-gradient features, suggesting schistose host rocks and hydrothermal demagnetization favorable for gold mineralization. Similarly, Ireburu and Itawur in the northern block lie near low magnetic zones and structural terminations, indicative of focused structural complexity and potential mineral traps [24]. The TMI map provides a robust framework for understanding lithological and structural controls on mineralization in the Ilesha Schist Belt. Low magnetic anomalies reflect favorable host rocks and alteration zones, while strong linear trends highlight structures that likely localize gold-bearing fluids. Integration of these magnetic signatures with derivative maps and geological data enhances the effectiveness of targeting gold mineralization zones, particularly around Iwaiji and Ipole [23-25].

Reduce to equator (RTE) map

The Reduced-to-Equator (RTE) map of Effon-Alaaye and surrounding areas (Fig 2) highlights the spatial distribution of magnetic anomalies after correcting for low-latitude effects, providing a clearer depiction of the subsurface magnetic sources [26-27]. High-amplitude positive anomalies (red–violet, $\sim$–10 to +128 nT) are observed in the northern sector around Ojejelu, Alawaye, and Itawure, indicating magnetically susceptible lithologies, likely mafic intrusions or charnockitic bodies, consistent with previous susceptibility studies in southwestern Nigeria basement terrains [28]. These anomalies appear structurally aligned along local shear zones, suggesting that the high-magnetization bodies may control fluid flow pathways and therefore represent potential sites for hydrothermal mineralization [29]. Moderate anomalies (yellow–green, $\sim$–40 to –20 nT) are dominant around Oke-Agbimo and central Effon-Alaaye, interpreted as intermediate gneissic or migmatitic lithologies, which could host disseminated base-metal mineralization along structural contacts [30]. Low-amplitude negative anomalies (blue–cyan, < –60 nT) near Erin-Oke, Erin-Ile, Ilogbo, and Ipole likely represent felsic or weathered rocks, potentially acting as traps for hydrothermally remobilized metals including uranium,

lead, and rare earth elements [26]. The intersections between contrasting high and low magnetic domains, particularly around Effon-Alaaye, Iwaji, and Oke-Agbimo, correspond to areas of enhanced structural complexity and are interpreted as favorable sites for hydrothermal alteration and polymetallic mineralization [27]. The RTE map provides a reliable framework for integrating structural and lithological data to guide targeted mineral exploration in this basement terrain [29-29].

Residual magnetic map

The residual magnetic map of Effon-Alaaye and its surrounding towns (Itawure, Ojejelu, Alawaye, Oke-Agbimo, Iwaji, Ilogbo, Ipole, Apopolu, Erin-Oke, Erin-Ile) (Fig 3) highlights short-wavelength magnetic anomalies that reflect shallow subsurface geological variations after removing the regional magnetic field. Such residual anomalies commonly delineate shallow intrusions, lithological contacts, and structural discontinuities that may control mineralization [31]. The colour scale indicates magnetic values ranging from strong positive anomalies (pink-purple) to strong negative anomalies (blue-green), and these reflect contrasts in magnetic susceptibility of the basement rocks. The northern part of the map, particularly around Itawure–Ojejelu–Alawaye, is dominated by high-amplitude positive anomalies, suggesting magnetite-rich intrusive bodies or mafic basement units with high magnetic susceptibilities. These areas are significant targets for iron-oxide or sulfide-related mineralization and have been similarly linked to intrusive-controlled mineralization in recent Nigerian aeromagnetic studies [32-33]. In contrast, the central corridor around Oke-Agbimo–Effon-Alaaye–Iwaji shows alternating high–low anomalies that define structural lineaments trending NE–SW and NW–SE. Such lineaments are likely faults, fractures or shear zones that could act as conduits for hydrothermal fluids, making them favourable for gold or base-metal mineralization where magnetite destruction from hydrothermal alteration creates magnetic lows [33]. The southern region (Ilogbo–Ipole–Apopolu–Erin-Oke–Erin-Ile) is characterized by lower magnetic intensity, implying felsic basement or alteration zones with reduced magnetite. Hydrothermal mineral systems frequently occur in these magnetically subdued environments, particularly along contacts between magnetic highs and lows [33]. Additionally, because Nigeria lies in a low-magnetic-latitude zone, remanent magnetization can sometimes invert anomaly response, requiring integration with geology, radiometric data, and ground investigations for accurate mineral targeting [33]. The map reveals structurally complex basement terrain with multiple intrusive and structurally controlled targets that warrant further exploration.

Analytical signal (AS) map

The Analytic Signal (AS) map of Effon Alaaye and its environs, including towns such as Alawaye, Ereguru, Ojejelu, Itawure, Oke-Agbimo, Effon-Alaaye, Iwaji, Ilogbo, Ipole, Apopolu, Erin-Oke, Erin-Ile, and Orita-Ijeda (Fig 4), highlights zones of significant magnetic susceptibility variations, corresponding to lithological boundaries and structural features within the basement complex. High AS (red–violet) zones, observed around areas like Oke-Agbimo, Itawure, and Ojejelu, likely correspond to strongly magnetic lithologies such as mafic intrusions, banded gneisses, and metavolcanic rocks, which are often enriched in magnetite or other ferromagnetic minerals; such interpretation is consistent with recent baseline magnetic susceptibility measurements in southwestern Nigeria that show very high susceptibilities for banded gneiss and related lithologies [23]. Conversely, low AS values (green–blue zones), observed across Ipole, Apopolu, Erin-Oke, and Erin-Ile, likely reflect felsic gneisses and granitic units, which tend to have lower magnetic susceptibility. Several recent aeromagnetic studies across Nigerian basement terrains demonstrate that AS maps can reliably distinguish between high susceptibility bodies (intrusives, migmatites, gneisses, and lower susceptibility granitoids or meta-sediments [34-35]. The map also reveals linear trends and elongated anomalies, interpreted as shear zones, faults, or structurally controlled intrusions, which could indicate structural control on the emplacement of magnetic lithologies. Indeed, a recent study of the North Central Nigerian basement highlighted that the combined use of AS, first vertical derivative (FVD), tilt derivative, and gravity–magnetic modelling delineated major lineaments (NE–SW and NW–SE), intrusions, and fault systems that correlate with documented gold occurrences [36]. Given that hydrothermal fluids often migrate along faults and fractures, these structural axis, marked by AS anomalies and derivative filter lineaments, particularly around Ilogbo, Iwaji, and Orita-Ijeda, are plausible targets for mineralization (e.g., magnetite-associated Fe, Cu–Ni sulfides, or other ores) [37]

First vertical derivative map

The First Vertical Derivative (FVD) map (Fig 5) enhances shallow magnetic anomalies and sharply defines the edges of magnetic source bodies such as faults, fractures, contacts, and intrusions, key controls for mineralization in the Ilesha Schist Belt of Southwestern Nigeria. High-contrast zones (red/white to blue) mark abrupt magnetic gradients that delineate major structural discontinuities, while moderate to low values (green/yellow) represent more homogeneous, less magnetic domains [22]. These enhanced structures coincide with the known Pan-African fabric and the metallogenic framework of the region. The dominant structural trends revealed by the FVD map include strong NNE–SSW to NE–SW lineaments, particularly across the central and eastern sections of the map. These align with the regional shear systems, including the Ifewara-Zungeru fault zone, widely recognized as conduits for gold-bearing hydrothermal fluids in the schist belt [33]. Secondary E–W and NW–SE cross-structures appear in the northern and southern sectors, representing later deformation zones that may have reactivated earlier shear fabrics, facilitating additional fluid ingress and mineral deposition [32]. The spatial relationship between the structural zones and the towns further refines mineralization potential. Iwaiji lies directly along a major NNE–SSW structural corridor and near a cross-cutting NE–SW feature, making it a prime target for lode-gold mineralization. Ipole and Agopoti occur within a high-density fracture network where major and secondary lineaments intersect, creating favourable sites for hydrothermal concentration and sulphide precipitation. Ireburu and Itawur correspond to shorter but distinct E–W to WNW–ESE structures, which may host localized mineralization, while Amaye and Agbin-O lie along the principal NNE–SSW structural belt, further confirming their mineral potential. The FVD map provides a clear structural framework that highlights zones of enhanced prospectivity. Areas where major NNE–SSW faults converge with secondary structures, especially around Iwaiji, Ipole, and Agopoti, represent the best targets for follow-up geological mapping, geochemical sampling, and drilling. These structurally complex zones are consistent with recent findings that link magnetic gradients, radiometric anomalies, and hydrothermal alteration to gold and base-metal mineralization in Nigerian basement terrains [38, 22]

Euler deconvolution map

The Euler deconvolution map (Fig 6) computes the spatial coordinates and structural index of magnetic anomaly sources, which are displayed as colored circles representing estimated elevation (depth). Light grey to light blue hues correspond to shallower solutions (>2260 m), while darker blues, greens, and black zones (<1860 m) indicate deeper sources. Clustering of solutions within similar elevation ranges typically marks geologic contacts, faults, shear zones, or intrusions that may control mineralization. Higher elevation solutions (>2260 m), particularly around Ojejelu, Ereguru, and Itawure, likely reflect structural highs that may act as conduits for hydrothermal fluids and pathways for base-metal mineralization [39]. Spatially, the Euler solutions reveal several structurally significant trends across the map area. A shallow E–W trending feature near Ireburu and Itawur suggests brittle fractures or near-surface dike-like bodies favourable for vein-type deposits. A more prominent NNE–SSW trend through Agbin-O and Amaye is marked by deeper (blue–green) clustered solutions, reflecting a major shear zone or deep-rooted intrusive contact. Intermediate elevation solutions (1960–2260 m), dominant around Agbimo, Onalaaye, and Iwaji, coincide with moderate relief terrain where secondary enrichment processes may localize Cu–Zn–Pb mineralization [40]. The southern sector, including Ipole, Apopolu, Erin-Oke, and Erin-Ile, displays lower elevation (<1960 m) solutions that align with valleys and potential alluvial or sediment-hosted mineralization zones [39]. The most significant anomaly occurs around Iwaiji, where dense clusters of intermediate to deep solutions (dark blue to black) indicate a large subsurface intrusive body or a steeply dipping fault system, making it highly prospective for deep-seated mineralization. Similarly, the Ipole–Agopoti intersection, marked by a mix of shallow and deep solutions, represents a structurally complex zone where hydrothermal alteration and sulfide deposition are likely concentrated [40]. The Euler deconvolution results highlight zones of structural complexity and depth variability that are favourable for mineralization. High-density clusters, especially around Iwaiji, Ipole, and Agopoti, should be prioritized for detailed geological mapping, geochemical sampling, and drilling, as they lie along fault-controlled corridors with enhanced susceptibility to hydrothermal alteration and sulfide mineral deposition.

Lineament map

The provided Lineament Map (Fig 7) displays linear features derived from remote sensing and geophysical data, representing surface expressions of subsurface structures such as faults, shear zones, fractures, joints, and

lithological contacts. In the context of orogenic gold exploration in the Nigerian Schist Belts, particularly the Ilesha Schist Belt, lineaments are critical as they mark primary fluid pathways and trapping sites for mineralizing hydrothermal solutions [24, 23] and [41]. Dominant lineaments trend NNE–SSW to NE–SW, reflecting Pan-African tectonics and correlating with major shear zones such as the Ifewara Fault system, which served as first-order conduits for gold-bearing fluids. Secondary E–W trends cross-cut these primary structures, representing later or subsidiary deformation events [24, 22]. Long, continuous lineaments are interpreted as major faults and shear zones characterized by high strain, fracturing, and hydrothermal alteration, creating favorable sites for gold deposition. Areas where primary and secondary lineaments intersect are particularly prospective due to localized stress dilation that can trap mineralizing fluids. High-density lineament zones indicate primary exploration targets, with towns like Iwaiji, Ipole, and Agopoti lying within structurally complex regions of intersecting NNE–SSW and E–W lineaments. Amaye is positioned along the main NNE–SSW corridor, confirming its structural association with regional fluid pathways. Secondary targets include Ireburu and Itawuru, located near E–W lineaments that may host localized or smaller-scale mineralization. Overall, the density, intersection, and orientation of lineaments define structural corridors that control the localization of orogenic gold deposits, providing a robust framework for targeted exploration [23, 41]. The lineament map confirms that Iwaiji, Ipole, and Agopoti lie within the most structurally favorable zones for gold mineralization. The combination of dense, intersecting lineaments and alignment with regional structural trends strongly supports these areas as primary exploration targets within the Ilesha Schist Belt [24, 22].

Lineament density map

The Lineament Density Map (Fig 8) provides a structural blueprint for assessing mineralization potential in the Ilesha Schist Belt of Southwestern Nigeria, where faults, fractures, and shear zones exert primary control over hydrothermal fluid migration. High lineament density zones (>2.10 m/km²), depicted in dark red, signify intensely fractured bedrock that has undergone repeated tectonic reactivation, consistent with regional African-wide structural imprints [32]. These structurally prepared axis are optimal for lode-gold and base-metal deposition because they enhance permeability and facilitate deep fluid circulation [42]. The most prospective areas coincide with towns such as Iwaiji, Ipole, and Agopoti, which lie directly within these high-density NNE–SSW structural belts. These belts likely represent splays or subsidiary strands of the Ifewara–Zungeru Fault System, a major crustal structure known to focus gold mineralization in the Schist Belt [23]. The spatial overlap between high-density corridors and these towns strongly suggests structurally controlled ore localization similar to patterns documented in aeromagnetic and radiometric studies across Southwestern Nigeria [32, 28]. Moderate-density zones (1.51–2.10 m/km², orange), including the Amaye region, reflect sustained but less intense deformation and may host secondary mineralized veins or shear-hosted alteration zones. Localized moderate-to-high density patches around Ireburu and Itawur may represent cross-faults or intersecting fracture networks, structural traps known to enhance gold deposition by focusing hydrothermal flow [43]. Conversely, low-density regions (<0.91 m/km², light green) exhibit limited structural preparation, reducing their mineralization potential. The Lineament Density Map highlights a structurally complex, interconnected deformation zone that aligns with documented mineralization trends in the Nigerian Basement Complex. Exploration should prioritize the high-density belts around Iwaiji, Ipole, Agopoti, and Amaye, where structural continuity and fracture connectivity create ideal conduits for hydrothermal fluid migration and ore deposition [23, 25].
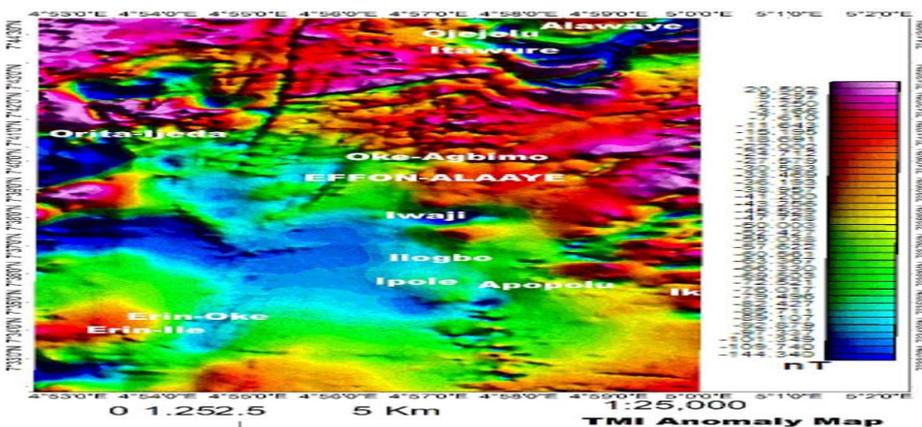

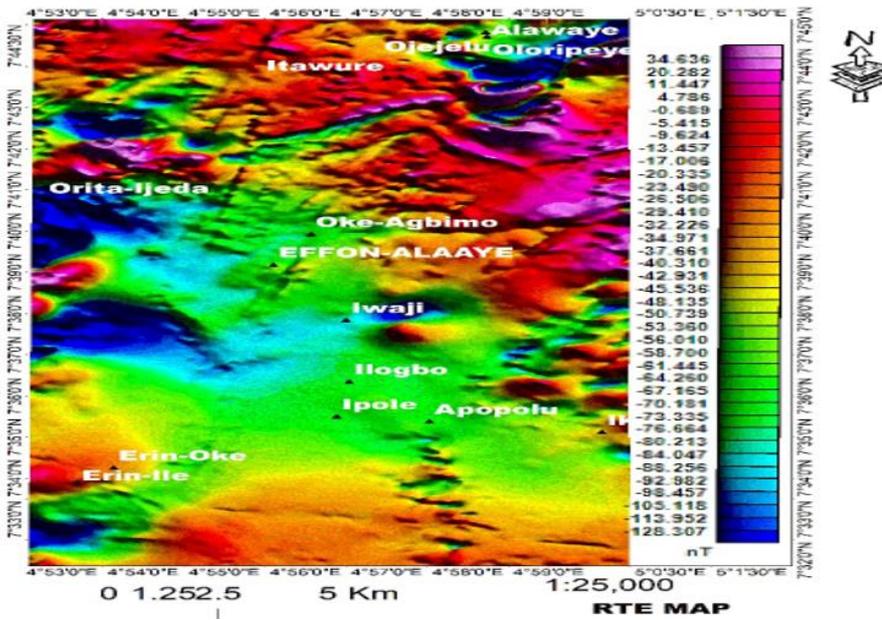Fig. 1 Total magnetic intensity anomaly map

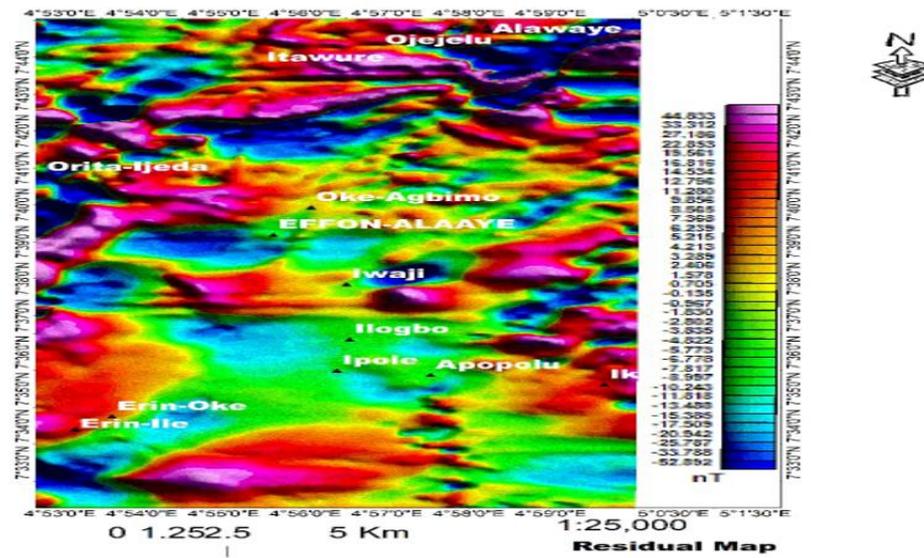Fig. 2 Reduce to equator map

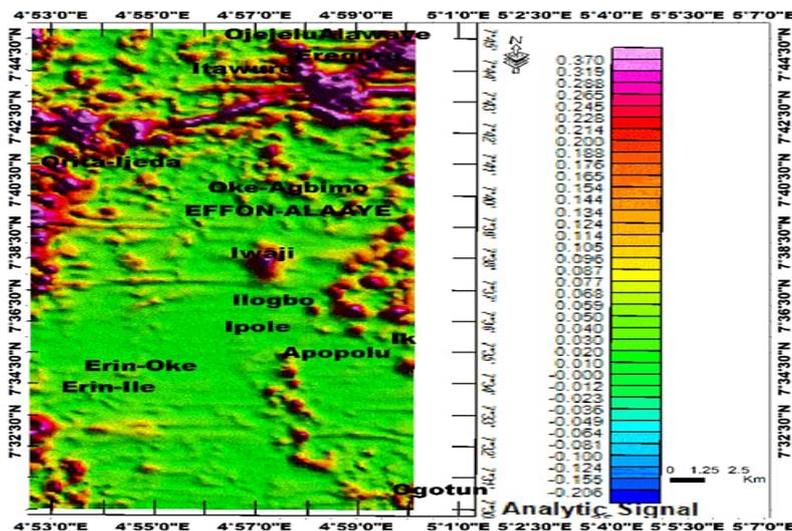Fig. 3 Residual anomaly map

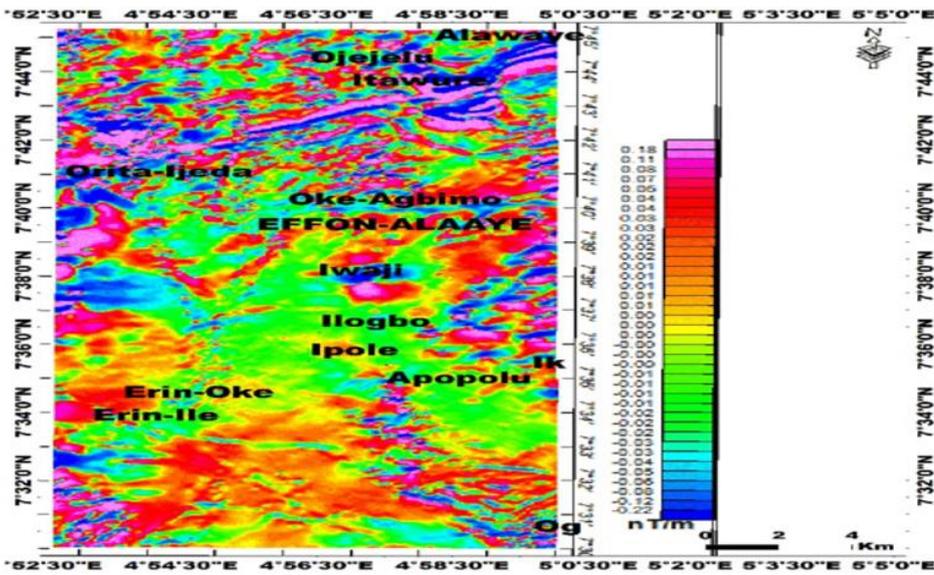Fig.4 Analytical signal map

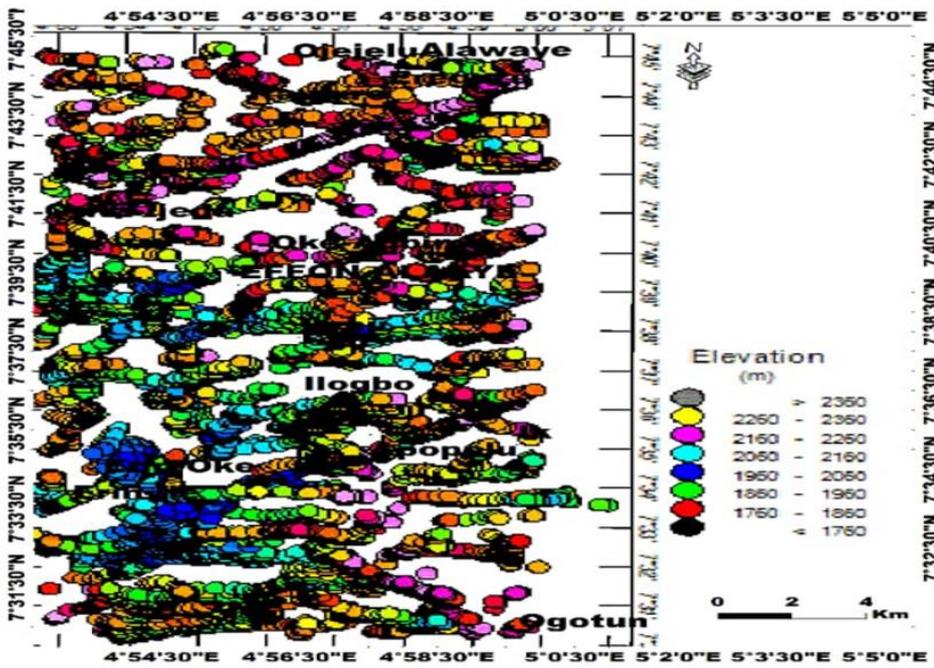Fig.5 First vertical derivative
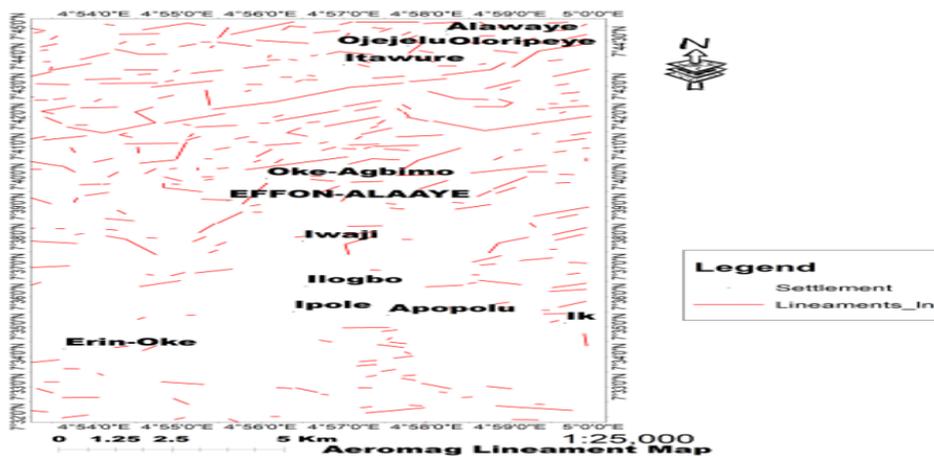

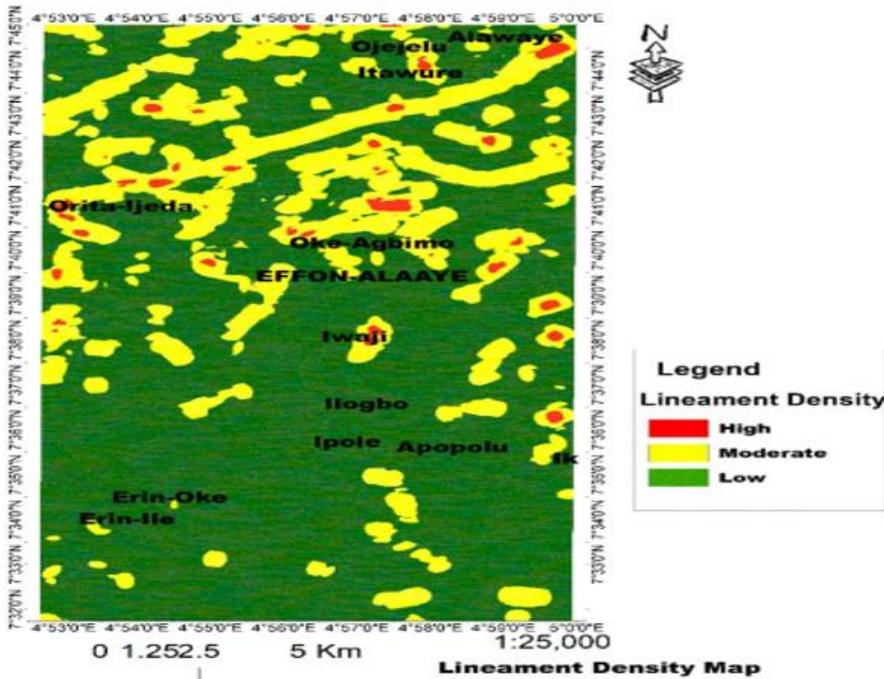Fig. 6 Euler deconvolution map

Fig. 7 Lineament map

Fig. 8 Lineament density map

RADIOMETRIC DATA SET RESULTS AND DISCUSSION

Potassium deviation anomaly map

The provided potassium deviation (Kd) Anomaly Map (Fig 9) derived from airborne gamma-ray spectrometric data, highlights areas where the potassium content of rocks deviates significantly from local background values, thereby delineating hydrothermal alteration zones. Potassium enrichment is a key indicator in gold and base-metal exploration because potassic alteration (e.g., sericitization, K-feldspar alteration) is commonly associated with orogenic gold mineralization in schist belts [24, 41, 22]. Alteration Signatures: The Kd map uses a color scale in which high positive anomalies (Red/Orange) indicate potassium enrichment from hydrothermal fluids, representing primary targets for gold mineralization. Background values (Yellow/Green) correspond to normal lithological potassium levels, while high negative anomalies (Blue/Purple) mark potassium depletion, which may reflect leaching, low-K lithologies, or specific alteration types that require corroborating data for mineralization assessment [24, 41]. Delineated Alteration Zones and Structural Linkages: The map reveals elongated high positive Kd anomalies, predominantly trending NNE–SSW, which correlate with known structural corridors such as major faults and shear zones controlling gold mineralization [24, 22]. A northern high Kd anomaly trends E–W to NE–SW, suggesting structural control on alteration distribution. Zones of potassium depletion (Blue) in the central-western and southern sectors likely correspond to low-K lithologies or advanced weathering, but may also represent alteration where K has been leached 41. Mineralization Potential near towns: Overlaying towns on the Kd map indicates that Iwaiji, Ipole, and Agopoti lie within or adjacent to major high Kd zones, implying extensive potassic alteration and high gold prospectivity. Amaye is positioned along a high-gradient corridor adjacent to the main NNE–SSW anomaly, while Ireburu and Itawur fall within the northern high Kd zone that aligns with structural lineaments, making them secondary targets for exploration [24, 41]. The potassium deviation map provides a direct geophysical proxy for hydrothermal alteration associated with gold mineralization. High Kd anomalies coincide with major structural zones and geophysical indicators (TMI, FVD, Lineament Density), highlighting zones of hydrothermal alteration and structural complexity. The NNE–SSW high Kd corridors near Iwaiji, Ipole, and Agopoti represent the most favorable targets for ground verification and exploratory drilling [24, 41, 22].

Potassium deviation reclassified map

The Potassium Deviation (Kd) Reclassified Map (Fig 10), derived from the original KD Anomaly Map, simplifies continuous anomaly values into discrete classes, High, Moderate, and Low, representing the

interpreted intensity of potassic alteration. In gold exploration within the Nigerian Schist Belts, potassic alteration (K enrichment) is a key pathfinder for hydrothermal systems responsible for lode gold mineralization [24, 41, 22]. The reclassified map directly delineates zones of anomalous K content, highlighting favorable geological environments for mineralization. Legend and Prospectivity: Red (High) zones indicate areas of strong potassic alteration (e.g., secondary muscovite/sericite or K-feldspar formation) and are considered primary targets for gold. Yellow (Moderate) zones represent intermediate K enrichment and serve as secondary targets, while Green (Low) corresponds to background K content and low prospectivity [24]. Delineated alteration zones: The map highlights major zones of high potassic alteration that follow regional structural fabrics. NNE–SSW corridors are the most prominent, confirming structural control by regional shear and fault systems. A northern cluster of High K anomalies represents localized hydrothermal activity, while Moderate zones often form halos around these High zones, indicating transitional alteration boundaries [41, 22]. Mineralization potential near towns: Towns such as Iwaiji, Ilogbo, Ipole, and Apopolu lie within or adjacent to the NNE–SSW High anomaly corridor, marking them as highest-priority targets for structurally controlled gold deposits. Ojejelu and Itawure align with the northern High K cluster, suggesting secondary exploration targets. Other towns, including Oke-Agbimo, Effon-Alaaye, and Orita-Ileda, fall within Moderate or Low zones, representing lower-intensity alteration. Erin-Oke and Erin-Ile have scattered High and Moderate anomalies, indicating intermediate prospectivity [24, 41]. The KD reclassified map effectively highlights the most intense zones of hydrothermal potassic alteration. The correlation of High K anomalies with major structural trends from FVD and lineament density maps identifies areas around Iwaiji, Ilogbo, Ipole, Apopolu, Ojejelu, and Itawure as geochemically favorable targets. These areas should be prioritized for ground truthing, sampling, and drilling to confirm gold and associated mineralization [24, 22].

Potassium anomaly map

The potassium anomaly map (Fig 11) over Effon-Alaaye and surrounding towns shows strong spatial variability in K concentration (0.145–1.620 % K), reflecting lithology, alteration, and structural controls. High-K zones (magenta to red) around Oke Agbimo, Effon-Alaaye, Iwaji, etc., likely represent felsic intrusives or potassic-altered basement rocks (rich in K-feldspar and micas) that are favourable for the exploration of granitoid-hosted and hydrothermal mineralisation [24]. Conversely, low-K areas (blue/green), for example, near Erin Ile and parts of Ipole and Ilogbo, may correspond to mafic lithologies or weathered/altered zones where potassium-bearing minerals have been depleted [22]. Further, the linear or banded high/low K-anomaly structures trending NE–SW or NW–SE coincide well with expected faults, shear zones, or structural lineaments. These structural zone may have acted as conduits for hydrothermal fluids; thus, the high-K anomalies along them could mark potassic alteration halos around mineralised zones [44]. In sum, the map indicates a heterogeneous basement with felsic intrusives, altered zones, and structural controls. Several high-K zones along lineaments represent priority targets for follow-up ground sampling and geochemical or geological investigations.

Potassium anomaly reclassified map

The reclassified potassium (K) map (Fig 12) covering part of Nigeria (showing towns such as Alawaye, Ojejelu, Itawure, Effon Alaye, Oke Agbimo, Iwaji, Ilugbo, Ipole, Apopolu, Erin Oke, Erin Ile, and Orita Ileda) displays three K concentration classes: High (red), Moderate (yellow), and Low (green). Low K zones (green) dominate much of the map, particularly across central and large northern–southern tracts, likely corresponding to basement lithologies such as crystalline gneiss, schist, and granites that reflect background potassium levels or areas where weathering and leaching have depleted surface K [24,41]. Scattered moderate K zones (yellow) occur near towns including Oke Agbimo, Iwaji, Ilugbo, and Ipole/Apopolu, and some southern localities. These areas may represent lithological variations, such as potassium-bearing minerals (feldspars, micas) in granitoids or metasediments, or weakly altered zones. High K anomalies (red), although more limited, appear along the eastern flank (near Alawaye, Itawure, and toward the northeastern corner) and in small western clusters (near Orita Ileda / Erin Ile). Elevated potassium (or high K/Th, K deviation, F parameter from radiometric data) typically highlights potassic/hydrothermal alteration zones in basement terrains, suggesting that these red anomalies may correspond to hydrothermal-alteration halos associated with faults, shear zones, or intrusive contacts, making them primary targets for detailed exploration including geochemical sampling, structural/magnetic mapping, and geological fieldwork [24,41]. However, moderate and high K anomalies alone do not guarantee mineralization, as they may also reflect K rich lithologies (e.g., granitoids, pegmatites) or weathering/regolith concentration

effects. Consequently, integration with other datasets, magnetic surveys, structural lineaments, geochemical analyses, and detailed geological mapping is crucial for accurate targeting of hydrothermal mineralization [22, 45]. Overlaying towns and infrastructure aids planning for accessible exploration, but mineralization could also exist in less populated green or yellow zone.

Thorium anomaly map

The Thorium (Th) Anomaly Map (Fig 13) derived from airborne gamma-ray spectrometric data, shows the spatial distribution of thorium in the study area, which is critical for lithological mapping and mineral exploration. Thorium is generally immobile in hydrothermal fluids, making it a reliable tracer of primary rock types in altered terrains [46]. High Th concentrations often indicate felsic lithologies such as granites or granitic gneisses, which may act as heat and fluid sources but are rarely direct hosts for orogenic gold. Moderate Th values correspond to gneisses and schists, while low Th concentrations are typical of mafic/ultramafic rocks that are structurally weak and favorable hosts for gold mineralization [47]. The map highlights a High Th zone in the northern and eastern sectors (e.g., east of Effon-Alaaye and Iwaiji), interpreted as felsic/granitic units, and a central Low Th corridor trending NNE–SSW through Iwaiji, Ilogbo, and Ipole, representing the primary schist belt host rocks [46]. Sharp gradients between High and Low Th zones indicate major lithological contacts or shear zones, which are key structural controls for hydrothermal fluid flow and gold deposition [47]. Towns such as Iwaiji, Ilogbo, Ipole, and Apopolu lie within the Low Th corridor, confirming their position on favorable host rocks, while proximity to sharp Th gradients suggests nearby structural contacts, enhancing fluid permeability and mineralization potential. Northern towns like Ojejelu, Alawaye, and Itawure are positioned along the transition between high and low Th areas, representing additional prospective zones. Effon-Alaaye and Oke-Agbimo lie along the main NNE–SSW gradient/contact, where structural-lithological interfaces further increase prospectivity due to competence contrasts [46]. The Thorium Anomaly Map effectively distinguishes felsic source rocks from schist belt host rocks, with sharp Th gradients and NNE–SSW trending corridors through Iwaiji, Ilogbo, and Ipole representing the most favorable structural and geochemical terrain for orogenic gold mineralization [46-47].

Thorium reclassified map

The Thorium (Th) reclassified map (Fig 14) derived from the original anomaly map, categorizes Th concentration into High, Moderate, and Low classes, providing a clear lithological framework for mineral exploration in the Nigerian Schist Belt. Thorium is largely immobile in hydrothermal systems, making it a reliable indicator of primary rock types and structural contacts [46-47]. High Th (Red) areas correspond to felsic intrusions or granite/gneiss bodies, often acting as sources of heat and mineralizing fluids, while Low Th (Green) zones typically reflect metasedimentary or mafic schist sequences, which are the favorable host rocks for orogenic gold. The map delineates three main zones: a central/southern Low Th corridor encompassing Iwaiji, Ilogbo, and Ipole, confirming the predominance of schist belt lithologies; eastern and northern High Th blocks near Alawaye, Apipolu, and Ojejelu, interpreted as felsic intrusions; and transitional Moderate Th zones surrounding the High Th areas. Sharp lithological boundaries between Low and High Th zones indicate major contacts and zones of strain, reinforcing structural interpretations from Lineament and FVD maps and highlighting potential fluid pathways [46]. Mineralization potential: Towns situated within the low Th zones adjacent to High Th contacts, such as Iwaiji, Ilogbo, and Ipole, represent the most prospective targets due to the combination of favorable host rock and proximity to heat/fluid sources. Northern towns near High Th intrusions (Alawaye, Ojejelu, Itawure) are secondary targets, reflecting the influence of structural and lithological contacts on mineralization patterns. The reclassified thorium map effectively separates prospective host rocks from potential source bodies, emphasizing the NNE–SSW trending corridor through Iwaiji and Ipole as a prime structural and lithological target for orogenic gold exploration [47, 46].
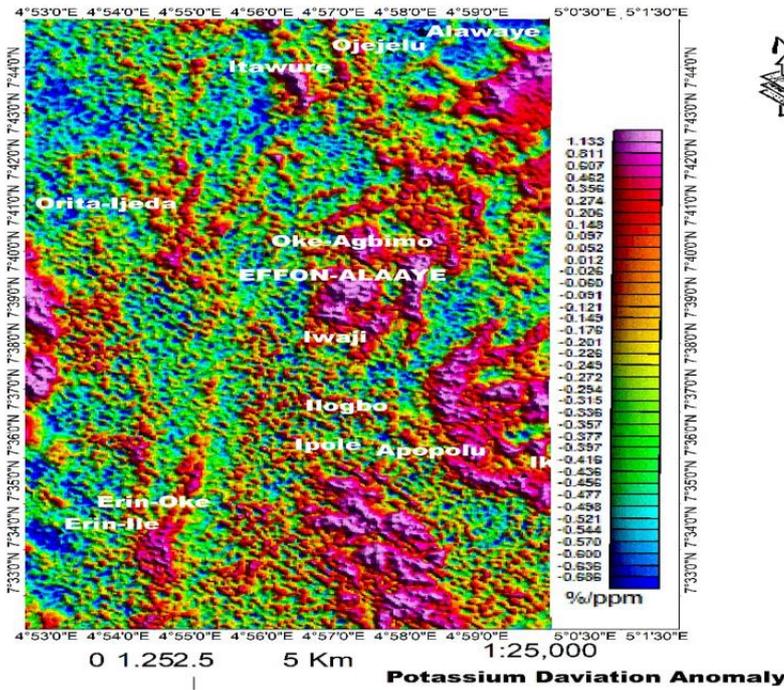
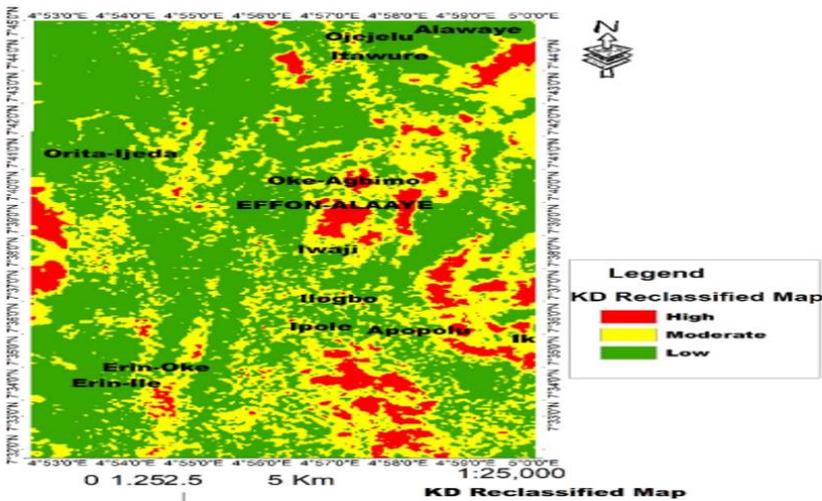Fig. 9 Potassium deviation anomaly map

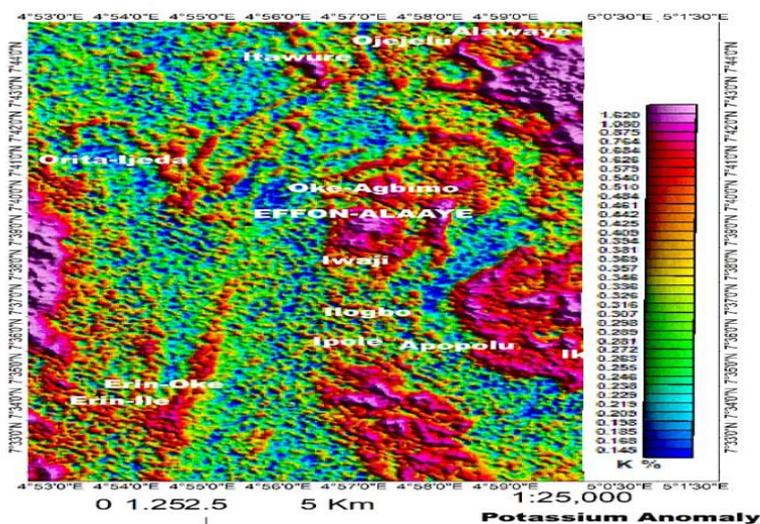

Fig. 10 Potassium deviation reclassified map
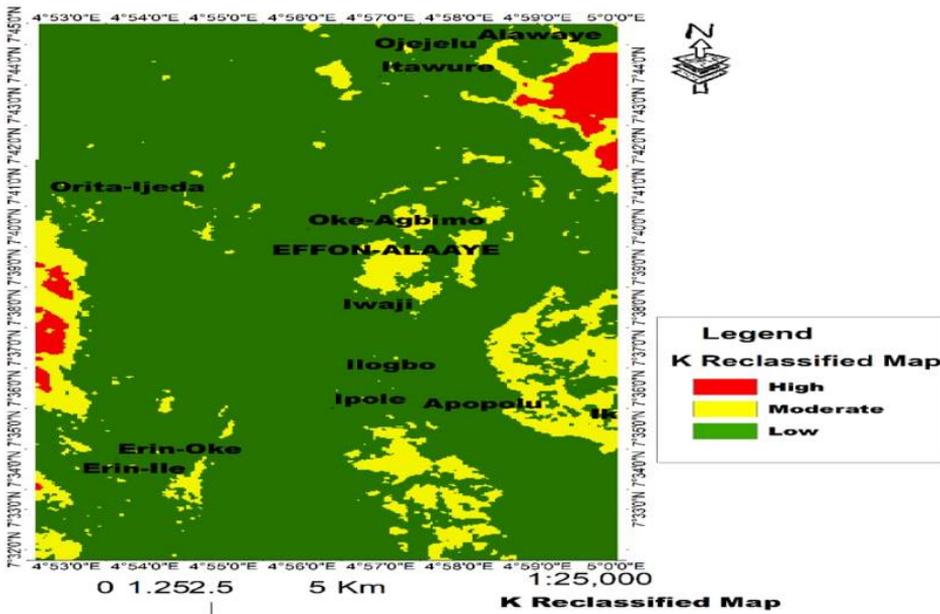

Fig. 11 Potassium anomaly map

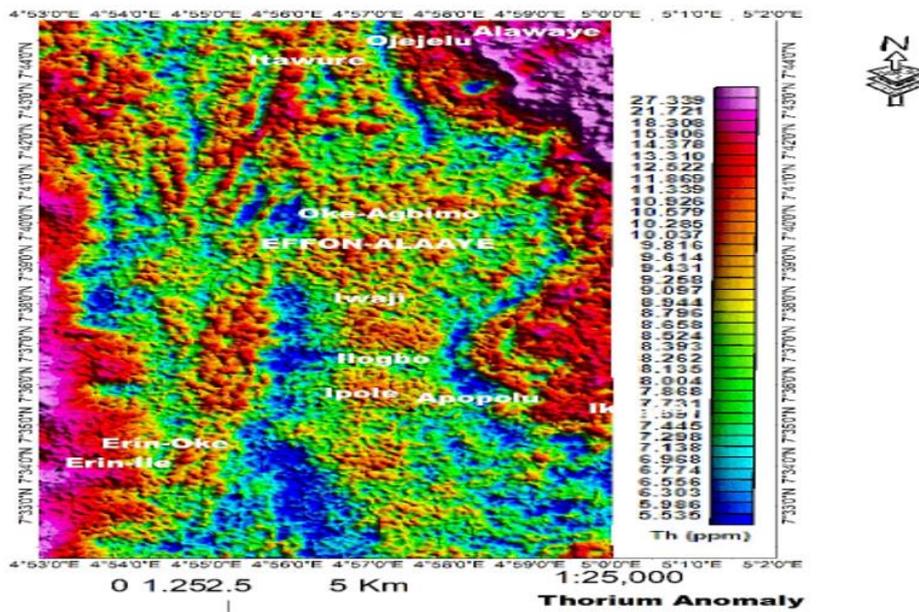Fig. 12 Potassium anomaly reclassified map
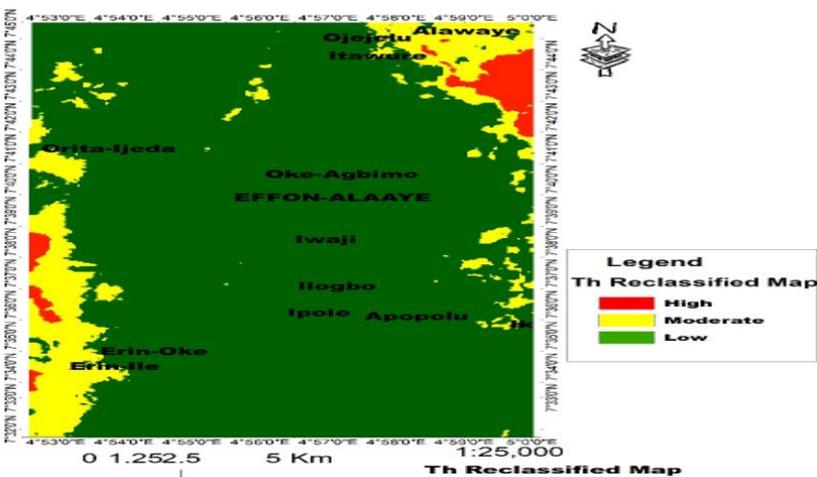

Fig. 13 Thorium anomaly map

Fig. 14 Thorium reclassified map

Uranium anomaly map

The uranium concentration map (Fig 15) reveals clear spatial variations in U (ppm), highlighting zones of anomalous enrichment that may indicate potential mineralization. The highest uranium anomalies, ranging from about 3.26–5.36 ppm, occur in the northeastern to north-central parts of the area, particularly around Ojejelu and Alawaye. These pink–magenta–purple zones represent the most significant radiometric highs, commonly associated with uranium-enriched lithologies, felsic intrusive bodies, or structurally controlled accumulations where uranium has been mobilized and redeposited [48]. Such high-intensity anomalies are consistent with zones of strong thorium–uranium enrichment typical of basement terrains affected by hydrothermal alteration or weathering fronts 23. Surrounding these peak anomalies are moderate-to-high concentrations (1.60–3.26 ppm), mapped in red, orange, and bright yellow shades, extending southwards toward Itawure. These zones may represent the geochemical halo around the main mineralized structures or smaller, independent pockets of enrichment. Previous studies show that such intermediate radiometric zones often define transition belts between highly mineralized cores and background terrains, reflecting partial enrichment or mixed lithologies [49]. The central and southern regions, covering settlements such as Erin-Oke, Erin-Ile, Oka-Agbimo, Effon-Alaaye, Iwaji, Ilogbo, Ipole Apopolu, and Ikoro, display low background uranium levels (0.10–0.93 ppm) represented by green to deep-blue colors. These values likely correspond to unmineralized basement units or stable crystalline rocks with minimal uranium-bearing minerals [48]. Their broad distribution suggests they form the regional baseline against which anomalies are defined. From a mineral exploration perspective, the areas north and northeast of Ojejelu–Alawaye and the zone northeast of Itawure represent the most promising targets for follow-up field investigations. Radiometric anomalies of this magnitude are frequently linked to structural traps, alteration zones, or felsic intrusives known to concentrate uranium in basement complexes [23, 48]. Consequently, these zones warrant priority for detailed mapping, geochemical sampling, and possible subsurface drilling.

Uranium Reclassified Map

The Uranium Reclassified Map (Fig 16) simplifies continuous radiometric data into three exploration-ready classes, High (Red), Moderate (Yellow), and Low (Green), allowing rapid identification of target zones for uranium mineralization. This classification approach aligns with recent advancements in radiometric uranium mapping, where reclassification enhances anomaly detection and supports exploration targeting [50] The High (Red) class marks statistically significant uranium enrichment and often correlates with structurally controlled or lithologically favorable bedrock units, similar to high-intensity anomalies mapped within uranium provinces in Namibia [51]. The Moderate (Yellow) zones represent elevated yet peripheral enrichment, forming geochemical halos that commonly outline the broader mineralizing system [50]. The Low (Green) class reflects background concentrations and defines areas with minimal exploration interest. Spatially, the map shows a clear relationship between uranium prospectivity and settlement locations. Alawaye, positioned directly within the High (Red) anomaly, represents the most compelling exploration target, as such concentrated radiometric peaks are typically associated with the core of mineralized systems. Ojejelu, Itawure, and Orita-Ileda, located within the Moderate (Yellow) zones, indicate secondary targets that may contain extension zones or satellite mineralization related to the main anomaly. Towns such as Oke-Agbimo, Effon-Alaaye, Iwaji, Ilogbo, Ipole, Apopolu, Ikoro, Erin-Oke, and Erin-Ile fall within the Low (Green) background zone, suggesting low likelihood of economic uranium occurrences. Exploration implications are significant: the primary red anomaly near Alawaye warrants the highest priority for detailed geological mapping, ground radiometric surveys, geochemical sampling, and possibly machine-learning-based ranking, an approach increasingly used in modern uranium prospectivity studies [52]. The moderate yellow halos outline the potential footprint of the mineralizing system and may contain complementary structural or lithological controls worth testing. The reclassified map effectively filters out unproductive terrain and focuses exploration toward the most promising uranium targets in the area.

Rose diagram

The rose diagram (Fig 17) illustrates the orientation and frequency of lineaments extracted from the study area, providing a clear representation of the structural architecture controlling deformation and potential mineralization pathways. Lineaments, encompassing fractures, faults, joints, and shear zones, are fundamental indicators of subsurface structural patterns and play a critical role in guiding hydrothermal fluid migration, thereby influencing ore deposition [53]. The dominant structural trend observed on the diagram is NE–SW,

corresponding to angular ranges of approximately 45°–75° and 225°–255°. This orientation aligns with the established Pan-African structural framework, which governs much of the basement deformation in southwestern Nigeria. Comparable studies have shown that major shear zones within this trend, such as the Ifewara–Zungeru system, commonly serve as first-order conduits for hydrothermal fluids and host significant mineralization along their lengths [53]. A secondary but notable concentration occurs along the WNW–ESE direction (around 90°–110° and 270°–290°). These cross-cutting structures are structurally important because they intersect the primary NE–SW fabric, forming dilation zones that enhance permeability and create favorable loci for ore accumulation. With a total of 805 lineaments measuring 846.46 km in cumulative length, the study area is intensely fractured, indicating a high structural complexity that increases the likelihood of fluid-rock interaction. The vector means at 257.14° and 77.1° further confirm a strong NE–SW to ENE–WSW directional dominance, reinforcing the interpretation that these trends serve as principal structural pathways for mineralizing hydrothermal systems. In mineral exploration, integrating this structural information with geophysical datasets such as TMI, KD, and FVD enhances the precision of target delineation. Zones where NE–SW structures intersect WNW–ESE fractures and coincide with magnetic anomalies or potassium alteration signatures represent the most promising exploration targets within the Ilesha Schist Belt [53]. Thus, the rose diagram not only reveals the structural grain of the region but also provides a robust framework for understanding mineralization controls and guiding field-based exploration.

Ternary Map

The ternary radiometric (RGB) map (Fig 18) integrates Potassium (K), Thorium (Th), and Uranium (U) concentrations into a single color-composite image to delineate lithological variations and identify alteration zones relevant to mineral exploration. This method has become central in modern geological mapping because K, Th, and U respond predictably to lithology and hydrothermal processes, allowing rapid discrimination of felsic rocks, intrusive bodies, and potential mineralization zones [50]. In the RGB scheme, Red = K, Green = Th, and Blue = U, while mixed colors (yellow, magenta, cyan, white) signify combined enrichment patterns. These radiometric signatures are increasingly used alongside machine-learning-assisted prospectivity mapping to refine exploration targeting [52]. The map reveals several key geochemical domains. The magenta/pink zones, dominated by high K–U enrichment, form the strongest uranium-bearing targets and are typically associated with potassic hydrothermal alteration where both elements have been mobilized and concentrated by mineralizing fluids. This signature, comparable to K-U alteration halos observed in active uranium districts such as those in Namibia [51] occurs prominently across the northern part of the map, particularly around Alawaye and Ojejelu, marking them as the highest-priority zones for follow-up mapping, sampling, and ground radiometrics. Surrounding these are bright white and yellow areas, especially north of Itawure, representing high total radioactivity (white: K–Th–U enriched) or K–Th-rich felsic bodies (yellow). These likely correspond to granitic or gneissic intrusions which commonly host, or structurally focus, uranium mineralization. In contrast, the central and southern sectors, including Effon-Alaaye, Ilogbo, Ipole Apopolu, and Erin-Ile, exhibit dark to deep blue-green signatures, reflecting low concentrations of all three radioelements. These areas are characteristic of mafic, metasedimentary, or younger sedimentary rocks that are naturally depleted in K–Th–U and therefore have low mineralization potential. The ternary radiometric map aligns strongly with the uranium reclassified map, confirming that the northern magenta anomaly is the most prospective target. Its combined K–U enrichment, proximity to large felsic intrusions, and radiometric intensity make it highly favorable for hydrothermal uranium mineralization.
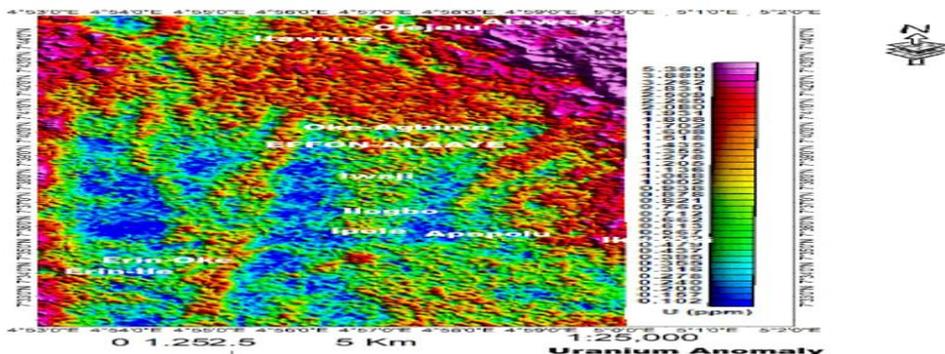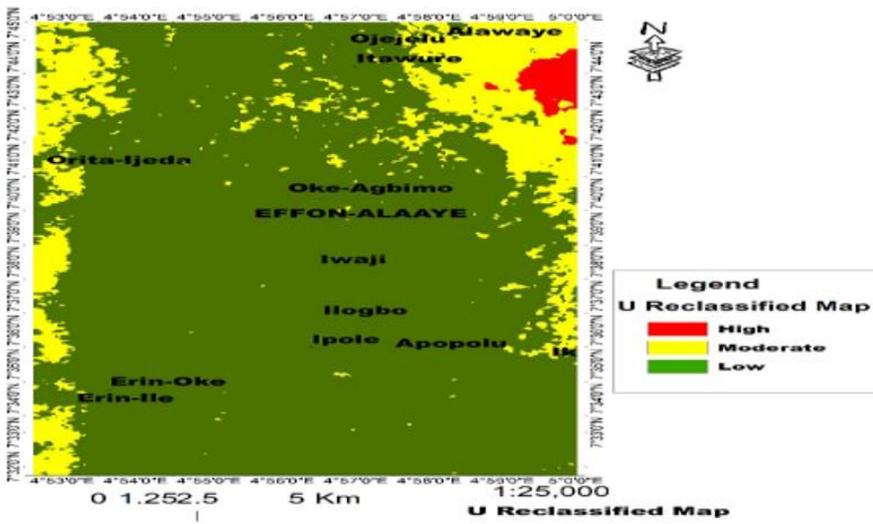

Fig. 15 Uranium anomaly map
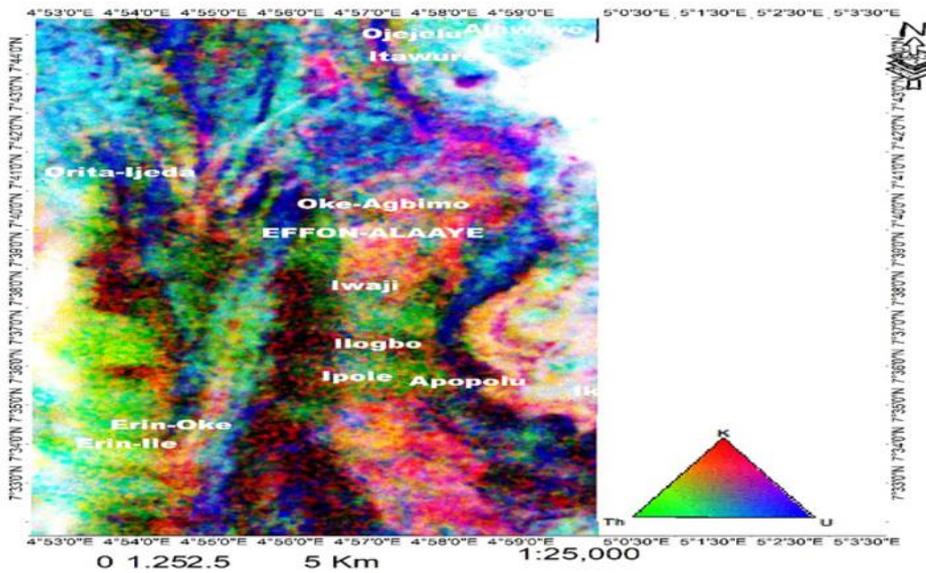
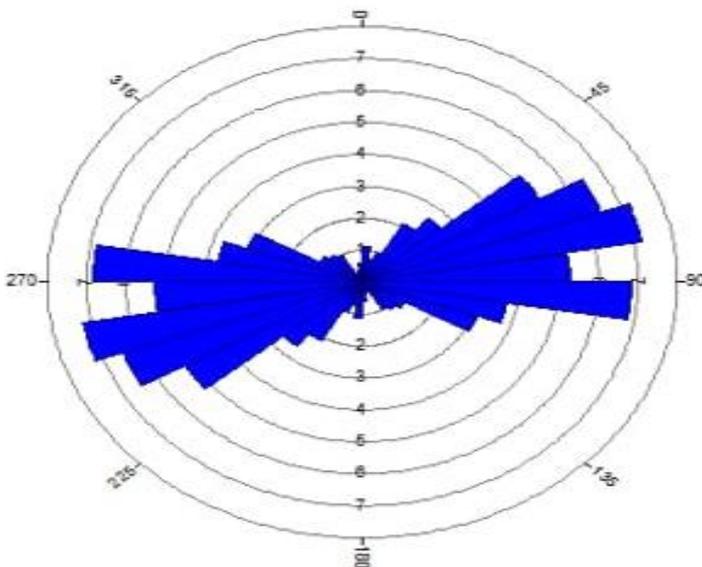Fig. 16 Uranium reclassified map

Fig. 17 Rose diagram

Fig. 18 Ternary diagram

Geological map of the research site

The geological map (Fig 19) presents the distribution of lithological units and structural fabrics that define the basement complex of the survey area, forming the basis for interpreting radiometric and geochemical anomalies. Geological mapping is a fundamental step in mineral exploration because it establishes the rock framework and identifies structural elements, such as contacts, folds, and lineaments that often control mineralization. Studies integrating geological mapping with remote sensing and aeromagnetic data in basement terrains [23] demonstrate how geological constraints significantly improve exploration accuracy. In southwestern Nigeria, radiometric datasets have been effectively used to delineate rock types, refine geological contacts, and validate mapped lithological boundaries, underscoring the central role of geological maps in defining lithological variability and guiding exploration strategies [54-55]. Map identifies three major basement lithologies typical of the Nigerian Basement Complex: Quartzite (QZ), Migmatite–Gneiss Complex (MGN), and Quartz-Mica Schist (QMS). Quartzite appears as narrow NE–SW trending ridges, representing competent, silica-rich metamorphosed sandstone that often influences structural fluid flow and mineral deposition, patterns consistent with quartzite ridges mapped across the southwestern basement terrain [21]. The Migmatite–Gneiss Complex dominates the area and aligns with widespread Pan-African basement units across Nigeria, where migmatites and granitic gneisses commonly host radiometric enrichments and related mineralization due to partial melting and deformation [42, 54]. The Quartz-Mica Schist belts occupy the central and western zones; although generally associated with lower uranium radiometric signatures, schist belts in Nigeria frequently host structurally controlled mineralization such as gold [23]. Structural interpretation shows a dominant NE–SW tectonic trend across all units. Such regional structural orientations are widely reported as key controls on mineralized corridors in Nigerian and West African basement provinces [42]. When this structural framework is integrated with radiometric anomalies, the highest uranium signatures correspond to contacts between the Migmatite–Gneiss Complex and adjacent Quartzite units, particularly around Alawaye. This litho-structural coincidence indicates that uranium mineralization is localized by favourable host rocks as well as by structural conduits such as shear zones and lithological boundaries. In contrast, areas dominated by Quartz-Mica Schist (e.g., Effon-Alaaye, Ilogbo) display low uranium concentrations but may be prospective for other mineral systems common within schist belts. Thus, the geological map not only explains the pattern of uranium anomaly distribution but also provides a structural and lithological framework to guide further exploration, field mapping, and geochemical sampling.

Potassium deviation superimposed on the geological map

The KD Potassium Deviation Superimposed on Geological Map (Fig 20) integrates airborne gamma-ray spectrometry data for Potassium Deviation (KD) with lithological units and settlements, providing a critical tool for identifying hydrothermal alteration zones indicative of mineralization. KD anomalies (pink/purple patches) reflect significant deviations from normal potassium concentrations, often associated with metasomatic alteration processes that introduce or redistribute potassium during hydrothe rmal fluid circulation [23]. Such anomalies are commonly targeted in uranium and other metallic mineral exploration because potassium metasomatism is a key marker of ore-fluid activity. Spatially, the KD anomalies correlate closely with high uranium zones identified on the Uranium Reclassified Map, particularly in the northeast around Alawaye, Ojejelu, and Itawure, suggesting a genetic link between potassium alteration and uranium mineralization. Lithologically, the anomalies are controlled by host rock type and structural contacts: Porphyritic Granite (OGp) hosts intense KD patches, consistent with its naturally high potassium content and potential as a source for radioelement mineralization; Amphibolite Schist (Su) exhibits KD anomalies at granite contacts, highlighting structural pathways for hydrothermal fluids; Migmatite (M) contains widespread KD anomalies, indicative of regional or pervasive alteration influenced by fracturing or proximity to intrusives; and Quartzite (Qs) anomalies near faults and shear zones signal potassium enrichment in typically potassium-poor units, emphasizing structurally controlled metasomatism1, [55]. Several settlements lie directly on or near KD anomalies, warranting attention for both exploration and environmental assessment. High-priority towns include Alawaye, Ojejelu, Itawure, Ilogbo, Ipole, Apopolu, and Ikogosi, all situated on or adjacent to linear or irregular KD patches correlating with uranium-rich zones. These patterns confirm that potassium metasomatism is both lithologically and structurally controlled and highlight areas for targeted ground geophysical and geochemical surveys [23].

Interpretation of the Euler Deconvolution and Lineament–Geological Map

The integration of Euler Deconvolution results, lineament patterns, and the geological framework (Fig 21) provides a strong basis for identifying structural controls on mineralization within the Effon-Alaye–Itawure corridor. The dense clusters of Euler solutions along major NE–SW and NNE–SSW shear zones correspond to deep-seated magnetic sources that typically represent faulted contacts, fractured granitic margins, or magnetite-bearing mineralized veins. These structural corridors align with the dominant African-wide tectonism fabric and are known to host gold-bearing quartz veins and sulfide-rich shear zones within the broader Ilesha Schist Belt [23, 56]. The coincidence of Euler depth solutions with high-frequency lineaments across gneiss–schist contacts, porphyritic granites, and migmatites suggests that these lithological boundaries served as permeable conduits for hydrothermal fluids, enhancing the potential for gold, pegmatite-associated rare-metal, and polymetallic mineralization. Notably, the intersections between NE–SW primary structures and WNW–ESF secondary fractures form dilation zones around Oke-Agbimo, Ipole, Erin-Ile, and the Itawure–Alawaye axis, which are the most favourable structural traps for ore deposition. Such intersections are globally recognized as fertile settings for gold deposition, sulfide enrichment, and quartz-tourmaline vein systems, owing to the pressure shadow zones they create [57]. The prominent Euler clustering along the margins of the porphyritic granite (OGp) near Itawure–Alawaye suggests magnetically responsive mineralized intrusions or contact metasomatism, potentially associated with Au-bearing quartz veins, Fe-oxide mineralization, or pegmatitic rare-metal veins (Sn–Nb–Ta-Be). The structurally intense zones between Effon-Alaye, Iwaji, Ilugbo, and Ipole, where migmatites and banded gneisses dominate, are also marked by closely spaced Euler anomalies. These features reflect shallow to intermediate-depth magnetic sources consistent with shear-hosted gold mineralization, often associated with magnetite, pyrrhotite, and arsenopyrite enrichment in African-wide orogeny basement terrains.
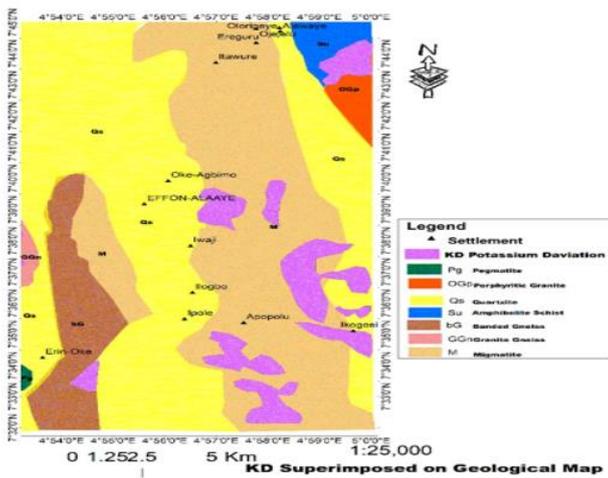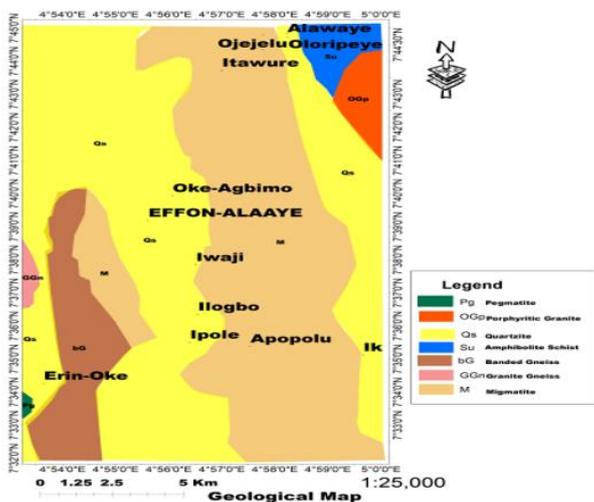

Fig. 19 Geological map of the research site after 2006

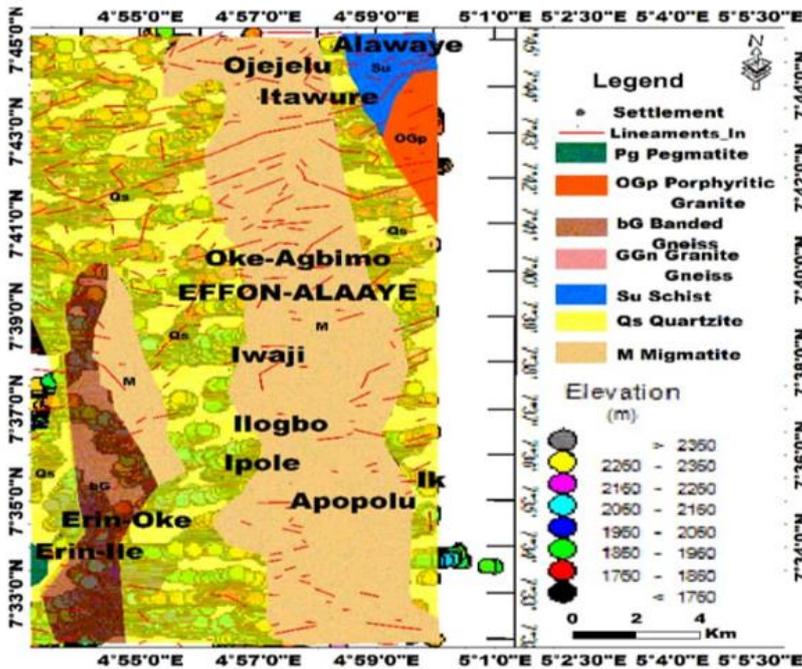Fig. 20 Potassium deviation superimposed on the   geological map

Fig. 21 EUD, lineament superimposed on geoloigical map

CONCLUSION AND RECOMMENDATIONS

This study demonstrates the effectiveness of integrating aeromagnetic and radiometric datasets for delineating hydrothermal alteration zones and evaluating the mineralization potential of Effon-Alaaye and its environs within the southwestern Nigerian Basement Complex. The combined interpretation of Total Magnetic Anomaly (TMA), Reduced-to-Equator (RTE), Analytic Signal (AS), First Vertical Derivative (FVD), residual magnetic maps, Euler deconvolution solutions, lineament analyses, and airborne gamma-ray spectrometric data (K, Th, U, KD, and ternary maps) provides a robust framework for identifying lithological contrasts, structural zone, and alteration footprints linked to mineralizing processes. Aeromagnetic results reveal a structurally complex basement characterized by dominant NNE–SSW to NE–SW trends consistent with Pan-African deformation. These structures manifest as linear magnetic gradients, clustered Euler solutions, and high lineament density corridors, indicating deep-seated shear zones, faults, and lithological contacts that serve as primary conduits for hydrothermal fluid migration. Zones of magnetic lows adjacent to magnetic highs, particularly around Iwaiji, Ipole, Agopoti, and Oke-Agbimo, are interpreted as areas of hydrothermal demagnetization and enhanced structural preparation, favourable for shear-hosted and vein-type mineralization. Radiometric data complement the magnetic interpretation by delineating alteration zones and geochemical footprints. Potassium and potassium deviation (KD) maps highlight extensive potassic alteration corridors aligned with major structures, confirming metasomatic processes related to hydrothermal fluid flow. High KD anomalies show strong spatial coincidence with magnetic lineaments, Euler depth clusters, and lithological boundaries, reinforcing their interpretation as alteration halos rather than purely lithological effects. Thorium maps effectively discriminate felsic intrusions from schist belt host rocks, while low-Th zone along NNE–SSW trends identify favourable host environments for orogenic gold mineralization. Uranium and ternary radiometric maps delineate a distinct uranium-enriched zone in the northeastern sector (Alawaye–Ojejelu–Itawure axis), spatially associated with felsic intrusions, KD anomalies, and structural intersections, suggesting structurally controlled hydrothermal uranium mineralization. Integrated interpretation indicates that the highest mineralization potential occurs where (i) major African-wide orogeny shear zones intersect secondary structures, (ii) magnetic contrasts coincide with radiometric alteration signatures, and (iii) favourable host rocks occur near intrusive contacts. Based on these criteria, Iwaiji, Ipole, Agopoti, Alawaye, Ojejelu, and Itawure are identified as the most prospective targets, with potential for orogenic gold, uranium, and associated polymetallic mineralization. Limitations: Despite the strong outcomes, this study is constrained by the resolution of regional airborne datasets, which limits the detection of very shallow or small-scale mineralized bodies. Radiometric responses may also be influenced by weathering, regolith development, and surface redistribution of radioelements in the tropical environment, potentially masking primary bedrock

signatures. In addition, the absence of ground geophysical validation, detailed geochemical sampling, and drilling data restricts direct confirmation of inferred mineralization.

Recommendations

To advance exploration in the study area, the following steps are recommended:

1. Detailed ground truthing, including structural mapping and trenching, across priority targets identified from integrated geophysical anomalies.

2. Systematic geochemical sampling (soil, stream sediment, and rock chips) along high KD zone, magnetic gradient zones, and structural intersections.

3. High-resolution ground geophysical surveys (magnetic, radiometric, and EM) to refine anomaly geometry and depth.

4. Exploratory drilling in the most prospective zones, particularly around Iwaiji–Ipole and Alawaye–Ojejelu–Itawure zone.

5. Advanced data integration, including machine-learning-based prospectivity modelling, to quantitatively rank targets and reduce exploration risk. This study confirms that integrated aeromagnetic and radiometric analysis provides a powerful, cost-effective approach for delineating hydrothermal alteration systems and mineralization potential in basement terrains. The results significantly improve the understanding of subsurface structural controls and alteration patterns in Effon-Alaaye and contribute valuable insights for future mineral exploration within the southwestern Nigerian Basement Complex.

Statements And Declarations

Funding:

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflicts of Interest:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical Approval:

Not applicable.

Consent to Participate:

Not applicable.

Availability of Data and Materials:

The datasets used during this study are available from the corresponding author upon reasonable request.

Authors' Contributions:

Olususi Joseph Ige designed the study, processed the radiometric and aeromagnetic data, wrote the first draft of the manuscript. Ayodele Olusiji Samuel supervised the research design, and reviewed the manuscript for technical accuracy. Adepoju Mohammed Olatoye managed the acquisition, compilation, and interpretation of the NGSA Aeromagnetic and radiometric datasets. Adebisi Matthew Iwabi conducted the literature searches,

assisted in field observations, and contributed to the geological interpretation. All authors read and approved the final manuscript.

Disclaimer (Artificial Intelligence)

The author (s) hereby declare that generative AI technologies such as Large Language Models have been used during the writing or editing of this manuscript. Details of the AI usage are given below:

1 Name of AI tool: ChatGPT (OpenAI, GPT-5.1)

2. Purpose of use: Only for language refinement, grammar correction, and improving clarity of expression.

3. No AI tool was used to generate data, interpret results, perform analysis, or draw scientific conclusions. All scientific content and interpretations are entirely the authors' own.

REFERENCES

1. Rahaman, M. A. (1988). Recent Advances in the Study of the Basement Complex of Nigeria. In Precambrian Geology of Nigeria (pp. 11–43). Geological Survey of Nigeria. Available via Science & Education Publishing: https://www.sciepub.com/reference/318092
2. **Ajibade, A. C., & Wright, J. B. (1989).** The Togo-Benin-Nigeria Shield: evidence of crustal aggregation in the Pan-African belt. **Tectonophysics, 165**, 125–129. DOI: 10.1016/0040-1951(89)90041-3
3. **Oyawoye, M. O. (1972).** The Basement Complex of Nigeria. In T. F. J. Dessauvagie & A. J. Whiteman (Eds.), **African Geology** (pp. 66–102). University of Ibadan Press, Ibadan. https://www.semanticscholar.org/paper/The-Basement-Complex-of-Nigeria-Oyawoye/35721fd80a1578290bb2350baa7f516395f81c5f
4. Omosanya, K., Ariyo, S. O., Kaigama, U., Mosuro, G. O., & Laniyan, T. A. (2009). An outcrop evidence for polycyclic orogenies in the basement complex of Southwestern Nigeria. Journal of Geography and Geology, 7(3), 24–34. **Link:** https://ccsenet.org/journal/index.php/jgg/article/view/49753
5. Samuel, A. O., & Emmanuel, A. F. (2021). Mineralization Characterization of Psammitic Rocks in Efon-Alaaye and Environs using Remote Sensing and Field Studies. Asian Review of Environmental and Earth Sciences, 8(1), 48–61. https://www.asianonlinejournals.com/index.php/AREES/article/view/3481
6. Akinduko, O. K., Salako, K., Alhassan, D. U., Lawrence, J., Alkali, A., Aliyu, B. & Damidami, L. (2022). Aero-magnetic and Aero-radiometric Prospecting for Potential Gold Mineralisation over Ilesha and its Environs, Southwestern Nigeria. Asian Journal of Geological Research, 5(3), 199–214. https://journalajoger.com/index.php/AJOGER/article/view/124
7. **Arogundade, A. B., Awoyemi, M. O., Ajama, O. D., Falade, S. C., Hammed, O. S., Dasho, O. A., & Adenika, C. A. (2022).** Integrated aeromagnetic and airborne radiometric data for mapping potential areas of mineralisation deposits in parts of Zamfara, North West Nigeria. Pure and Applied Geophysics, 179(1), 351–369. https://doi.org/10.1007/s00024-021-02913-w
8. **Mam, D., Tawey, M. D., Adetona, A. A., & Alhassan, U. D. (2021).** Aeroradiometric Data Assessment of Hydrothermal Alteration Zones in Parts of North-Central Nigeria. Asian Journal of Geological Research, 4(2), 57–72.: https://journalajoger.com/index.php/AJOGER/article/view/63
9. **Akingboye, A. S., Bery, A. A., Ogunyele, A. C., Dick, M. D., Ale, T. O., Titus, E. A., … & Oyeshomo, A. V. (2025).** Magneto-radiometric and geochemical mapping of structurally controlled hydrothermal gold mineralization in the Okpella Neoproterozoic terrain, Igarra Schist Belt, SW Nigeria. Scientific African, 19, e02960. https://doi.org/10.1016/j.sciaf.2025.e02960 https://www.sciencedirect.com/science/article/pii/S2468227625004302
10. **Carranza, E. J. M. (2009).** Geochemical anomaly and mineral prospectivity mapping in GIS. In M. Hale (Ed.), Handbook of Exploration and Environmental Geochemistry (Vol. 11). Elsevier, Amsterdam. **Publisher / Book link (Elsevier / University repository / metadata page):** https://researchonline.jcu.edu.au/40323/1/40323_Carranza_2009_FrontPages.pdf

11. **Elueze, A. A. (1982).** Geochemistry of the Ilesha Granite Gneiss in the Basement Complex of Southwest Nigeria. Precambrian Research, 19(2), 167–177. https://www.mindat.org/reference.php?id=701973

12. **Oyinloye, A. O. (2011).** Geochemistry and geotectonic setting of the Precambrian Basement Complex rocks of SW Nigeria. Earth and Environmental Sciences (IntechOpen). https://doi.org/10.5772/26990

13. **Adeoti, B., & Okonkwo, C. (2016).** Structural geology of the Basement Complex rocks in Iwaraja area, southwestern Nigeria. International Letters of Natural Sciences, 58, 16–28. https://doi.org/10.56431/p-m654ru

14. OlaOlorun, O. A., Akinola, O. O., & Oyinloye, A. O. (2023). Petrology and geochemical features of crystalline rocks in Ora-Ekiti, Southwestern Nigeria. Advances in Geological and Geotechnical Engineering Research, 5(2), 24–37. https://doi.org/10.30564/agger.v5i2.5243 Link: https://journals.bilpubgroup.com/index.php/agger/article/view/5243

15. Adeyemi, T., & Oladipo, O. (2024). Lithologic relationship and structural features of crystalline rocks in Ekiti area. Advances in Earth and Environmental Science, Uniscience Publishers. PDF: https://unisciencepub.com/wp-content/uploads/2024/04/Lithologic-Relationship-and-Structural-Features-of-Crystalline-Rocks.pdf

16. Bamigboye, O. S., Bamidele, T. E., Adedoyin, A. D., Issa, T. A., & Omorinoye, O. A. (2022). Shear Sense Analyses of Basement Complex Rocks in Parts of Southwestern Nigeria. **International Journal of Earth Sciences Knowledge and Applications**, 4(2), 157–166. Available at: https://www.ijeska.com/index.php/ijeska/article/view/151

17. **Nigerian Geological Survey Agency – NGSA (2006).** Geophysical Mapping of Nigeria: Airborne Radiometric and Magnetic Survey Data. https://ngsa.gov.ng

18. **Olurin, O. T., Ganiyu, S. A., Hammed, O. S., & Aluko, T. J. (2016).** Interpretation of aeromagnetic data over Abeokuta and its environs, Southwest Nigeria, using spectral analysis (Fourier transform technique). Materials and Geoenvironment, **63**(4), 199–212. https://doi.org/10.1515/rmzmag-2016-0018

19. **Talabi, A. O., Oyinloye, A. O., Olaolorun, O. A., Obasi, R. A., Eluwole, A. B., Adebayo, O. F., & Ademilua, O. L.** (2018). Petrography and Geochemistry of Orin-Ekiti Basement Rocks, Southwestern Nigeria: Implications on Bauxitization. **American Journal of Applied Sciences**, 15(4), 230–239. **DOI / Full Article Link:** https://doi.org/10.3844/ajassp.2018.230.239 **Full Text / Publisher Page:** https://thescipub.com/abstract/ajassp.2018.230.239

20. **Ogunyele, A., Adegbuyi, O., Odindu, M., & Erinfolami, T.** (2017). Geochemical Characteristics and Petrogenesis of Basement Rocks in Idoani Area, Ondo State, Southwestern Nigeria. **International Journal of Advanced Geosciences**, 5(2), 102–108. **DOI:** 10.14419/ijag.v5i2.8377

21. Adekoya, J.A., Olarewaju, V.O., & Okunlola, O.A. (2020). Evolution of Basement Complex terrains in Southwestern Nigeria. https://www.researchgate.net/publication/344392320

22. **Ohwo, M. U., & Soalpe, F. S.** (2024). Integration of ASTER and Airborne Radiometric Data in the Exploration for Hydrothermal Alteration Zones Associated with Mineral Deposits in Igarra Schist Belt, Nigeria. **International Journal of Earth Sciences Knowledge and Applications**, 6(2), 220–228. **DOI / Full Article Link:** https://dergipark.org.tr/en/pub/ijeska/issue/87240/1553919 **Publisher / Journal Page:** https://ijeska.com/index.php/ijeska/article/view/419

23. **Salawu, N. B., Omosanya, K. O., Eluwole, A. B., Ajadi, J., & Adebiyi, L. S. (2023).** Structurally-controlled gold mineralization in the Southern Zuru Schist Belt NW Nigeria: Application of remote sensing and geophysical methods. **Journal of Applied Geophysics**, 211, 104969. **DOI:** 10.1016/j.jappgeo.2023.104969 https://doi.org/10.1016/j.jappgeo.2023.104969

24. Akinlalu, A. A. (2023). Radiometric mapping for the identification of hydrothermally altered zones related to gold mineralization in the Ife–Ilesa Schist Belt, Southwestern Nigeria. Indonesian Journal of Earth Sciences, 3(1). DOI: 10.52562/injoes.2023.519 → Available at: https://journal.moripublishing.com/index.php/injoes/article/view/519

25. Ogunkoya, C. O., & Alasi, T. K. (2025). Integrating Aeromagnetic Data for Subsurface Characterization in the Ilesha Schist Belt. Geological Behavior. https://geologicalbehavior.com/gbr-02-2025-62-68/

26. Okpoli, C., Michael, O., & Herrero-Bervera, E. (2024). Baseline magnetic susceptibility measurements of rocks in the Precambrian basement terrain of southwestern Nigeria. International Journal of Advanced

Geosciences, 12(2), 106–114. https://www.sciencepubco.com/index.php/IJAG/article/view/32896?utm_source=chatgpt.com

27. Akingboye, A. & Ogunyele, A. (2017). Basement Classification through Enhanced Magnetic Data Reductions in parts of Ekiti State, Southwestern Nigeria. This is published in International Journal of Advanced Geosciences, 6(1), 1–13. f https://sciencepubco.com/index.php/IJAG/article/view/8573 DOI link: https://doi.org/10.14419/ijag.v6i1.8573

28. Nwugha, V. N., Ikoro, D. O., Okeke-Oguegbe, C. N., & Ezebunanwa, A. C. (2019). Magnetic Susceptibility Mapping of Rocks and Depth Estimation of Anomalies: A Case Study of Igarra and Its Environs. Journal of Geography, Environment and Earth Science International, 22(2), 1–11. https://journaljgeesi.com/index.php/JGEESI/article/view/401?utm_source=chatgpt.com

29. Obasi, R. A., & Oluwatoyin, O. A. (2020). The Migmatite and Gneisses in the Basement Complex of Southwestern Nigeria: a re-appraisal of their structural, mineralogical, and geochemical diversity. IJRDO-Journal of Applied Science, 6(8), 1–17. https://www.ijrdo.org/index.php/as/article/view/3817?utm_source=chatgpt.com

30. Ojo, A., Adeloye, M., Egbedele, I., & Akinwande, F. (2020). Magnetic rocks distribution and depth to basement analysis on an old Quarry Site, Abeokuta, SW Nigeria. Iranian Journal of Earth Sciences, 12(3), 176–183. https://oiccpress.com/ijes/article/view/5669?utm_source=chatgpt.com

31. AAPG Wiki (2024). Magnetics: Total Intensity and Residual Magnetic Maps. Available at: https://wiki.aapg.org/Magnetics:_total_intensity_and_residual_magnetic_maps

32. Akingboye, A. S., Bery, A. A., Ogunyele, A. C., Gnapragasan, J., Adewumi, T., Oyeshomo, A. V., Akakuru, O. C., & Balogun, O. (2025). Magneto-radiometric and geochemical mapping of structurally controlled hydrothermal gold mineralization in the Okpella Neoproterozoic terrain, Igarra Schist Belt, SW Nigeria. Scientific African. Available at: https://www.sciencedirect.com/science/article/pii/S2468227625004302

33. Wemegah, D. D., Preko, K., Noye, R., Boadi, B., Menyeh, A., Danuor, S., & Amenyoh, T. (2015). Geophysical Interpretation of Possible Gold Mineralization Zones in Kyerano, South-Western Ghana Using Aeromagnetic and Radiometric Datasets. Journal of Geoscience and Environment Protection, 3, 67–82. doi:10.4236/gep.. 2015.34008. Available at:https://www.scirp.org/journal/paperinformation?paperid=57659

34. Joshua, E. O., Layade, G. O., & Adewuyi, S. O. (2018). Analytic Signal Method (Hilbert Solution) for the Investigation of Iron-Ore Deposit Using Aeromagnetic Data of Akunnu-Akoko Area, Southwest, Nigeria. Physical Science International Journal, 17(2), 1–9. https://doi.org/10.9734/PSIJ/2018/39004

35. Ayuba, B. J., Mallam, A., & Osagie, A. (2024). Structural Characterization of High Resolution Aeromagnetic Data for Potentially Mineralized Zones Identification Within the North-Central Basement Complex of Nigeria. International Journal of Latest Technology in Engineering Management & Applied Science, 13(7), 13–23. https://doi.org/10.51583/IJLTEMAS.2024.130703

36. Osita, L. J., Mallam, A., Abdulsalam, N. N., & Nzeghi, G. J. (2025). Integrated Gravity and Magnetic Derivative Modelling for Structural Control of Gold Mineralization in North-Central Nigeria. Asian Journal of Geological Research, 8(3), 376–391. https://journalajoger.com/index.php/AJOGER/article/view/205

37. Ema Abraham, Ayatu, U. K., Chima George-Best, & Iheanyi Ikeazota. (2024). Magnetic inversion modeling of subsurface geologic structures for mineral deposits mapping in southeastern Nigeria. Bulletin of MRE. https://dergipark.org.tr/en/pub/bulletinofmre/issue/84117/1267876

38. **Babagana, M., Adamu, A., Idris, E.-Y. A., Fatima, S. M., Muhammad, W. M., Muhammad, I. M., Abba, T. U., & Ahmed, H. (2023).** Reassessment of Geophysical Investigation of Zinc (Zn), Copper (Cu) and Lead (Pb) Potential Mineralization Deposits Using Aeromagnetic Data in Wase Middle Benue Trough, Nigeria. **International Journal for Research in Applied Science & Engineering Technology (IJRASET), 11(IV)**. https://www.ijraset.com/research-paper/reassessment-of-geophysical-investigation-of-zinc-cupper-and-lead

39. Ndatuwong, L. G. (2023). Assessment of radioelement hosting structure and hydrothermal alteration zones using aero-radiometric data in basement rock of north-central Nigeria. Global International Interdisciplinary Research Journal (GIIRJ). Available at: https://media.neliti.com/media/publications/598646-assessment-of-radioelement-hosting-struc-3207e3b6.pdf

40. **Abraham, E. M., Uwaezuoke, A. E. & Usman, A. O. (2024).** Geophysical investigation of subsurface mineral potentials in North-Central Nigeria: implications for sustainable mining and development. Geomechanics and Geophysics for Geo-Energy and Geo-Resources, 10, 192. https://doi.org/10.1007/s40948-024-00913-3

41. Olomo, K. O., Bayode, S., Alagbe, O. A., Olayanju, G. M., & Olaleye, O. K. (2022). Aeromagnetic Mapping and Radioelement Influence on Mineralogical Composition of Mesothermal Gold Deposit in Part of Ilesha Schist Belt, Southwestern Nigeria. NRIAG Journal of Astronomy and Geophysics, 11(1), 177–192. https://journals.ekb.eg/article_452843.html

42. **Abubakar, F., Alao, J. O., Ogah, A. J., Uche, S., & Others (2024).** Evaluation of gold mineralisation potential using AHP systems and weighted overlay analysis. Scientific Reports, 14, 21263. https://doi.org/10.1038/s41598-024-70957-8

43. **Adewale, A., Obideyi, O. I., Afolabi, D. O., Adiat, K. A., & Adeola, O. J. (2024).** Gold prospectivity mapping using the SWARA model on geophysical datasets in parts of the Ilesa Schist Belt, Southwestern Nigeria. Results in Earth Sciences, 2, 100039. https://doi.org/10.1016/j.rines.2024.100039

44. Abdelrady, M., Mohammed, M. A. M., Alarifi, S. S., Mohamed, A., & Othman, A. (2023). Geophysical investigations for the identification of subsurface features influencing mineralization zones. Journal of King Saud University – Science, 35, 102809. → PDF available at: https://jksus.org/content/185/2023/35/7/pdf/10.1016_j.jksus.2023.102809.pdf

45. Mamudu, A., Akanbi, E.-M. S., & Odewumi, S. C. (2025). Hydrothermal alteration and mineral potential zones of Bauchi area Northeastern Nigeria using interpretation of aeroradiometric data. Journal of the Nigerian Society of Physical Sciences, 7(1), 2193. https://journal.nsps.org.ng/index.php/jnsps/article/view/2193

46. Taiwo, A., & Damidami, L. (2025). Aero-magnetic and Aero-radiometric Prospecting for Potential Gold Mineralisation over Ilesha and its Environs, Southwest, Nigeria. **Asian Journal of Geological Research**. https://journalajoger.com/index.php/AJOGER/article/view/124

47. **Onyejiuwaka, I.S., & Nwokeabia, C.N. (2020).** Application of airborne radiometric method in geologic mapping of Malufashi area and Environs, Northwestern Nigeria. International Journal of Advanced Geosciences, **8**(2), 179–185 **DOI / Publisher page / Full text link:** https://doi.org/10.14419/ijag.v8i2.31071 https://sciencepubco.com/index.php/IJAG/article/view/31071

48. **IAEA. (2010).** Radioelement Mapping. IAEA Nuclear Energy Series No. NF-T-1.3. IAEA, Vienna. Full link / PDF: https://www-pub.iaea.org/MTCD/publications/PDF/Pub1463_web.pdf

49. **Arbuzov, S. I., Spears, D. A., Ilenok, S. S., & Chekryzhov, I. Yu.** (2021). Modes of occurrence of germanium and tungsten in the Spetsugli germanium ore field, Pavlovka brown coal deposit, Russian Far East. **Ore Geology Reviews, 132**, **103986**. https://doi.org/10.1016/j.oregeorev.2021.103986

50. **Assran, A.S.M., El-Sayed, M.M., El-Zehery, A.S., & Youssef, M.M. (2025).** Delineating the uranium anomalous zones using remote sensing and radiometric data: a case study from Gabal Umm Tinassib area, North Eastern Desert, Egypt. Journal of Umm Al-Qura University for Applied Sciences. https://doi.org/10.1007/s43994-024-00158-6 https://link.springer.com/article/10.1007/s43994-024-00158-6

51. **ReeXploration Inc. (2025).** ReeXploration Identifies Large-Scale Uranium Target at Eureka Project, Namibia. Company news release. https://rareearthexploration.com/reexploration-identifies-large-scale-uranium-target-at-eureka-project-namibia/

52. **Kong, W., Chen, J., & Zhu, P. (2024).** Machine Learning-Based Uranium Prospectivity Mapping and Model Explainability Research. Minerals, 14(2), 128. https://doi.org/10.3390/min14020128 https://www.mdpi.com/2075-163X/14/2/128

53. Salawu NB, Fatoba JO, Adebiyi LS, Orosun MM, Dada SS (2021) New insights on the Ife-Ilesa schist belt using integrated satellite, aeromagnetic and radiometric data. Sci Rep 11:15314.**DOI:** 10.1038/s41598-021-94813-1

54. **Ademila, O., Akingboye, A. S., & Ojamomi, A. I. (2018).** Radiometric survey in geological mapping of parts of the Basement Complex area of Nigeria. Vietnam Journal of Earth Sciences, 40(3). https://doi.org/10.15625/0866-7187/40/3/12619

55. **Olatunji, S., et al. (2021).** Integration of remote sensing and geophysical methods for structural and lithological mapping in Precambrian basement rocks, Northern Nigeria. Journal of Fundamental and Applied Sciences, 14(1), 161–180. https://doi.org/10.4314/jfas.v14i1.9

56. **Jooshaki, M., Nad, A., & Michaux, S.** (2021). A systematic review on the application of machine learning in exploiting mineralogical data in mining and mineral industry. **Minerals, 11(8), 816.** https://doi.org/10.3390/min11080816

57. **Crawford, A. F., Thébaud, N., et al.** (2024). Structural and rheological controls on hydrothermal fluid flux within orogenic gold systems — insights from the Oberon deposit (Granites-Tanami Orogen). **Economic Geology, 119(8), 1809–1832.** https://doi.org/10.5382/econgeo.5116