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Geochemical and Mineralogical Processes Controlling Gold Mineralization in the Ilesha-Ifewara Belt of Southwestern

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ABSTRACT
This study presents a novel integration of tectonic discrimination diagrams and mineralogical characterization to investigate the geochemical and mineralogical controls on gold mineralization in soils derived from the Precambrian Pan-African Basement Complex of the Ilesha–Ifewara Belt, southwestern Nigeria. Fieldwork involved systematic sampling of B- horizon lateritic profiles samples across Araromi (Ile-Ife), Ilesha, Iwara and Ifewara, areas historically recognized for auriferous quartz veins and structurally controlled mineralization. Major and trace element concentrations were determined using X-ray Fluorescence and Atomic Absorption Spectroscopy, while mineral phases were characterized by X-ray Diffraction and Scanning Electron Microscopy. Geochemical variation diagrams, including K_2O/Na_2O vs SiO_2 and Ba-Rb- Nb plots, reveal a consistent Oceanic Island Arc signature, indicating that the regolith inherits its chemistry from arc-related igneous protoliths emplaced during the Pan-African orogeny. The soils are silica (50 – 56 wt%) - and alumina (26-30 wt%) -rich, with marked depletion of CaO (>2 wt%), Na_2O (>0.5wt%) and K_2O (>1.0 wt%) and strong enrichment of immobile oxides (Al_2O_3 (< 25 wt%), TiO_2 (<1.0 wt%)), reflecting prolonged tropical lateritization. Gold occurs in association with cobalt, zinc, and nickel, while ternary diagrams highlight cobalt as a robust pathfinder, correlating with the highest gold values. The results demonstrate that integrating geochemical variation diagrams with mineralogical data effectively identifies the tectonic setting, alteration processes, and pathfinder elements of gold deposits. The findings provide a scientific framework for exploration in the Ife-Ilesha Schist Belt and similar West African terrains, underscoring the importance of lateritic geochemistry for targeting concealed orogenic gold mineralization.

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INTRODUCTION

Gold mineralization is a major subject in economic geology due to its strategic role in global finance, industry, and investment. Gold mineralization in Nigeria is primarily concentrated in the western part of the country and is closely associated with supracrustal belts. This mineralization occurs in alluvial and eluvial placer deposits as well as in primary veins distributed throughout various segments of the schist belts in the northwest and southwest regions. Studies have identified four principal goldfields within Nigeria's western basement rock province (Akande et al., 1988; Garba, 2000; Talaat and Mohammed, 2010).

Recent research on the structural controls of gold mineralization (Salau et al., 2016) and related hydrothermal alteration patterns (Oyinloye, 2011; Gajere et al., 2018) has demonstrated that gold accumulation is strongly controlled by favorable geological structures and particular alteration features. Structural data suggest that gold deposition took place during the late Pan-African orogeny, with subsidiary fault zones adjacent to major transcurrent faults playing a significant role in localizing the mineralization (Garba, 2000). Gold exploration research in this area also includes the analyses of trace elements and grain size distributions to locate secondary (alluvial/placer) deposits and primary bedrock sources from soil and sediment (Omang et.al., 2026; Usman et al., 2020). However, modern studies on gold mineralization have moved beyond basic ore detection and now involve sophisticated geochemical tools such as variation diagrams. These diagrams such as Zr/Y vs Zr, Zr/Nb/Y, and Ba-Rb-Nb plots allow researchers to infer the tectonic setting, alteration types, and magma evolution associated with gold-bearing formations. International studies on laterite-hosted and orogenic gold systems have demonstrated that integrating geochemical signatures, mineralogical characterization, and tectonic frameworks provides a robust basis for understanding gold mineralization and improving mineral exploration (Groves et al., 1998; Goldfarb & Groves, 2015; Sunkari et al., 2018; Meyer, 2023; Dufréchou et al., 2024). The integration of mineralogical characterization and geochemical variation analysis is essential in unraveling the origin, concentration, and recoverability of gold deposits, especially in terrains influenced by hydrothermal processes such as the Ifewara-Ilesha area. This research will improve the knowledge base of gold exploration within the Ilesha schist belt.

In Araromi, Ilesha, Iwara and Ifewara, gold is hosted predominantly in quartz veins and amphibolite sequences within the Ife-Ilesha Schist Belt. Studies using X-ray Diffraction (XRD) have confirmed the occurrence of gold grains within silicate matrices like quartz and feldspar (Adetula et al., 2019). However, what remains underexplored is the tectonic and geochemical context that facilitates such mineralization. This research integrates variation diagrams to interpret the nature of the source magma, degree of crustal contamination, and tectonic environment responsible for gold deposition in the study areas. The aim is to use geochemical variation diagrams in conjunction with mineralogical data to investigate the processes responsible for gold mineralization in soil samples from Araromi (Ile-Ife), Ilesha, Iwara and Ifewara.

Local Geology of the Study Areas

Araromi (Ile-Ife) Geology

Ile-Ife is geologically situated within the Precambrian Basement Complex, specifically within the Ife-Ilesha Schist Belt, featuring a complex interplay of meta-sedimentary and meta-igneous rocks (Nwokeabia et al., 2018; Eshimiakhe et al., 2019). The area is structurally marked by multiple deformation events producing tightly folded and faulted sequences, with major fault systems trending NE-SW and NNE-SSW as part of the mineralized Ife-Ilesha fault system. Gold mineralization is primarily hosted in quartz-feldspar veins intruding foliated biotite gneiss and amphibolite units (Adetula et al., 2019).

Ilesha Gold Mineralization

The Ilesha area within the schist belt is renowned for significant gold mineralization, structurally divided by the major Iwaraja fault and the NNE-SSW trending Ifewara shear zone (Oyinloye,
2011: Jessell et al., 2012; Salawu et al., 2021). The western portion features notable alluvial and lode gold deposits at Igun and Itagunmodi, while the eastern section contains auriferous quartz veins hosted in biotite granite gneiss between Odo and Iperindo villages. Integrated geophysical studies reveal mineralized structures at depths of 90-200 m, confirming the area's exploration potential (Ogungbemi et al., 2022).

Iwara Structural Setting

Iwara exhibits a complex structural evolution characterized by two major deformation phases: an initial fabric-forming event (D1) producing steeply dipping foliations, followed by development of the NNE-SSW trending Iwara ductile shear zone (D2) with sub-vertical mylonitic foliations and sub-horizontal mineral lineations (Adeoti and Okonkwo, 2016). This structural complexity provides multiple fluid pathways essential for gold mineralization processes.

Ifewara Fault Zone

The Ifewara transcurrent fault zone represents a major NE-SW trending structure characterized by mylonitic rocks and cataclasites, with structural fabrics indicating both contractional and extensional regimes linked to Pan-African orogeny. This fault system has been crucial in facilitating hydrothermal fluid migration responsible for gold deposition throughout the region.

MATERIALS AND METHODS

The research integrates fieldwork, laboratory analyses, and advanced geochemical plotting techniques to deduce mineralization trends, source rock characteristics, and tectonic implications using variation diagrams. The research locations Araromi (Ile Ife), Ilesha, Iwara and Ifewara are situated within the Ilesha Schist Belt, a structurally significant region known for hydrothermally altered gold deposits.

A total of 20 soil samples were collected from Araromi, Ilesha, Iwara, and Ifewara using random grid sampling within known mineralized corridors. Each sample location was guided by surface expressions such as quartz veins, ferruginous caps, or artisanal diggings.

Each sample, weighing approximately 500g, was collected at a depth of 0.5, 1.0 m to avoid surface contamination. The cone and quartering method were applied in the field and laboratory to ensure sample representativity, as gold occurrence tends to be highly heterogeneous and grain-size dependent (Adetula et al., 2019).

GPS coordinates and geological descriptions were logged for all locations, focusing on lateritic profiles, amphibolites, and sheared gneisses that dominate the host lithology. XRF analysis was conducted to determine major and trace element composition. The technique enabled identification of key elements such as Ba, Cu, Co, Ta, Rb, Cr, Zn, Nb, and Au.

The procedure includes Crushing of each sample with an electric crusher and then pulverized for 60 seconds using Herzog Gyro-mill (Simatic C7-621). Pellets were prepared from the pulverized sample, first by grinding 20g of each sample with 0.4g of stearic acid for 60 seconds. After each grinding, the Gyro-mill was cleansed to avoid contamination. A gram of stearic acid was weighed into an Aluminium cup to act as binding agent and the cup was subsequently filled with the sample to the level point. The cup then taken to Herzong pelletizing equipment when it was passed at a pressure of 200KN for 60 seconds. The 2 mm pellets were added into a sample holder of the x-ray equipment (Phillips PW- 1800) for analysis. SEM-EDX analysis was critical for detailed microstructural study. Prepared polished sections were placed in the SEM chamber and subjected to high-energy electron bombardment. Adetula et al. (2019) observed that in the Iperindo samples, gold grains occur within quartz-feldspar matrices and exhibit fracture-filling textures, indicating precipitation from hydrothermal fluids. EDX spectra provided elemental confirmation of gold (Au) presence and its association with Si, Al, K, and Fe, confirming host rocks composed predominantly of quartz and silicates details of which is provided in another manuscript.

RESULTS AND DISCUSSION

The geochemical results obtained from soil and regolith samples collected within the Ilesha–Ifewara gold belt of southwestern Nigeria. The results are based on X-ray Fluorescence (XRF) and Atomic Absorption Spectroscopy (AAS) analyses and are aimed at establishing the geochemical characteristics of the study area with respect to gold enrichment and associated trace elements.

The analysed samples were collected across known and suspected gold-bearing zones within the Precambrian Basement Complex terrain of southwestern Nigeria. Sampling was carried out systematically to ensure adequate spatial coverage of the study area and to obtain representative geochemical data from the regolith.

The results are presented as major element composition, trace element distribution, statistical summaries, and geochemical variation diagrams. Emphasis is placed on gold and associated pathfinder elements relevant to mineral exploration in basement complex terrains. The datasets are organised into tables and figures to facilitate clear presentation and interpretation of geochemical patterns within the Ilesha–Ifewara gold belt.

Sample Locations and Description

Field sampling was conducted across four key localities—Araromi, Ilesha, Ifewara, and Iwara— within the Ilesha–Ifewara gold belt of southwestern Nigeria (Figure 3). The belt forms part of the Nigerian Precambrian Basement Complex and is characterised by structurally controlled gold mineralization associated with schistose metasediments, gneisses, and Pan-African shear zones. A total of 20 samples comprising regolith materials were systematically collected to capture variations in lithology and structural setting. Nine samples were obtained from Araromi, six from Ilesha, and three samples each from Ifewara and Iwara. Sampling targeted lateritic and residual soils developed over quartz schist, amphibolite, granitic gneiss, migmatite, and shear-hosted quartzites.

Soil samples were collected from collected from the B-horizon (50 cm /0.5 m depth) to minimize surface contamination and ensure representation of the geochemically active regolith. Sample locations were georeferenced using a handheld GPS, and field observations of lithology, soil characteristics, and evidence of artisanal activity were recorded. This spatially distributed sampling provides a reliable basis for assessing geochemical variation and gold distribution across the Ilesha–Ifewara gold belt (Oyinloye, 2018).

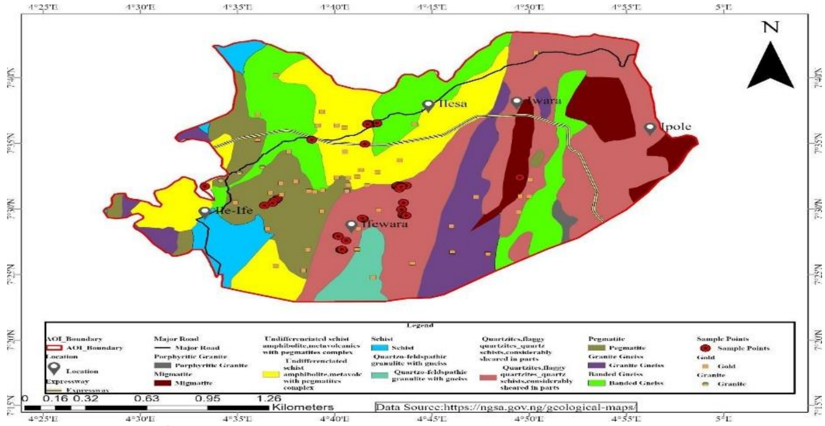

Figure 1: Map of Study Area

Geochemical Data Presentation

This section presents the full geochemical dataset obtained from the twenty soil and regolith samples collected in Araromi, Ifewara, Ilesha and Iwara. Results are grouped into three parts:

i. Major element composition,
ii. Trace element distribution, and
iii. Location-based statistical summary.

All values originate from X-ray Fluorescence (XRF) and Atomic Absorption Spectroscopy (AAS) analyses carried out on dried, homogenised B-horizon materials. These data form the basis for the subsequent interpretation of gold mineralization trends in the Ilesha, Ifewara belt.

Major Element Composition

The soils are characteristically silica-rich and aluminous, reflecting derivation from felsic basement rocks subjected to strong tropical weathering. Table 1 lists the full major-oxide dataset for each individual sample.

Table 1: Major Element Composition of Soil Samples (wt %)

S/N	Sample ID	Location	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	P_2O_5	K_2O	MnO	MgO	Na_2O	LOI
1	L4 IFW	Ifewara	52.54	28.85	3.65	1.17	1.94	0.00	0.95	0.01	0.08	0.05	10.20
2	Active Mine-IFW	Ifewara	55.35	30.27	3.60	1.05	1.45	0.01	0.98	0.01	0.44	0.30	10.55
3	L7 WR	Iwara	55.70	28.20	3.50	1.23	1.30	0.00	0.90	0.01	0.50	0.25	10.24
4	L3 Ilesha SS C	Ilesha	54.72	27.50	2.82	0.53	0.20	0.03	0.80	0.01	0.60	0.47	11.30
5	L1E(IFW)	Ifewara	50.60	30.77	3.65	1.20	1.90	0.00	0.95	0.08	0.09	-	10.20
6	L5 WR	Iwara	55.40	30.22	3.63	1.09	1.48	0.01	0.90	0.01	0.45	0.28	10.50
7	L10AWR	Iwara	55.64	29.24	2.50	1.20	1.30	0.00	0.92	0.01	0.50	0.25	10.20
8	L1ARAIFE	Araromi	54.50	27.72	2.84	0.55	0.20	0.05	0.85	0.01	0.55	0.45	11.30
9	L2 ARA IFE	Araromi	52.80	28.50	3.63	1.20	1.90	0.00	0.99	0.08	0.05	-	10.20
10	L4BARAIFE	Araromi	56.35	29.25	3.65	1.05	1.48	0.01	0.92	0.01	0.49	0.25	10.50
11	L5ARAROMI SSIFE	Araromi	55.70	29.20	2.50	1.23	1.30	0.00	0.90	0.01	0.50	0.25	10.24
12	L4ARAROMI	Araromi	54.54	27.70	2.82	0.55	0.20	0.03	0.85	0.01	0.55	0.47	11.30
13	L6ANTHILL	Araromi	50.70	30.67	3.60	1.23	1.90	0.00	0.99	0.08	0.07	-	10.20
14	L16IPONLEANT	Araromi	56.40	29.20	3.67	1.04	1.45	0.01	0.95	0.01	0.45	0.28	10.55
15	LA MOUNTCARMEL	Araromi	55.48	29.50	2.50	1.22	1.30	0.00	0.80	0.01	0.50	0.25	10.24
16	L1 ILESHA SS	Ilesha	54.90	27.32	2.64	0.75	0.20	0.05	0.85	0.01	0.55	0.45	10.30
17	L3 Ilesha B	Ilesha	54.72	27.52	2.84	0.53	0.20	0.05	0.83	0.01	0.58	0.45	11.30
18	L3ILESHA F	Ilesha	52.50	28.80	3.60	1.20	1.95	0.00	0.97	0.08	0.05	-	10.20
19	L4ILESHA A	Ilesha	56.35	29.25	3.65	1.05	1.48	0.00	0.92	0.01	0.49	0.25	10.50
20	L4ILESHAC	Ilesha	55.90	29.20	2.20	1.20	1.33	0.00	0.92	0.01	0.50	0.23	10.20

The range of SiO_2 (50.6, 56.4 wt %) and Al_2O_3 (27.3, 30.8 wt %) is typical of lateritic soils derived from felsic gneisses, while very low CaO and Na_2O (<0.5 wt %) confirm intense leaching of mobile cations under humid tropical conditions (Rahaman, 1988; Amponsah et al., 2015).

Trace Element Composition

Trace-element results highlight the presence of gold and pathfinder elements such as cobalt and zinc. The complete dataset is shown in Table 2.

Table 2: Trace Element Composition of Soil Samples (ppm)

S/N	Sample ID	Location	Ba	Cu	Cr	Ni	Zn	Pb	Rb	La	Nb	Ta	Au	Co
1	L4 IFW	Ifewara	670.6	28.85	95.3	30.4	212.45	10.2	6.7	0.2	3.22	0.2	0.22	2.2
2	Active Mine-IFW	Ifewara	662.6	28.30	112.2	29.95	214.40	10.2	5.6	0.24	5.70	0.2	0.30	4.3
3	L7 WR	Iwara	660.6	29.30	120.2	30.20	210.22	11.4	6.33	0.22	5.60	0.2	0.34	5.6
4	L3 Ilesha SS C	Ilesha	650.4	28.20	120.2	22.23	220.30	12.2	4.80	0.20	5.20	0.2	0.30	6.5
5	L1E(IFW)	Ifewara	670.6	28.20	112.3	30.50	210.50	12.2	6.30	0.24	6.20	0.22	0.20	5.6
6	L5 WR	Iwara	670.6	26.30	112.2	32.55	210.55	12.5	8.30	0.22	5.54	0.20	0.33	8.5
7	L10AWR	Iwara	660.62	20.45	110.2	30.50	210.25	16.2	8.25	0.22	6.40	0.22	0.25	5.5
8	L1ARAIFE	Araromi	679.4	28.20	11.2	25.30	220.44	10.2	6.30	0.20	6.50	0.20	0.20	7.6
9	L2 ARA IFE	Araromi	669.61	24.35	100.6	31.60	210.45	11.0	8.40	0.20	5.12	0.21	0.28	8.2
10	L4BARAIFE	Araromi	669.37	28.34	112.2	31.65	210.45	10.2	7.60	0.22	5.74	0.20	0.33	5.4
11	L5ARAROMI SSIFE	Araromi	662.6	27.35	110.22	30.60	214.25	12.8	6.40	0.22	5.59	0.20	0.34	8.6
12	L4ARAROMI	Araromi	670.57	28.24	120.2	28.45	220.34	12.5	7.80	0.20	6.22	0.20	0.28	6.2
13	L6ANTHILL	Araromi	668.6	28.23	100.2	30.40	212.40	12.2	8.32	0.25	6.20	0.22	0.20	8.2
14	L16IPONLEANT	Araromi	670.6	26.32	112.2	32.62	220.45	12.5	5.30	0.22	5.54	0.20	0.33	6.5
15	LA MOUNTCARMEL	Araromi	655.62	25.45	117.2	28.40	210.25	10.4	8.25	0.28	6.40	0.22	0.25	7.6
16	L1 ILESHA SS	Ilesha	670.6	24.22	120.2	26.30	220.46	10.2	8.32	0.22	6.50	0.20	0.23	8.62
17	L3 Ilesha B	Ilesha	6723.4	28.20	15.2	22.30	220.44	10.2	6.50	0.22	6.70	0.20	0.20	7.6
18	L3ILESHA F	Ilesha	677.6	24.33	110.6	31.40	210.40	11.0	4.60	0.20	5.12	0.21	0.25	8.2
19	L4ILESHA A	Ilesha	674.33	28.54	112.2	28.40	215.20	10.2	4.20	0.22	5.74	0.20	0.32	5.4
20	L4ILESHAC	Ilesha	665.6	27.40	115.22	30.60	210.25	12.4	6.40	0.22	5.59	0.20	0.34	8.6

Note: Sample L3 Ilesha B shows anomalous Ba and Cr values and requires verification during quality control.

Gold occurs between 0.20 and 0.34 ppm, while cobalt reaches up to 8.6 ppm, values comparable to pathfinder concentrations reported from other West African lateritic gold belts (Bamba et al., 2021).

Statistical Summary by Location

To highlight regional contrasts, descriptive statistics were calculated for each locality (Table 3).

Table 3 Location-Based Statistical Summary of Major and Selected Trace Elements

Element	Unit	Araromi (n=9)	Ifewara (n=3)	Ilesha (n=6)	Iwara (n=3)
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
SiO_2	wt.%	54.02 ± 2.09	52.83 ± 2.38	54.52 ± 1.48	55.58 ± 0.15
Al_2O_3	wt.%	29.09 ± 1.01	29.96 ± 1.09	28.10 ± 0.86	29.22 ± 1.01
Fe_2O_3	wt.%	3.21 ± 0.59	3.63 ± 0.03	2.83 ± 0.58	3.21 ± 0.65
LOI	wt.%	10.52 ± 0.43	10.32 ± 0.20	10.58 ± 0.50	10.31 ± 0.17
Au	Ppm	0.27 ± 0.06	0.24 ± 0.05	0.27 ± 0.05	0.31 ± 0.05
Co	Ppm	6.99 ± 1.16	4.03 ± 1.70	7.22 ± 1.30	6.53 ± 1.53
Cu	Ppm	26.87 ± 1.50	28.45 ± 0.33	26.82 ± 2.18	25.35 4.43

Geochemical Variation Diagrams

The geochemical behaviour of the sediments in the Ilesha–Ifewara gold belt (Table 4 to Table 6), reflects derivation from a common Pan-African calc-alkaline arc basement, subsequently modified by intense tropical lateritization (Figure 2). Tectonic discrimination diagrams consistently place all samples within the Oceanic Island Arc (OIA) field (Figure 3). The depletion of Niobium (Nb) and Tantalum (Ta) when compared to other elements infers Oceanic Island Arc origin and while the enrichment in elements like Barium (Ba), Strontium (Sr), and Thorium (Th), which reflect subduction-fluid inputs (Damanik, 2024: Ali et al., 2024: Perera, 2013). Major and trace element variation (Table 4 to Table 6) patterns show strong residual enrichment of Al_2O_3, TiO_2 and Fe_2O_3 and pronounced depletion of CaO, Na_2O and K_2O (Figure 4), reflecting prolonged chemical weathering and feldspar breakdown under humid tropical conditions. The preservation of primary geochemical ratios despite lateritization demonstrates that the regolith faithfully records the chemistry of its parent rocks rather than being dominated by secondary alteration.

Ternary discrimination diagram (Figure 5) further indicates a felsic-dominated granitoid source with subordinate mafic contributions. Enrichment in Ba and stable Nb values point to potassium- feldspar-rich granitoids, while Ni, Cr and Co reveal input from mafic and amphibolitic units within the belt. The clustering of gold-rich samples toward the Co apex (Figure 5) highlights cobalt as a reliable pathfinder element for orogenic gold mineralization. Co and Au have strong affinity for iron sulfide minerals such as pyrite, and both get incorporated into pyrite lattice during hydrothermal fluid circulation (Iglesias-Martinez et al., 2024). Co most often has a wider spread and concentration compared to Au, thus making it easier to locate and serve as a good pathfinder for gold.

Overall, gold mineralization in the Ilesha–Ifewara corridor is structurally controlled, laterite-hosted, and genetically linked to weathered Pan-African arc-derived basement rocks. The combination of immobile major oxides and trace-element pathfinders provides a robust geochemical framework for targeting ferruginous horizons and shear-zone-controlled mineralization within the belt.

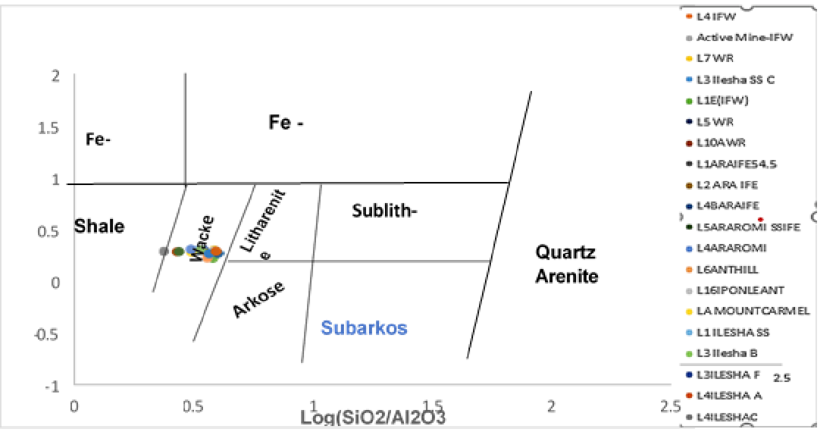

Figure 2: Geochemical Classification after Herron 1988

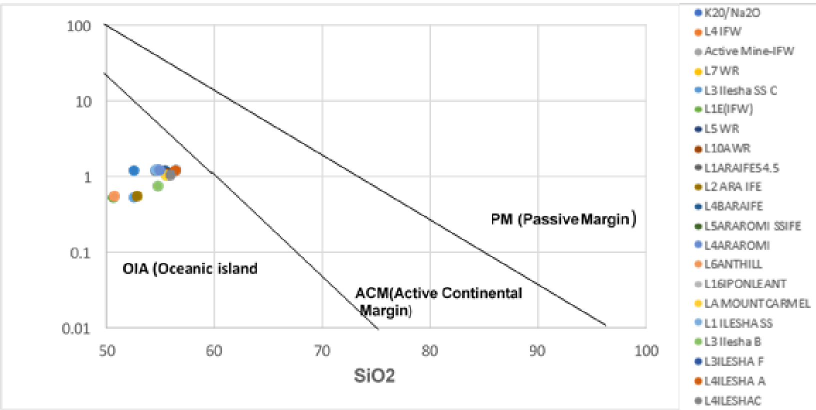

Figure 3: Tectonic setting discrimination SiO2 vs K2O/Na2O (after Roser and Korsch 1986)

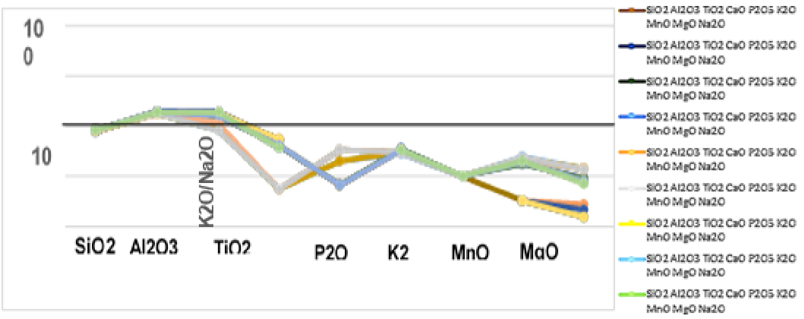

Figure 4: Major oxides of elements composition

Table 4: Table Showing Ternary Distribution of Ba, Rb, Nb

Location	Ba	Rb	Nb
L4 IFW	670.6	6.7	3.22
Active Mine-IFW	662.6	5.6	5.7
L7 WR	660.6	6.33	5.6
L3 Ilesha SS C	650.4	4.8	5.2
L1E(IFW)	670.6	6.3	6.2
L5 WR	670.6	8.3	5.54
L10AWR	660.62	8.25	6.4
L1ARAIFE54.5	679.4	6.3	6.5
L2 ARA IFE	669.61	8.4	5.12
L4BARAIFE	669.37	7.6	5.74

Location	Ba	Rb	Nb
L5ARAROMI SSIFE	662.6	6.4	5.59
L4ARAROMI	670.57	7.8	6.22
L6ANTHILL	668.6	8.32	6.2
L16IPONLEANT	670.6	5.3	5.54
LA MOUNTCARMEL	655.62	8.25	6.4
L1 ILESHA SS	670.6	8.32	6.5
L3 Ilesha B	6723.4	6.5	6.7
L3ILESHA F	677.6	4.6	5.12
L4ILESHA A	674.33	4.2	5.74
L4ILESHAC	665.6	6.4	5.59

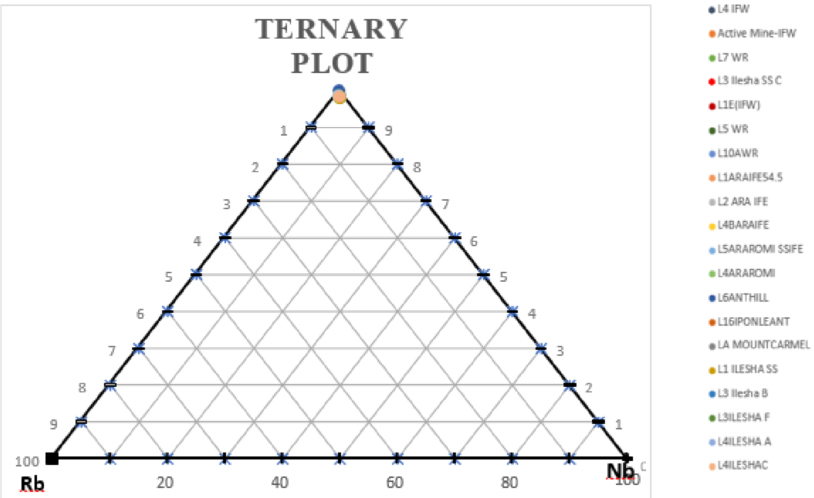

Figure 5: Ternary Plot (Ba, Rb, Nb)

Table 5: Table showing Ternary Distribution of Cu, Pb, Zn

Locations	Cu	Pb	Zn
L4 IFW	28.85	10.2	212.45
Active Mine-IFW	28.3	10.2	214.4
L7 WR	29.3	11.4	210.22
L3 Ilesha SS C	28.2	12.2	220.3
L1E(IFW)	28.2	12.2	210.5
L5 WR	26.3	12.5	210.55
L10AWR	20.45	16.2	210.25
L1ARAIFE54.5	28.2	10.2	220.44
L2 ARA IFE	24.35	11	210.45
L4BARAIFE	28.34	10.2	210.45
L5ARAROMI SSIFE	27.35	12.8	214.25
L4ARAROMI	28.24	12.5	220.34
L6ANTHILL	28.23	12.2	212.4
L16IPONLEANT	26.32	12.5	220.45
LA MOUNTCARMEL	25.45	10.4	210.25
L1 ILESHA SS	24.22	10.2	220.46
L3 Ilesha B	28.2	10.2	220.44
L3ILESHA F	24.33	11	210.4
L4ILESHA A	28.54	10.2	215.2
L4ILESHAC	27.4	12.4	210.25

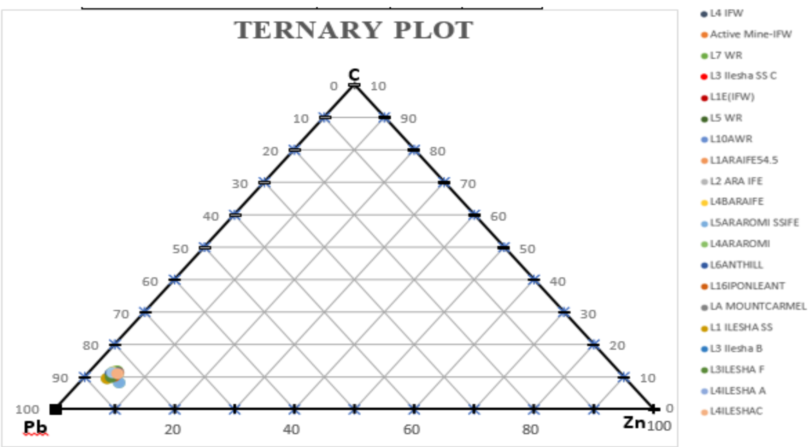

Figure 6: Ternary Plot (Cu, Pb, Zn)

Table 6: Table Showing Ternary distribution of Ni, Cr, Co

Locations	Ni	Cr	Co
L4 IFW	30.4	95.3	2.2
Active Mine-IFW	29.95	112.2	4.3
L7 WR	30.2	120.2	5.6
L3 Ilesha SS C	22.23	120.2	6.5
L1E(IFW)	30.5	112.3	5.6
L5 WR	32.55	112.2	8.5
L10AWR	30.5	110.2	5.5
L1ARAIFE54.5	25.3	11.2	7.6
L2 ARA IFE	31.6	100.6	8.2
L4BARAIFE	31.65	112.2	5.4
L5ARAROMI SSIFE	30.6	110.22	8.6
L4ARAROMI	28.45	120.2	6.2
L6ANTHILL	30.4	100.2	8.2
L16IPONLEANT	32.62	112.2	6.5
LA MOUNTCARMEL	28.4	117.2	7.6
L1 ILESHA SS	26.3	120.2	8.6
L3 Ilesha B	22.3	15.2	7.6
L3ILESHA F	31.4	110.6	8.2
L4ILESHA A	28.4	112.2	5.4
L4ILESHAC	30.6	115.22	8.6

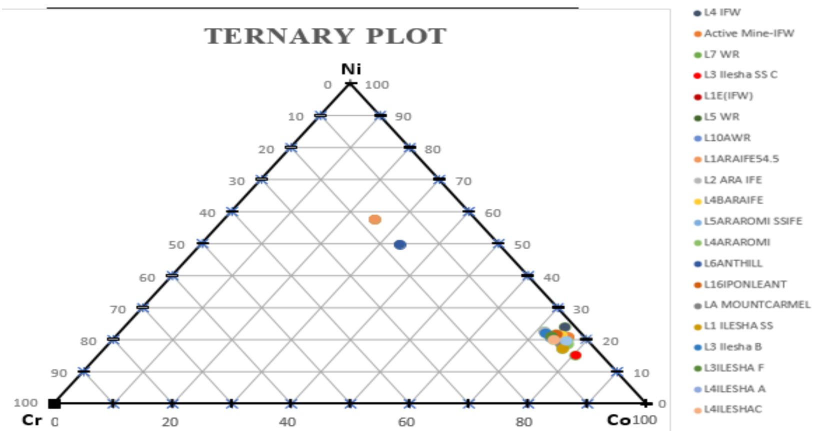

Figure 7: Ternary Plot (Ni, Cr, Co) shows that most of the samples are very high in Cobalt (~80–90%), low in Nickel (~10–20%), and very low in Chromium (~0–5%)

Gold-Associated Minerals and Elemental Stability in the Ilesha–Ifewara Belt

Gold mineralization in the Ilesha–Ifewara schist belt is characteristic of a Pan-African orogenic gold system, where gold occurs in association with quartz veins, shear zones, and sulphidised wall rocks. Gold is rarely present as a pure phase; instead, it is closely linked with sulphide minerals— mainly pyrite and arsenopyrite—with minor chalcopyrite, galena, sphalerite, and pentlandite. During intense tropical weathering, these sulphides are oxidised, but gold is retained within secondary iron oxides such as goethite and hematite, as well as within residual quartz and lateritic horizons.

Oxide and clay minerals play a crucial role in preserving gold within the regolith. Immobile phases such as rutile, anatase, gibbsite, and kaolinite act as stable hosts or adsorption sites for gold released during sulphide breakdown. This mineralogical assemblage explains the persistence of gold within lateritic profiles long after primary mineralization has been destroyed.

Geochemical data confirm strong elemental stability patterns typical of mature laterite, with residual enrichment of Al_2O_3, Fe_2O_3, and TiO_2 and severe depletion of CaO, Na_2O, and K_2O. Among trace elements, Ba, Cr, and Ni remain largely immobile and reflect felsic–mafic basement contributions, while Co shows localized enrichment and a strong association with gold. In contrast, Cu, Pb, and Zn exhibit weak relationships with gold, ruling out polymetallic sulphide systems.

Overall, it demonstrates that cobalt is the most reliable geochemical pathfinder for gold in the Ilesha–Ifewara belt. The dominance of immobile oxides and Co-bearing phases confirms a structurally controlled, laterite-hosted orogenic gold system and provides a robust geochemical framework for exploration across similar Pan-African basement terrains in West Africa.

Elemental Correlation and Integrated Interpretation of Gold Mineralization

Elemental correlation analysis provides important insight into the geochemical behaviour of gold and associated pathfinder elements within the Ilesha–Ifewara schist belt. Pearson correlation coefficients reveal that gold (Au) shows its strongest positive relationship with cobalt (Co) ($r = 0.34$), indicating that gold enrichment is preferentially associated with cobalt-bearing phases. This relationship is characteristic of laterite-hosted and orogenic gold systems, where Co persists in sulphides and secondary oxides formed during weathering and therefore serves as a reliable pathfinder element (Bamba et al., 2021). In contrast, Au exhibits a negative correlation with copper (Cu), suggesting that gold mineralization is not linked to copper-rich sulphide systems and that Cu was preferentially leached during supergene alteration, consistent with tropical regolith environments. Weak positive correlations between Au and Pb, Ni, and Cr reflect minor contributions from galena-bearing phases and mafic–ultramafic lithologies interlayered within the felsic basement (Rahaman, 1988).

Strong correlations between Ni–Cr and Cu–Ni confirm a shared mafic to ultramafic source for these elements, though their weak association with gold indicates that gold mineralization is not primarily controlled by magmatic sulphide systems. Instead, the elemental relationships support a structurally controlled, hydrothermal gold system overprinted by intense lateritic weathering.

Integrated interpretation of major oxides, trace elements, and discrimination diagrams shows that the regolith is derived from felsic to intermediate arc-related protoliths with subordinate mafic input. Samples plot mainly within the wacke–litharenite field and consistently fall in the Oceanic Island Arc (OIA) tectonic setting, reflecting calc-alkaline arc magmatism prior to Pan-African metamorphism and deformation (Rahaman, 1988; Ajibade et al., 2008). Prolonged tropical weathering selectively removed mobile alkalis and alkaline earths while concentrating immobile oxides such as Al_2O_3, TiO_2, and Fe_2O_3, producing a mature lateritic profile that preserves primary tectono-magmatic signatures.

Gold distribution is spatially variable but structurally focused, with the highest values recorded around Iwara. The strongest geochemical control on gold is its association with cobalt, reflecting deposition from hydrothermal fluids along shear zones such as the Ifewara fault, followed by oxidation and residual concentration in ferruginous and clay-rich horizons. Pathfinder relationships derived from ternary diagrams further support this interpretation: Co-rich samples coincide with elevated Au, Ba-dominant signatures indicate potassic alteration linked to granitoid intrusions, and Zn enrichment reflects supergene concentration in oxide and gossanous horizons. These patterns are consistent with orogenic gold systems developed within mixed felsic–mafic basement terrains (Elueze & Bolarinwa, 2004).

The present surface geochemical signature is therefore the product of three interacting processes: primary hydrothermal gold deposition along structurally controlled pathways, intense tropical weathering that destroyed primary sulphides while preserving gold and cobalt in residual oxides, and pedogenic reworking that locally redistributed gold within the regolith. The persistence of cobalt as a pathfinder element despite lateritization confirms its value for surface exploration in deeply weathered terrains (Bamba et al., 2021).

Overall, the data support a coherent genetic model in which gold mineralization in the Ilesha– Ifewara belt is orogenic, structurally controlled, and laterite-hosted. Cobalt emerges as the most reliable geochemical guide to mineralization, while integration of soil geochemistry, structural analysis, and targeted geophysics provides the most effective strategy for delineating drill-ready targets within the Pan-African Nigerian Basement Complex (Rahaman, 1988; Amponsah et al., 2015).

Discussion

The geochemical evidence obtained from the soils and regolith of the Ilesha–Ifewara gold belt reveals a close interplay between the Pan-African basement geology and intense tropical weathering processes. Major-oxide chemistry shows that aluminium (Al_2O_3) and titanium (TiO_2) are consistently enriched across all sites, while sodium (Na_2O), potassium (K_2O) and calcium (CaO) are strongly depleted. This pattern is a hallmark of prolonged lateritization, where continuous leaching by acidic, percolating waters removes mobile cations and leaves behind immobile oxides such as gibbsite, rutile and hematite. Comparable trends have been described for other West African laterite profiles, confirming that the study area has undergone mature chemical weathering typical of humid tropical climates (Rahaman, 1988; Adetunji et al., 2018).

Tectonic discrimination using the K_2O/Na_2O versus SiO_2 diagram places all analysed samples firmly within the Oceanic Island Arc (OIA) field. The uniform OIA signature across all locations confirms a shared tectono-magmatic provenance and minimal variation in basement source rocks. Indicating inheritance of chemistry from subduction-related igneous protoliths typical of the Nigerian Basement Complex. This geochemical signature reflects derivation from calc-alkaline volcanic arc protoliths, a setting consistent with the Neoproterozoic Pan- African Mobile Belt, where oceanic arcs were accreted onto the West African Craton (Ajibade et al., 2008). The persistence of this arc-related signature, despite the region's intense weathering, highlights the chemical resilience of the parent granitoid and granodioritic gneisses and indicates that post-weathering metasomatism has been minimal.

Multi-element "spider" diagrams normalized to average upper crust display parallel enrichment– depletion patterns across all locations Araromi, Ifewara, Ilesha and Iwara implying a shared basement source and a uniform regional weathering regime. The similarity of these profiles supports previous petrochemical characterizations of the Nigerian Basement Complex, which emphasize the dominance of felsic to intermediate igneous protoliths such as granitic gneisses and migmatites (Elueze & Bolarinwa, 2004).

Ternary variation plots add further insight. Ba–Nb–Rb diagrams show clustering near the Ba apex, pointing to potassium-feldspar–rich granitoids as the main contributors to the regolith, while subdued Rb values record leaching of alkalis during tropical weathering. Ni–Cr–Co relationships reveal two distinct populations: a Cr-rich group representing minor mafic or ultramafic input and a Co-rich group that coincides with the highest measured gold concentrations. This consistent association of gold with cobalt strongly supports the interpretation of cobalt as a pathfinder element for orogenic gold systems, a relationship also reported across the Birimian terranes of Ghana and Burkina Faso (Bamba et al., 2021).

Taken together, these results show that the lateritic soils faithfully preserve the primary geochemical fingerprints of their Pan-African source rocks while also recording the supergene processes that concentrate gold. The uniform distribution of immobile elements and the spatial alignment of cobalt with gold anomalies provide clear exploration vectors, confirming that integrated major- and trace-element geochemistry is a powerful tool for gold prospecting in deeply weathered basement terrains.

Interpretation of Key Findings

The integrated geochemical dataset provides a coherent picture of gold enrichment mechanisms and their geological controls within the Ilesha–Ifewara belt. By examining the major oxides, trace elements, and gold values in concert, several critical insights emerge.

Gold Distribution and Localised Anomalies

Gold concentrations range from 0.20 to 0.34 ppm, with the highest values consistently recorded in soils from Iwara, followed by Araromi, Ilesha and Ifewara. This spatial pattern highlights Iwara as the most prospective zone. The gold anomalies coincide with slightly elevated cobalt and nickel contents, reinforcing the role of transition-metal association as an exploration guide. The presence of cobalt in particular shows a positive correlation with gold ($r \approx 0.34$), a relationship observed in other West African orogenic belts where cobalt-bearing phases host or adsorb fine gold particles during hydrothermal alteration (Bamba et al., 2021).

Source Rock and Tectonic Context

Major oxide ratios and tectonic discrimination diagrams consistently point to calc-alkaline, oceanic island-arc–derived protoliths within the Pan-African Mobile Belt. Despite intense tropical weathering, the primary arc-related signature is preserved, suggesting that lateritic profiles in the study area are geochemically robust. This stability is critical for exploration because it means that surface soil chemistry can reliably reflect the composition of underlying basement rocks rather than only the effects of secondary alteration (Rahaman, 1988; Ajibade et al., 2008).

Weathering Processes and Residual Enrichment

Spider diagrams normalized to upper continental crust reveal strong depletion of CaO, Na_2O and K_2O and marked enrichment of Al_2O_3 and TiO_2, patterns typical of mature laterites formed under prolonged humid tropical conditions (Adetunji et al., 2018). Such chemical maturity indicates a long history of leaching that removes mobile elements while concentrating immobile oxides and resistant heavy minerals, including native gold, within the regolith. The retention of Fe_2O_3 further supports the development of ferruginous horizons capable of trapping and protecting fine gold particles.

Pathfinder Element Relationships

Correlation analysis highlights cobalt as the most effective pathfinder for gold in these lateritic soils, outperforming more traditional indicators such as copper or lead. This reflects the geochemical behaviour of cobalt, which tends to remain stable during intense weathering and can substitute into iron oxides or form discrete Co-bearing phases that host or adsorb gold. The association of gold with cobalt-rich samples mirrors observations from other West African gold provinces, underlining its reliability as a geochemical vector in tropical terrains (Bamba et al., 2021).

Regional Implications

In a low temperature environment Gold experiences, a complex array of chemical and biogeochemical interactions occurs. Deep weathering and laterization within the West Africa terrains commonly leads to element redistribution (Bacha, 2021). Mobile elements such as As, Bi, Sb, and W create much larger geochemical anomalies forming strong, co-precipitating halos, High Field Strength Elements (HFSEs) act as pathfinders to directly locate hidden gold deposits (MacLean, 1993; Barrett et al. ,1993). Rare Earth Elements (REEs) act as immobile discriminators in gold exploration (Amoldago and Sunkari, 2026), effectively mapping regolith architecture and primary lithology (Bacha et al., 2021) The convergence of these findings demonstrates that the Ilesha–Ifewara belt represents a mature lateritic environment derived from Pan-African arc-related granitoids and gneisses, where deep chemical weathering has concentrated gold in near-surface soils. This finding contradicts the Oceanic Island Arc (OIA) geochemical signature that is related to mafic to intermediate volcanic source terrain, characterized by high=field strength elements (HFSE), flat REE and depleted in Eu (typical of an oceanic subduction zone) found in parts of Central Africa Mobile belts) Ondobo et. al. (2026) This interpretation not only validates the use of major- and trace-element geochemistry in tropical exploration but also identifies Iwara as the priority target for follow-up drilling and structural mapping, with cobalt- based anomalies serving as a practical exploration guide across the wider basement complex of southwestern Nigeria.

CONCLUSION

This study demonstrates that the lateritic soils of the Ilesha–Ifewara belt retain a clear geochemical fingerprint of their Pan-African basement source rocks and provide reliable indicators of gold mineralization. Gold values, though modest in absolute concentration, show a consistent spatial pattern with the highest enrichment at Iwara, indicating that this locality represents the most prospective zone for further exploration. The association of gold with cobalt and, to a lesser degree, nickel confirms the value of these transition metals as pathfinder elements, a relationship that remains stable despite the intense tropical weathering that characterizes the region.

Major oxide data highlight pronounced depletion of alkali and alkaline earth elements and enrichment of immobile oxides such as Al_2O_3, TiO_2 and Fe_2O_3. These signatures confirm that the soils have undergone advanced lateritization, a process that both concentrates resistant heavy minerals and preserves the trace-element signature of the underlying granitoid and granodioritic gneisses. Consequently, the soil geochemistry reflects not only the effects of supergene enrichment but also the composition of the Pan-African crust from which the regolith was derived. Exploration framework is positioned within the larger Pan-African and West African metallogenic context, where orogenic gold is fundamentally controlled by crustal-scale shear zones most of which are deeply weathered and lateralized. Within the African terrain, the Paleoproterozoic greenstone belts of the West African Craton (WAC), the Neoproterozoic mobile belts of the Trans-Sahara and Arabian-Nubian Shields are great examples. In all these regions lateritic gold deposits have been identified as low-cost production source of gold due to their proximity to the surface (Iglesias-Martínez et. al., 2024).

Collectively, these findings show that surface geochemical surveys can reliably guide gold exploration in deeply weathered tropical terrains. The Ilesha–Ifewara belt exemplifies how cobalt anomalies, when integrated with major and trace element data, can delineate concealed mineralization zones. The results therefore provide a strong geochemical rationale for detailed structural mapping, trenching, and shallow drilling in the Iwara sector, where the highest gold and cobalt concentrations coincide (Yao & Robb, 2000). More broadly, the study underscores the enduring value of integrated soil geochemistry as an exploration tool in the Pan-African Nigerian Basement Complex and similar Precambrian terranes across West Africa.

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