

Mesothermal Quartz Vein Gold Deposits of the Dikko Area, Part of Zungeru–Minna–Birnin Gwari Schist Belt, North-Central Nigeria

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Abstract

This study investigates the geochemical and mineralogical characteristics of mesothermal quartz vein gold deposits in the Dikko area, within the Zungeru–Minna–Birnin Gwari Schist Belt, North-Central Nigeria. Twenty-one samples from seven quartz veins were analyzed using fire assay (FAA), ICP-MS, XRF, XRD, and ore microscopy. Results show an average gold concentration of 3.9 ppm, exceeding the economic threshold (0.69–1.37 ppm). Associated elements include Cu (79 ppm), Ag (8.9 ppm), and Fe (7,900–33,200 ppm), indicating gold occurrence within sulphide phases, particularly arsenopyrite. Ore microscopy reveals gold as blebs within quartz fractures hosted by amphibolites, commonly associated with arsenopyrite and silver. XRD confirms crystalline gold. Geochemically, Cu correlates positively with Au, while Pb and Cu serve as pathfinder elements. Exceptionally high Pb (560.6 ppm), Cu (184.7 ppm), and Au (3.59 ppm) at location L2 define the primary mineralized zone. Elevated Rb (560.6 ppm) and low Sr (2.8 ppm) produce high Rb/Sr ratios (>200), indicating intense hydrothermal alteration. Ba and Sr anomalies further delineate alteration halos, while REE patterns show LREE enrichment, HREE depletion, and a negative Eu anomaly. These signatures indicate multiple hydrothermal fluid pulses and well-developed alteration zoning from phyllic to potassic and sulfide-rich phases. The Dikko gold mineralization is a structurally controlled mesothermal (orogenic) system linked to Pan-African tectonism. Exploration should focus on detailed mapping, trenching, and drilling around L2, with extended surveys along the L2–L5–L7 corridor to delineate ore zones.

Keywords: Mesothermal; Dikko area, Ore microscopy, Quartz vein

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Introduction

Since time immemorial, man's appetite for gold has been tremendous; hence the global search that led a lot of explorationists into this business. Nigeria's gold deposits are mainly concentrated in schist belts made up of older rocks, including gneisses, schists, quartzites, amphibolites, and granitoids [1–8]. There are several exposures of the Zungeru–Birnin Gwari Schist belt surrounding the study area, including those along the border between the Suleja Local Government in Northwestern Niger and Kwakuti and Gedan areas, and those along Gurara Local Government of Niger State, which geologically belong to the belt. In Nigeria, several workers have studied gold mineralization and its host rock [5, 9–11]. Numerous parts of Nigeria's supracrustal (schist) belts, found in both northwestern and southwestern Nigeria, contain gold mineralization in alluvial and eluvial placers and also in the form of primary veins [11]. He further noted that areas of Anka, Bin Yauri, Gurmana, Iperindo, Kwaga, Malele, Maru, Okolom-Dogondaji and Tsohon Birnin Gwari had the most significant occurrences (Fig. 1). Many sulphide and hydrothermal deposits, as well as streams and rivers

around the globe, contain native gold as a mineral in their oxidized zones. In orogenic belts dating back to the Precambrian to the late Tertiary, deposits of gold are bounded from hydrothermal action. They commonly coexist with stocks, batholiths, and other intermediate to acidic igneous intrusions. The Dikko Gold is mainly present in quartz veins. The deposit was discovered during a follow-up work on alluvial gold occurrences within the Zungeru–Minna–Birnin Gwari Schist belt, using traditional exploration techniques of rock-sediment sampling, pan concentrate and outcrop sampling. The primary objectives of this article are to provide the major and trace element geochemical characteristics of the gold possibilities in the Dikko area and to assess the likelihood of finding Copper (Cu), Silver (Ag), and Lead (Pb) deposits. The mobile elements Arsenic (As), Copper (Cu), Zinc (Zn), Nickel (Ni), and Lead (Pb) in particular the Light Rare Earth Element (LREE), Titanium dioxide (TiO₂), and Zircon (Zr) in the altered wall rocks if present, will be used as indices in locating any buried gold mineralization within the area. Interpretation of the scale and pattern of fractionation and the rate of enrichment/depletion will



also be provided. Answers regarding whether the ratio of these elements is associated with late magmatic crystallization will be provided too in this work. The mineralogical characteristics will also be studied here.

Gold mineralization within Precambrian schist belts has attracted sustained exploration interest due to its economic significance and genetic association with orogenic processes. In Nigeria, gold occurrences are predominantly hosted within the Pan-African basement complex, particularly within the schist belts composed of gneisses, schists, quartzites, amphibolites, and granitoids. These deposits are typically structurally controlled and occur as quartz vein-hosted mineralization, often linked to hydrothermal activity during Pan-African tectonism.

The Zungeru–Minna–Birnin Gwari Schist Belt represents one of the major metallogenic provinces in North-Central Nigeria, where several studies have documented gold mineralization in both primary veins and secondary placers. However, despite these regional investigations, the Dikko area remains relatively underexplored, particularly with respect to integrated geochemical and mineralogical characterization of its quartz vein-hosted gold deposits. Previous studies have largely focused on regional geology and structural controls, with limited quantitative data on trace element geochemistry, alteration indices, and mineralogical associations necessary for understanding ore-forming processes and exploration targeting.

The key research problem to be addressed in this study will be the lack of detailed, integrated geochemical–mineralogical data required to constrain the origin, alteration patterns, and exploration significance of gold mineralization in the Dikko area. Specifically, there is insufficient understanding of pathfinder element relationships, rare earth element (REE) behavior, and fluid–rock interaction signatures that define mesothermal gold systems within this segment of the schist belt.

To address this gap, this study employs a multi-analytical approach combining fire assay (FAA) for gold determination, Inductively Coupled Plasma–Mass Spectrometry (ICP-MS) and X-Ray Fluorescence (XRF) for major and trace element analysis, X-Ray Diffraction (XRD) for mineral phase identification, and ore microscopy (SEM/EDX and optical methods) for textural and mineralogical characterization. This integrated methodology enables a robust evaluation of elemental associations, alteration zoning, and mineral assemblages.

By linking geochemical signatures with mineralogical evidence, this study aims to (i) characterize the compositional and mineralogical features of the Dikko

gold-bearing quartz veins, (ii) identify pathfinder elements and alteration indicators, and (iii) establish a genetic model for mineralization. The results provide new insights into mesothermal gold systems in the Nigerian basement and contribute to improved exploration strategies within the Zungeru–Minna–Birnin Gwari Schist Belt.

The Geology of Dikko

An area of 110 km² is proposed for this study within the latitudes of 9°13'00"N to 9° 22'00"N and longitudes of 7° 00'00"E to 7° 11'15"E at the boundary of Suleja Local Government Area of Niger State, in Northcentral Nigeria (Fig. 2). Nigeria is home to eleven Precambrian to Early Paleozoic Schist Belts, with the research area identified as portion of the Zungeru–Minna–Birnin Gwari Schist Belt (Fig. 1) [1, 11–13]. The research area encompasses parts of north-central and northwest Nigeria and is primarily distinguished into three lithostratigraphic units: The Pan-African granitoid, supracrustal schist belts, and the migmatite-gneiss complex. There is generally an amphibolite facies grade of metamorphism in migmatite-gneiss complexes around Archean and Early-Proterozoic isotopic age [14]. A vast number of granitoid plutons of Pan-African magmatism have invaded them and they exhibit complex structural styles. The underlying gneiss-migmatite complex and the Late-Proterozoic schist belts were both deposited and morphed during the Pan-African tectonism. These belts exhibit intricate structural patterns and comprise assemblages of the Banded Iron Formation (BIF), pelitic sediments, and mafic igneous rocks. The belts generally turn into a greenschist facies grade, due to metamorphism and deformation, with structural attributes trending N-S and NNE-SSW. The granitoid is mainly syn- to late-tectonic, with granites, granodiorites and diorites with some gabbros and syenites as Pan-African intrusions. They were deposited into both the migmatites-gneiss and supracrustal rocks shortly after the primary phase of Pan-African deformation, and vary in size between small sub-circular, crosscutting stocks to enormous elongate concordant batholithic bodies [1]. At elevations between 420 and 630 meters Above Mean Sea Level (alms), there are a few rock exposures that distinguish the site. Amphibolite schist, amphibolites, gneisses, migmatites, and pegmatites constitutes the local rock types. There are a few networks of what seem to be ephemeral streams in the area, which pass amid the hills and empty into a river southward of Kwachife. The area is easily accessible due to a network of unpaved roads and footpaths.

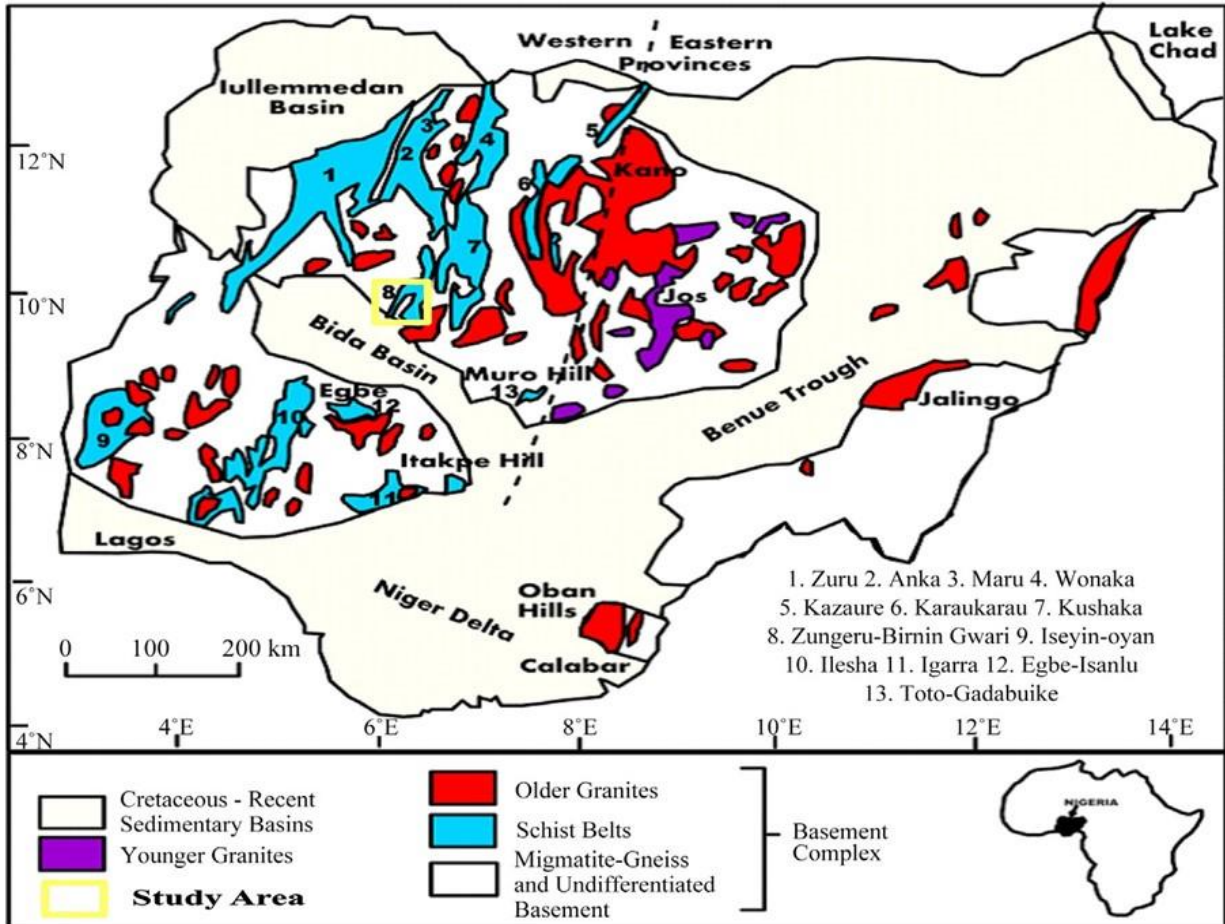


Figure 1: Schist belt localities within the context of the geology of Nigeria (modified after Ajibade *et al.* [3])

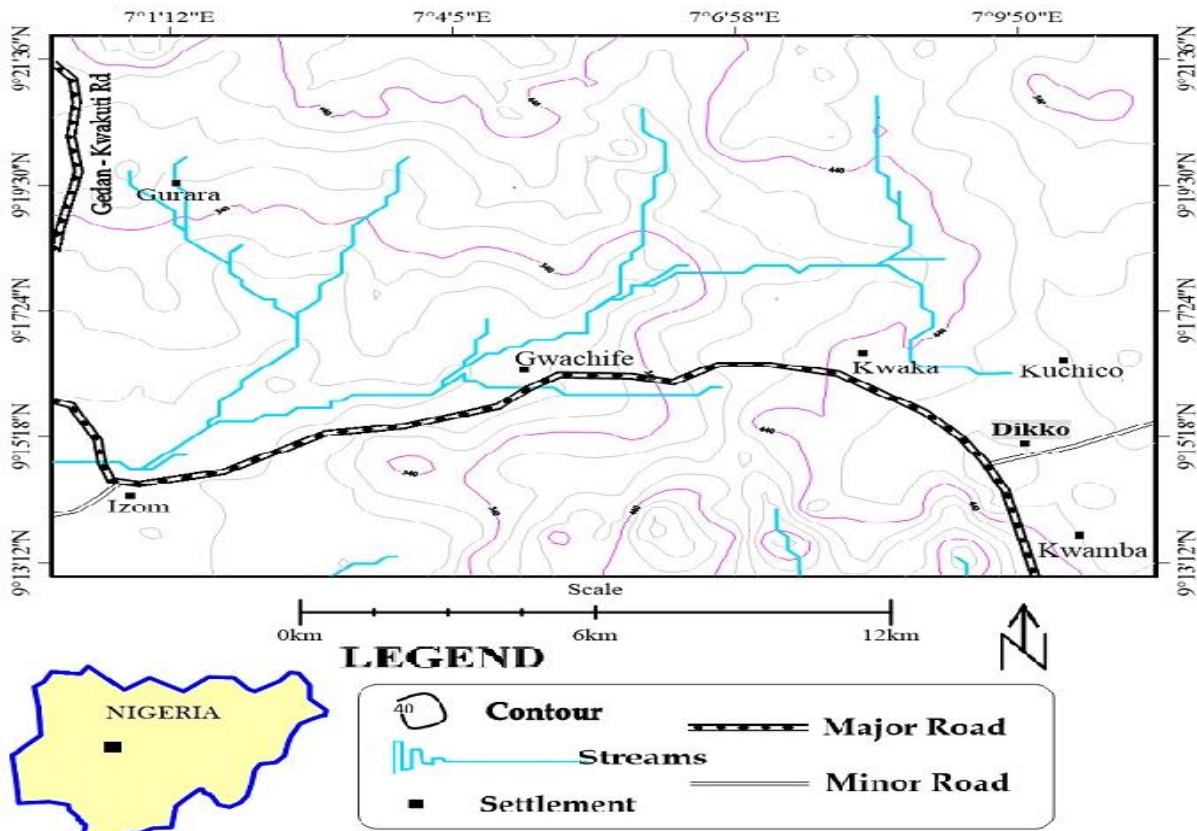


Figure 2: Location map of the study area



Materials and Methods

Sampling

A total of twenty-one (21) samples were collected from Seven (7) gold-bearing quartz veins that were dug at shallow depths. Samples were weighed using an automated weighing balance after the random sampling process. The samples were then milled till 80 % passed through the 75 μm mesh. The milled samples were homogenized before analysis. For compositional analysis, Induced Couple Plasma – Mass Spectroscopy (ICP-MS) which is a semi-quantitative analytical technique was employed in the determination of the chemical composition. Identification of the associated mineral phases was achieved using the X-Ray Diffraction (XRD) method. For ore microscopy, true fractions representing the gold-bearing quartz vein samples were organized and examined with the aid of the Scanning Electron Microscope–Energy Dispersive X-ray (SEM/EDX).

Chemical composition of the gold-bearing quartz veins

The elemental analysis of the Dikko gold-bearing ore samples from the quartz vein was performed utilizing the fire assay technique. Fire assaying is a technique used in gold determination. A fluxing agent is combined with the weighted, pulverized sample. The flux promotes the separation of the gangue material from valuable metals, helps the sample fuse at an acceptable temperature, and aids in melting. Lead is additionally provided as a collector along with the flux. The sample is then burned in a furnace, where it melts and separates from the collection material “button”, which holds valuable minerals. Aqua regia is used to dissolve the sample, and after that, it is inhaled in an acetylene flame. A beam of light with the same wavelength as gold is directed through the flame. According to the element's concentration in the solution, the amount of light that the sample's gold absorbs varies. By comparing the absorption of the sample with a reference solution, the concentration of gold in the sample can be calculated. The technique employed for bulk assay analysis is Flame Atomic Absorption (FAA).

Major and Trace element analysis of the gold-bearing quartz vein samples was accomplished via the X-Ray Fluorescence (XRF) and Induced Coupled Plasma–Mass Spectroscopy (ICP-MS) analytical techniques as with the Fire Assay technique at the Activation Laboratory, Ontario Canada (ACLAB). 20 g of the Gold-bearing rock samples from each of the seven (7) veins were milled to powder form which was afterward fed into the sample holder of the apparatus. The major and trace element composition of the Dikko gold-bearing quartz vein samples is presented as averages from individual veins (Tables 2 and 3).

Microscopy and mineralogy of the Dikko gold-bearing quartz veins

Ore microscopy

Ore microscopy was performed on the rock samples at National Geosciences Research Laboratory Centre

Kaduna, Nigeria. Prior to examination under an optical microscope with a high-definition photographic device for both transmitted and reflected light, we cut the samples into blocks, polished and dried.

X-ray diffractometry

The mineral composition of quartz vein samples containing gold was ascertained at the National Geosciences Research Laboratory Centre in Kaduna, Nigeria, using an X-Ray Diffractometer (XRD). 20 g of the material was crushed and subjected to X-rays of a set wavelength. X-rays were both radiated and reflected. The radiation's intensity that was reflected was then measured and documented. Fig. 3 gives a schematic diagram/flowchart illustrating the step-by-step methodology adopted in this study.

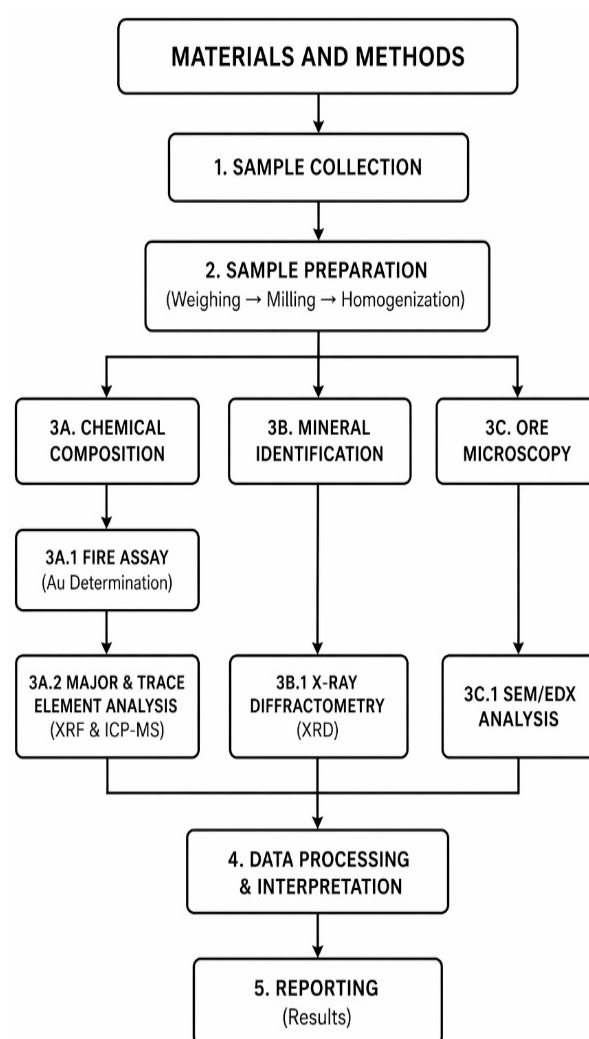


Figure 3: schematic diagram/flowchart illustrating the step-by-step methodology adopted in this study

Results and Discussion

Geology and field relationship

The study area falls between latitude 9°13'00" N to 9°22'00" N and longitude 7°00'00" E to 7°11'15" E which span an area of about 110 km^2 , geographically located along the border of Suleja Local Government

Area of Niger State (Fig. 2), Northcentral Nigeria. The study area geologically forms part of the Zungeru–Minna–Birnin Gwari Schist belt (Fig. 4) which is one of the eleven Precambrian to early Paleozoic schist belts in Nigeria as documented by Turner [12].

Structurally, the study area is located in a highly strained zone, where the country rocks are highly deformed, foliated and affected by brittle – ductile shear zones. The dominant tectonic fabric in the study area is a N–S steeply dipping phyllitic to slaty cleavage, which is mainly axial planar to tight isoclinal folds. Folding occurring during two successive phases of deformation resulted in isoclinal folds and cleavage development. In the schist belts, crenulation cleavage and kink bands are

imposed on early primary foliations, some of which are localized around plutons, and are regarded as products of forceful magmatic emplacement. The area is characterized by some rock exposures, with elevations ranging between 420 m to about 630 m above sea level. The rocks of the area include amphibolite schist, amphibolites, gneisses, migmatites and pegmatites.

Plates 1, 2 and 3 are field sample of a quartz vein and hand specimen sample of a quartz mineral, hand Specimen Samples of Amphibolite, Amphibolite Schist, Gneiss, Porphyroblastic Gneiss and field Samples of migmatites and Amphibolite.

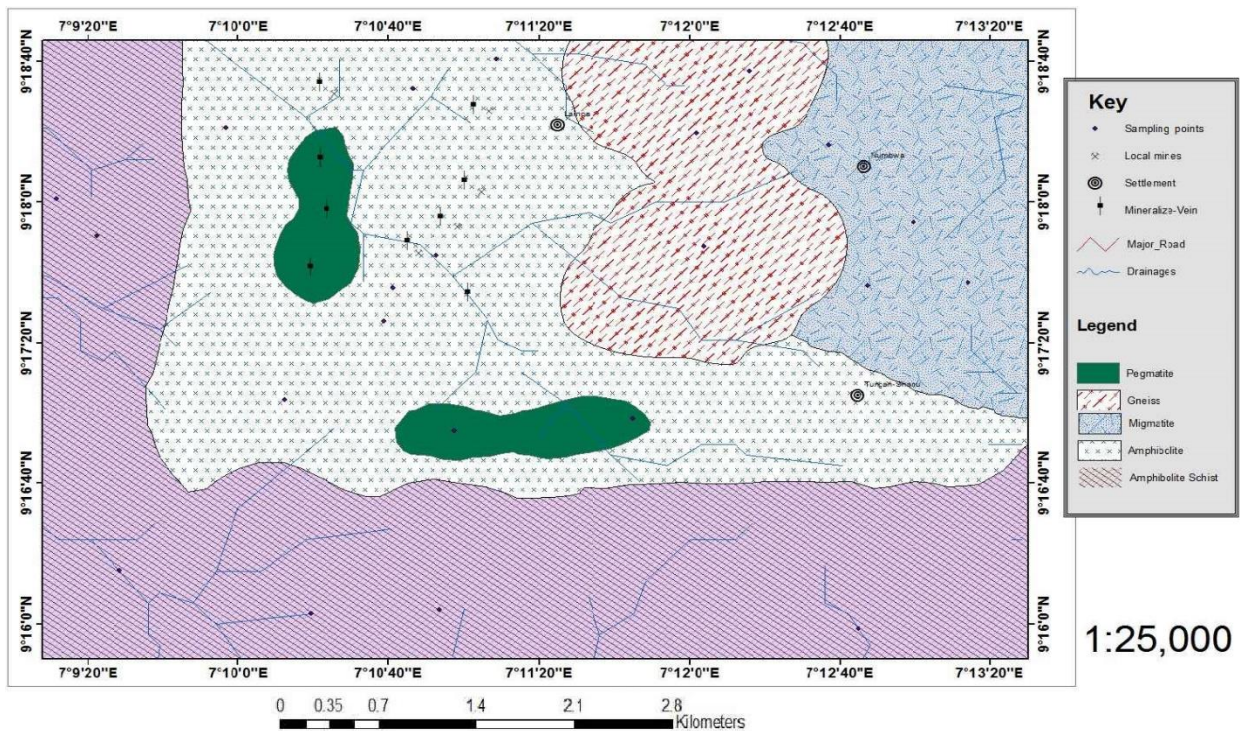


Figure 4: Geological map of the study area (Dikko and environs)

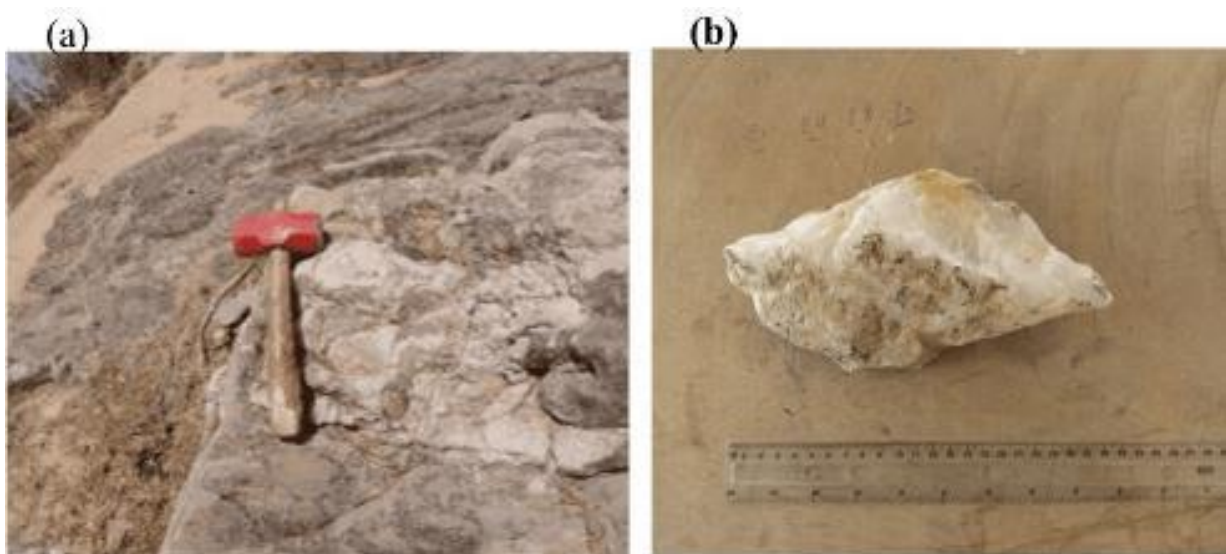


Plate 1: (a) Field sample of a quartz vein, and (b) hand specimen sample of a quartz mineral

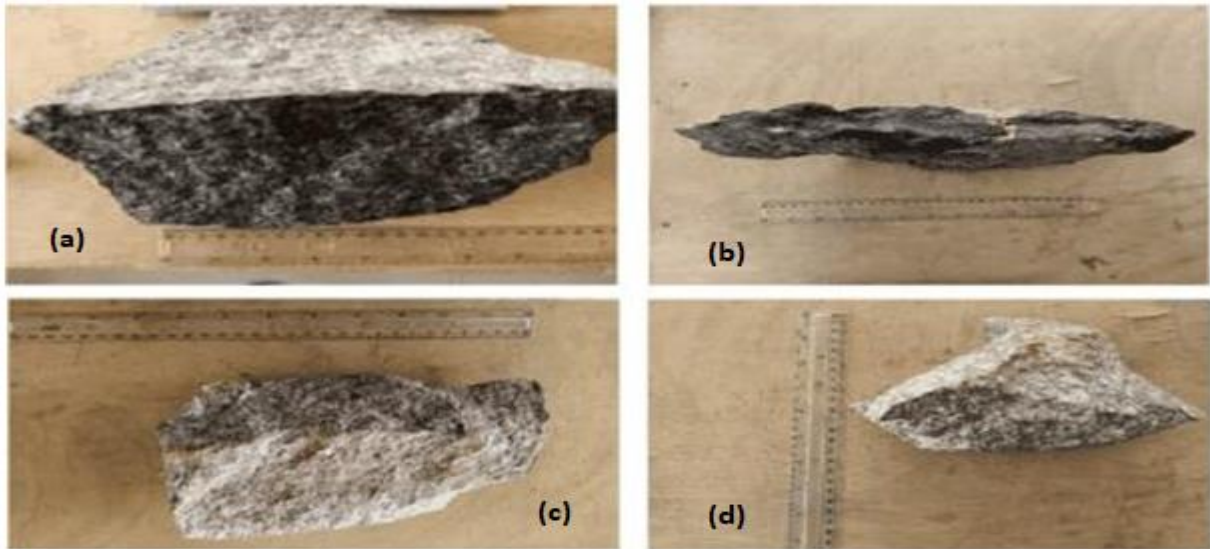


Plate 2: Hand specimen samples of (a) amphibolite, (b) amphibolite Schist, (c) gneiss, and (d) porphyroblastic gneiss

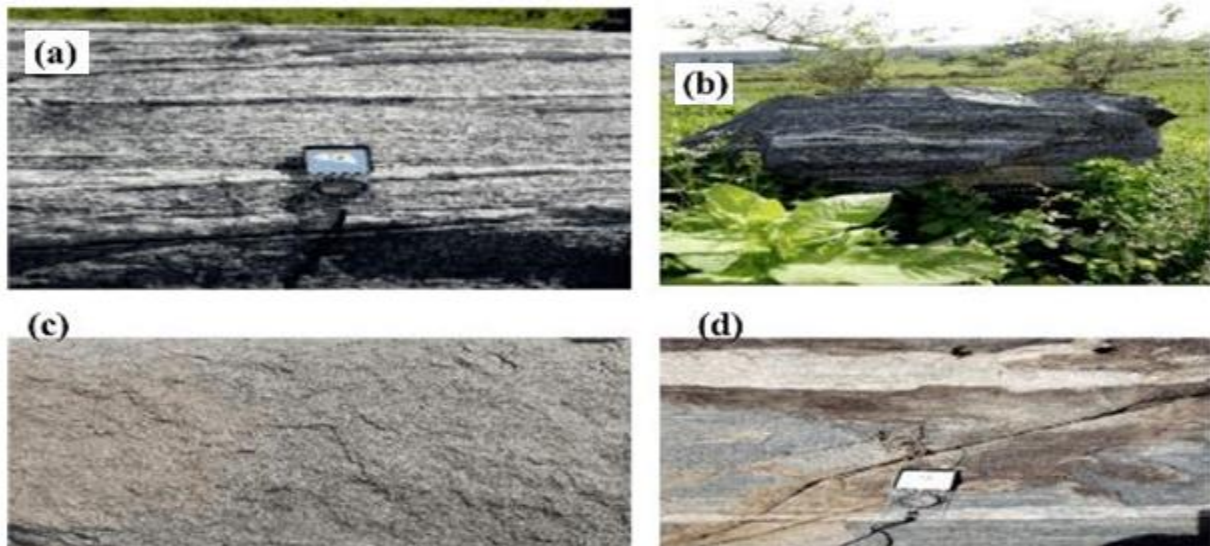


Plate 3: Field samples of migmatite (a), (b) and (d), while (c) is an amphibolite

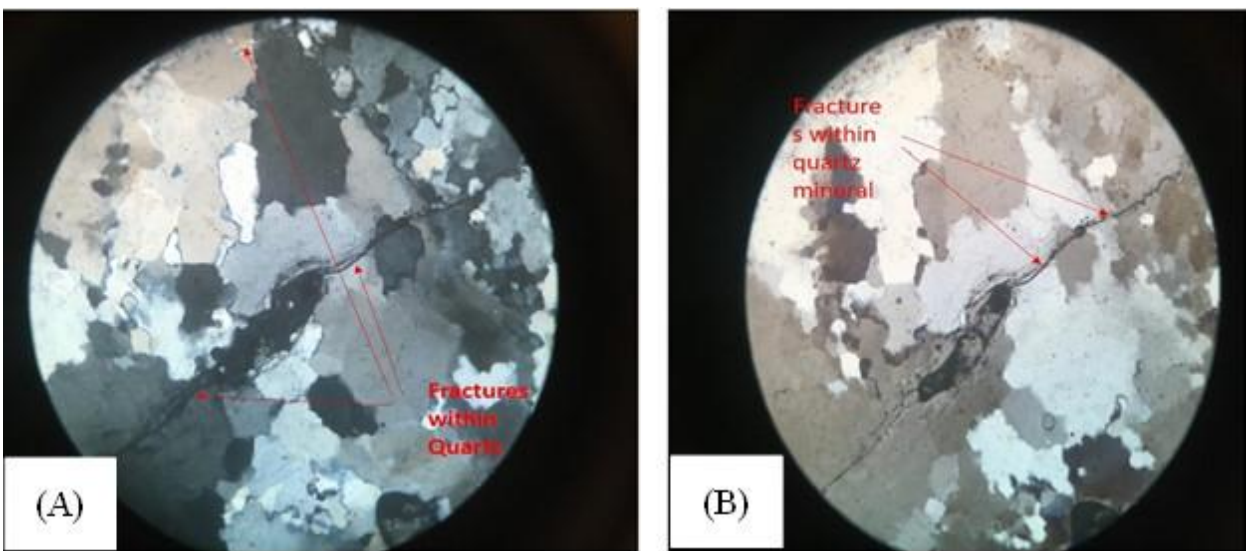


Plate 4: Photomicrographs (a & b) showing fractures or veinlets within Quartz minerals under Cross polarized

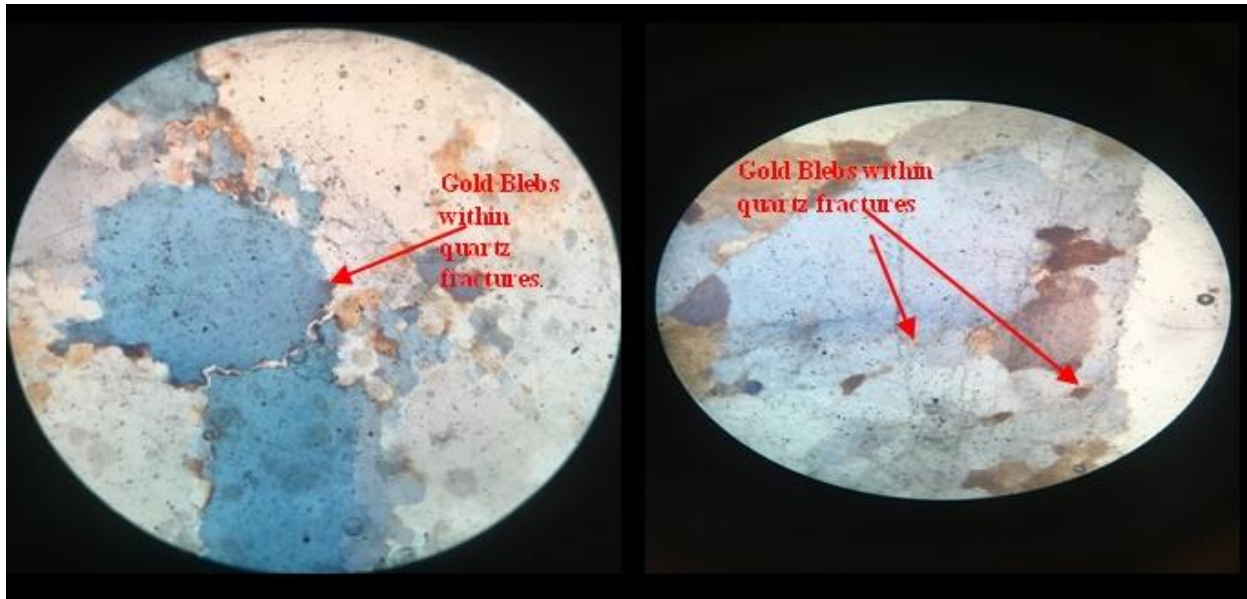


Plate 5: Photomicrograph (a & b) showing Blebs of Gold within quartz fractures/veins under cross polarized light. Mag. X100

Compositional analysis

The concentrations of the Dikko gold-bearing ore samples from the fire assay are presented in Table 1. The concentrations of Gold (Au), Copper (Cu), and Silver (Ag) are 3.9, 79 and 8.9 ppm respectively. Based on this result, it can be concluded that Dikko's gold-bearing rock ore samples have gold in them. It was found that the 3.9 ppm obtained was higher than the minimum value of 0.69-1.37 ppm prescribed for economically viable extraction [15]. Iron (Fe) is believed to be the principal element in gold ore and the result of Fe in Table 2 shows a range after conversion from 7900-33200 ppm of the gold-bearing rock sample analysis. This implies that gold occurs in ores as distinct particles among sulphide minerals, primarily pyrite and arsenopyrite [16]. Additionally, it supports the claim made by Anuar *et al.* [17] that iron can be found in a variety of hydroxide, oxide, silicate sulfate, and sulfide minerals.

Table 1: Elemental analysis of bulk assay using fire assay analysis (FAA) in ppm

Bulk Assay	Mn	Cu	Au	Ag	Pb	Zn
Concentration (ppm)	31.960	79.000	3.900	8.900	789.120	98.000

Table 2: Results of major element analysis (wt. %) of the Dikko quartz vein rock samples

Sample ID	L1	L2	L3	L4	L5	L6	L7
SiO ₂	65	72	68	79	71	69	76
Al ₂ O ₃	0.48	0.02	1.35	0.11	2.05	1.01	0.78
Fe ₂ O ₃	1.34	0.79	2.27	1.15	3.32	1.15	2.32
CaO	0.17	0.02	0.5	<0.01	1.21	0.5	0.19
MgO	0.29	<0.01	1.09	<0.01	1.76	0.3	1.01
K ₂ O	0.35	<0.01	1.18	<0.01	1.67	1.26	0.05
Na ₂ O	0.04	<0.01	0.05	<0.01	0.09	0.02	<0.01
P ₂ O ₅	349	18	1171	30	277	137	45
Mn ₂ O ₃	214	160	461	139	664	321	227
TiO ₂	0.084	<0.005	0.155	<0.005	0.231	0.08	<0.005

Table 3 gives the trace element composition (ppm) of the Dikko gold-bearing quartz vein rocks with their sample coordinates.

High concentrations of cobalt (Co) and chromium (Cr) (Table 3) indicate mantle source materials [18]. While Cr is concentrated in spinel and clinopyroxene, Co is concentrated in olivine. Similar to the Heavy Rare Earth Elements (HREE), Yttrium (Y) is a frequently incompatible element that is strongly divided into garnet and amphibole. The addition of sphene and apatite as accessories may have a substantial impact because they both concentrate Y. When K is absent in K-feldspar, Mica, or hornblende, the incompatible element Barium (Ba) and Rubidium (Rb) are substituted. The K/Ba ratio may be utilized to differentiate between these phases because Rb substitutes less frequently in hornblende than in K-feldspar and Mica. Strontium (Sr) can be used to replace K in K-feldspar and, to a lesser extent, Ca in plagioclase (but not in pyroxene). Plagioclase forms at a relatively low pressure, and it is compatible at that pressure, but it is incompatible at higher pressures when plagioclase is no longer stable. All these elements are used for petrogenetic indications [18].



Table 3: Trace element composition (ppm) of the Dikko gold-bearing quartz vein rocks with their sample coordinates

Sample ID	L1	L2	L3	L4	L5	L6	L7
Coordinates	N 9° 17' 29'' E 7° 10' 8''	N 9° 17' 46'' E 7° 10' 19''	N 9° 18' 8'' E 7° 10' 9.2''	N 9° 18' 36'' E 7° 10' 6.8''	N 9° 18' 38'' E 7° 10' 16''	9° 18' 00'' 7° 10' 14''	9° 17' 30'' 7° 10' 11''
Rb	8.2	560.6	8.1	4.7	1.4	8.3	1.6
Sr	16.7	2.8	44.2	2.6	22.5	43	22.5
Ba	61	84	82	<10	126	55	182
Be	0.18	<0.0	0.32	0.08	0.1	0.1	0.1
Co	3	0.8	9.3	1.1	18.3	0.5	1.2
Cs	2.07	0.07	7.16	0.4	2.19	2	2.15
Ga	4.68	0.28	9.52	0.96	7.05	0.75	0.45
Hf	0.15	<0.02	0.05	<0.02	0.08	<0.02	0.05
Nb	0.79	<0.05	0.3	0.14	<0.05	0.2	0.1
Ta	0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
Th	13.9	0.3	21.9	0.9	1.2	11.11	2.45
U	1.25	0.14	1.13	0.56	0.31	1	0.25
V	19	5	42	4	92	76	12
Zr	4.7	<0.5	1.4	0.6	2.2	1.2	2.2
Y	7.32	0.12	4.14	0.57	3.29	0.98	1.12
Sn	0.8	0.2	0.7	0.2	0.3	0.4	0.2
As	0.7	0.4	0.8	2.8	1.6	0.4	1.2
Au	<0.0005	3.5896	0.0052	0.0089	<0.0005	2.5555	<0.0005
Pb	8.2	560.6	8.1	4.7	1.4	4.0	8.9
Zn	26	<1	55	1	64	1	78
W	0.1	3.33	0.14	23.43	0.24	0.15	6.65
La	34.8	0.8	62.5	2.6	4.4	5.5	28.07
Ce	54.85	0.92	107.34	4.3	0.21	45.02	0.34
Cd	0.01	0.06	0.02	<0.01	0.02	0.02	0.01
Cr	22	63	58	64	117	55	65
Ga	4.68	0.28	9.52	0.96	7.05	9.23	5.05
Ge	0.1	<0.05	0.18	<0.05	0.13	<0.05	0.1
Cu	1.8	184.7	1.8	8.1	11.1	5.1	112.1
Eu	0.16	0.3	1.61	0.87	0.32	2.02	1.59
Sm	0.7	4.96	6.31	2.8	1.17	8.13	40.36
Yb	0.22	7.59	2.18	0.57	0.21	1.26	5.2
Nd	4.3	16.3	31	14.9	4.8	28.9	123.4
Pr	1.1	4.54	7.9	3.66	1.13	6.73	27.02
Lu	0.04	1.05	0.32	0.08	0.03	0.17	0.67

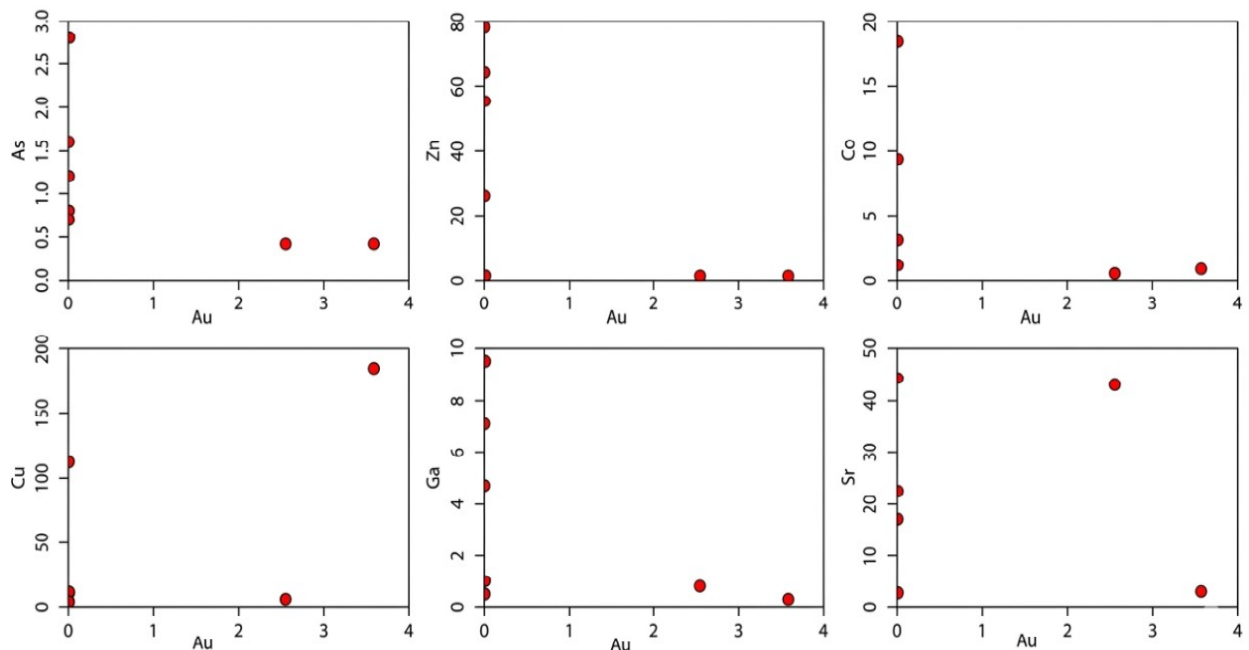


Figure. 5: Bivariate plot for mobile elements Cu, Pb, Zn, Co, Ga and Sr against Au

There is a negative to the zero-correlation coefficient ($\rho = -1$, $-1 < \rho < 0$) of the bivariate plots (Fig. 5) of the elements Sr, Zn, Co and Ga against gold (Au). For Cu and Pb against Au, the result shows a weak positive correlation coefficient and a weak negative correlation coefficient respectively. The base metals Ni, Zn, Pb, As, Cu and Ag are a chemically active metals, whereas Au is a precious metal that is chemically inactive (in most cases). Detecting buried gold mineralization in the Essase Concession, Eastern Region, Ghana, is made possible through the use of these mobile elements (As, Cu, Ni, Pb and Zn). The resultant direct proportional relationship between Au/Pb, Au/Cu portray that Pb and Cu are pathfinder elements for Au in areas (Fig. 5). The result shows here that Cu correlates positively with Au in the study area.

Figure 6, is a multi-element variation diagram [19] highlighting the average ratios of Ba/K₂O and Sr/K₂O. This shows that studied samples are well fractionated and enriched with these elements in the melt, while Rb/K₂O is less fractionated which could probably be due to the composition of Rb in some of the samples as against others. The Rb may also likely be depleted in the melt or there was no thorough mixing during the melting process. The three ratios studied appear to have the estimated average crustal composition and this ratio are ratios linked with late magmatic crystallization. The enriched compositions of K, Ba and Rb (Tables 2 & 3), gives an indication that the Dikko gold bearing ore

occurs as a product of hydrothermal crystallization within the veins of the amphibolites and veinlets of quartz crystals. The host amphibolite has probably been hydrothermally altered and this characteristic indicate that the Dikko gold bearing rock ore is a typical mesothermal gold deposit [20, 21].

Figure 7, is a chondrite-normalized plot of rare earth elements of seven quartz vein samples. The rare earth elements pattern showcases high values of LREE i.e., Lanthanum (La), Cerium (Ce), and Praseodymium (Pr) with a corresponding lower value of HREE i.e., Erbium (Er), Thulium (Tm), Ytterbium (Yb), and Lutetium (Lu). The samples depict strong enrichment of LREE (Lanthanum (La) – Samarium (Sm)) in the melt with a depletion of HREE (Gadolinium (Gd) - Lutetium (Lu)), a negative Eu anomaly and corresponding positive Gd and Y signatures. This gives a strong LREE/HREE fractionation pattern with (La/Yb). The negative Eu anomaly suggests that during the partial melting, Europium (Eu²⁺) has been removed from our samples either by plagioclase remaining in the source (residuum) or that some plagioclase has crystallized. So, in a reduced system, then, (Eu²⁺) has been compatible in plagioclase. Either some plagioclase in the source has not been melted and has retained the europium or during transit between the mantle and the crust, our magma has crystallized some plagioclase and thus, remove some of the Europium.

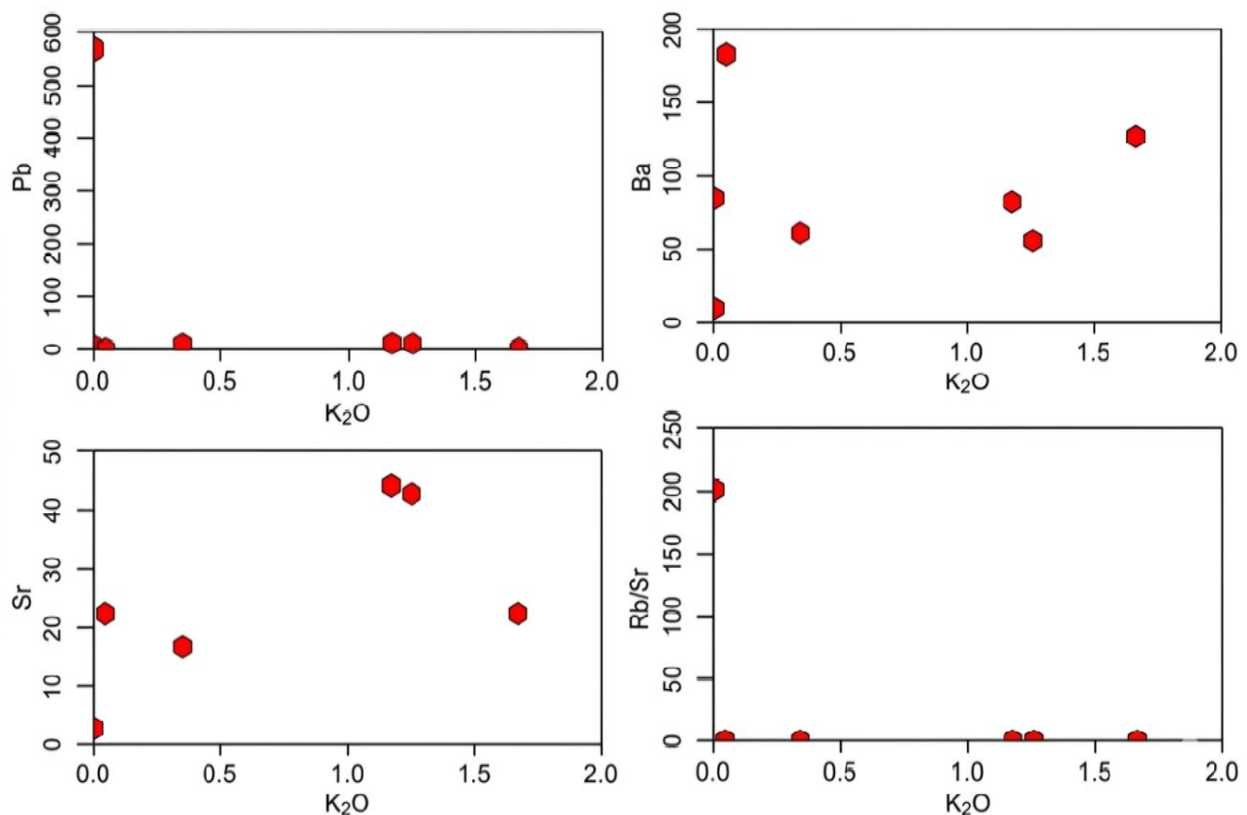


Figure 6: Multi-element variation diagram [19]

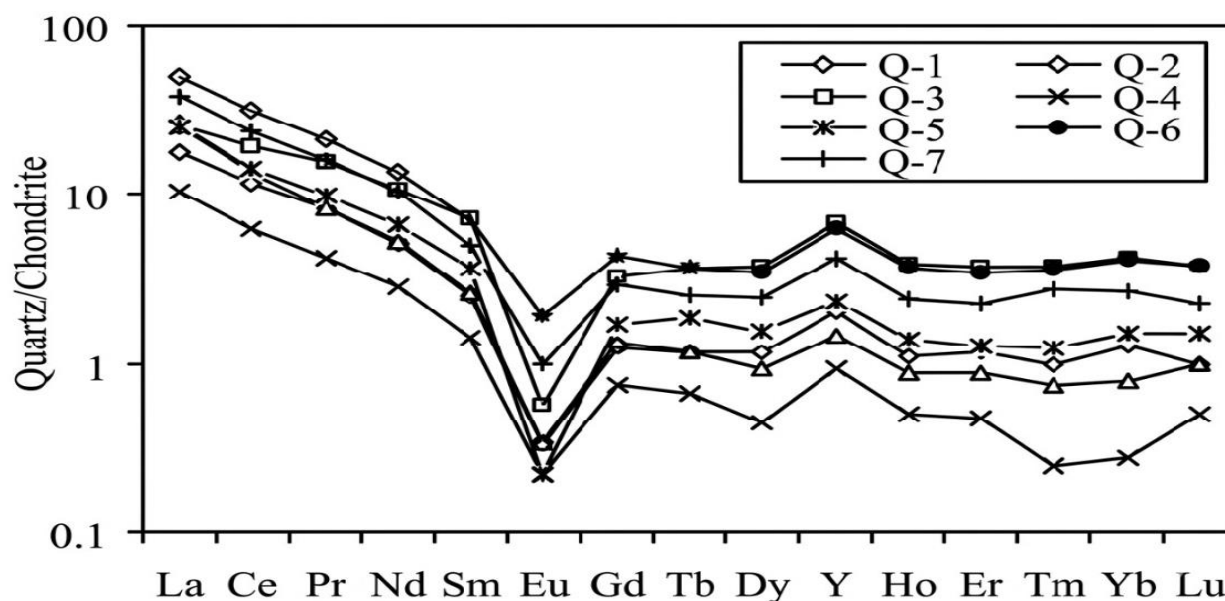


Figure. 7: Chondrite normalized plot for the seven quartz vein samples (the chondrite values are from McDonough and Sun [22])

Trace elements anomalies versus gold mineralization of the Dikko area

Fluid source and evolution, alteration zoning and exploration takeaway

From the four scatter plots (Fig. 6), showing Pb vs K_2O , Ba vs K_2O , Sr vs K_2O , and Rb/Sr vs K_2O for the Dikko area, observations and interpretation highlights include;

- Pb vs K_2O :** Pb shows extremely high values at very low K_2O and near-zero elsewhere. This could suggest that Pb enrichment is not directly tied to potassic alteration, or the highest Pb content at low K_2O may indicate association with sulfide mineralization in less-altered host rocks (possibly in feldspar-poor lithologies). Also, Pb is often linked with galena and may occur with gold in late-stage hydrothermal veins. This may mark structural trap zones rather than widespread alteration halos.
- Ba vs K_2O :** Ba concentrations increase moderately with K_2O , though there's also a high-Ba point at low K_2O . This could suggest also that Ba often substitutes into K-feldspar or occurs as barite ($BaSO_4$) in hydrothermal systems, or that the positive association with K_2O hints at potassic alteration phases where Ba is incorporated into feldspars or co-deposited with quartz-K-feldspar veins, or that the high Ba at low K_2O could represent barite mineralization independent of feldspar alteration possibly linked to sulphate-rich hydrothermal fluids.
- Sr vs K_2O :** There is a moderate positive correlation here. Sr highest in moderately K_2O -rich samples. Sr can be hosted in plagioclase and K-feldspar but is mobile during hydrothermal alteration. The trend suggests Sr enrichment during early to intermediate hydrothermal alteration, possibly from feldspar breakdown and re-precipitation. In gold systems, Sr

anomalies often accompany Ba and K in wall rock Halos.

- Rb/Sr vs K_2O :** Extremely high Rb/Sr at low K_2O , very low elsewhere. This suggest that Rb/Sr ratios are a strong alteration index. High values often mean intense K-metasomatism (Rb-rich) or severe Sr leaching. Here, the highest ratios at low K_2O could indicate Rb-enrichment unrelated to bulk K_2O content, possibly due to selective Rb incorporation in sericite/muscovite during phyllic alteration. This pattern may reflect fluid-rock interaction along fractures before extensive potassic alteration developed.

The decoupling between Pb, Ba, and Sr from bulk K_2O suggests multiple fluid pulses. Pb-rich fluids are possibly late-stage, sulfide-dominated, and structurally controlled. Ba-Sr-rich fluids are associated with feldspar alteration and possibly barite precipitation and Rb-enrichment are linked to phyllic alteration zones, potential gold halo indicators. The data hint at alteration zonation from phyllic (high Rb/Sr) to potassic (high Ba, Sr with K_2O) to sulfide-rich zones (high Pb, low K_2O). For targeted exploration, high Pb at low K_2O could pinpoint vein margins or structurally controlled ore shoots. Moderate Ba and Sr with elevated K_2O may highlight the main alteration envelopes around quartz-gold veins. Also, high Rb/Sr spikes should be checked for proximity to gold anomalies which can occur in sericitized halos.

To link these plots directly to targeting, Fig. 8 is a composite geochemical interpretation map overlaying these anomalies on the Dikko structural geology, so we can visually see where Pb, Ba, Sr, and Rb/Sr align with known gold occurrences.

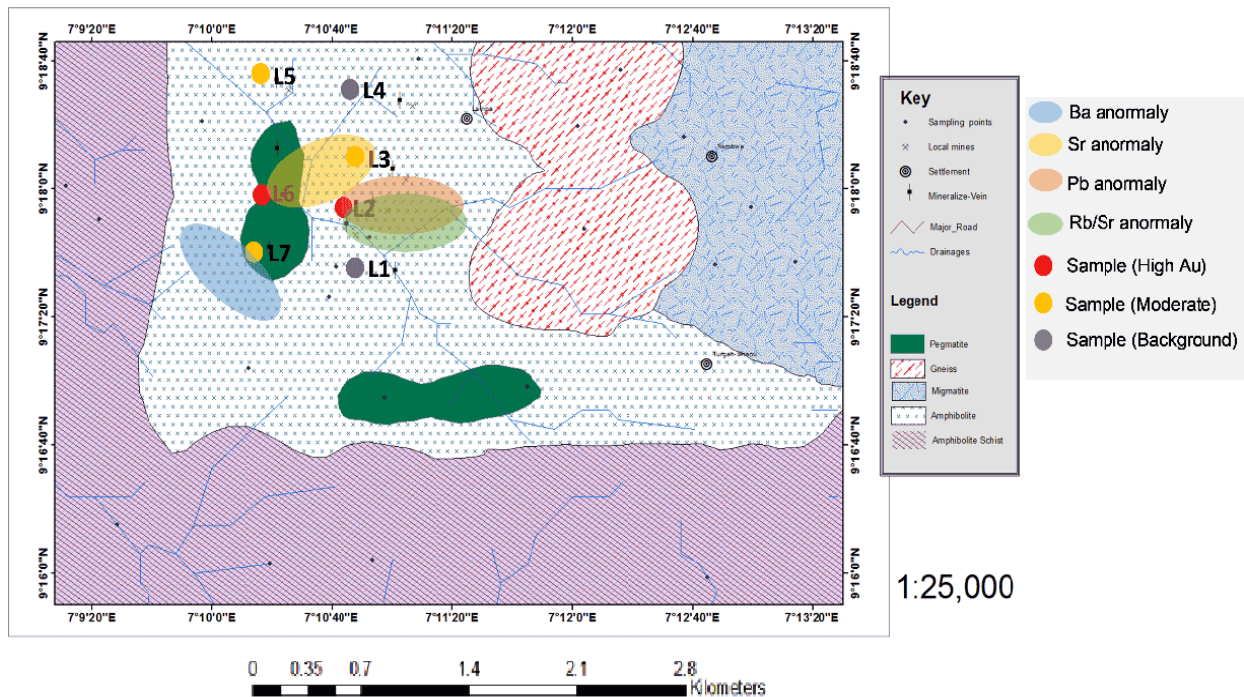


Figure 8: Composite geochemical overlay map of the Dikko structural geology

Integrating the geochemical patterns from the anomaly maps with the regional geology and gold mineralization models for the Dikko area, suggestions are;

- a) **Lead (Pb) anomalies:** Observations are that Pb is extremely high at L2 (560.6 ppm) compared to all other locations (mostly <10 ppm). Such a sharp Pb peak suggests a localized sulfide-rich zone, likely containing galena (PbS) in quartz veins or brecciated structures. This could also suggest a late-stage hydrothermal pulse with Pb-rich fluids or its isolation from high K₂O areas, suggesting Pb enrichment is not directly linked to potassic alteration but to structural traps (fault intersections, vein terminations). L2 also has very high Au (3.59 ppm), suggesting Pb–Au association, typical of mesothermal lode systems where Pb-rich phases precipitate alongside native gold during cooling.
- b) **Barium (Ba) anomalies:** Ba is highest at L7 (182 ppm) and also high at L5 (126 ppm), moderate at L2–L3. Ba can occur in K-feldspar or as barite (BaSO₄). The association with K₂O (in previous plots) suggests part of the Ba may be linked to potassic alteration zones. High Ba at L7 with moderate Au (< detection limit) might represent alteration halo zones peripheral to gold veins. Ba enrichment is often seen in alteration zones surrounding gold mineralization. This may be used as a vectoring tool towards ore zones.

- c) **Strontium (Sr) anomalies:** Sr peaks at L3 (44.2 ppm) and L6 (43 ppm), moderate at L5 and L7. Sr often substitutes for Ca in plagioclase and is mobile during hydrothermal alteration. Elevated Sr in L3 and L6 could indicate feldspar breakdown and re-precipitation during hydrothermal activity. Its scattered distribution suggests multiple fluid pulses affecting different lithologies. Sr can be enriched in the wall rock halos around Au-bearing veins especially in intermediate alteration zones.
- d) **Rb/Sr ratio:** Highest at L2 (200+) due to extreme Rb enrichment and Sr depletion; low to moderate elsewhere. High Rb/Sr ratios are a strong indicator of intense K-metasomatism (Rb-rich mica, sericite) or strong Sr leaching. At L2, this points to phyllic alteration in a high-temperature fluid pathway. In mesothermal gold systems, high Rb/Sr zones often overlap with high gold grades. Again, matching L2's Au anomaly.

Microscopy and mineralogical assemblage of the Dikko gold-bearing quartz veins

Ore microscopy

The result of the ore microscopy obtained for the Dikko gold-bearing ore; shows that the gold grain is embedded within quartz crystals of the amphibolites (Plate 6a & b).

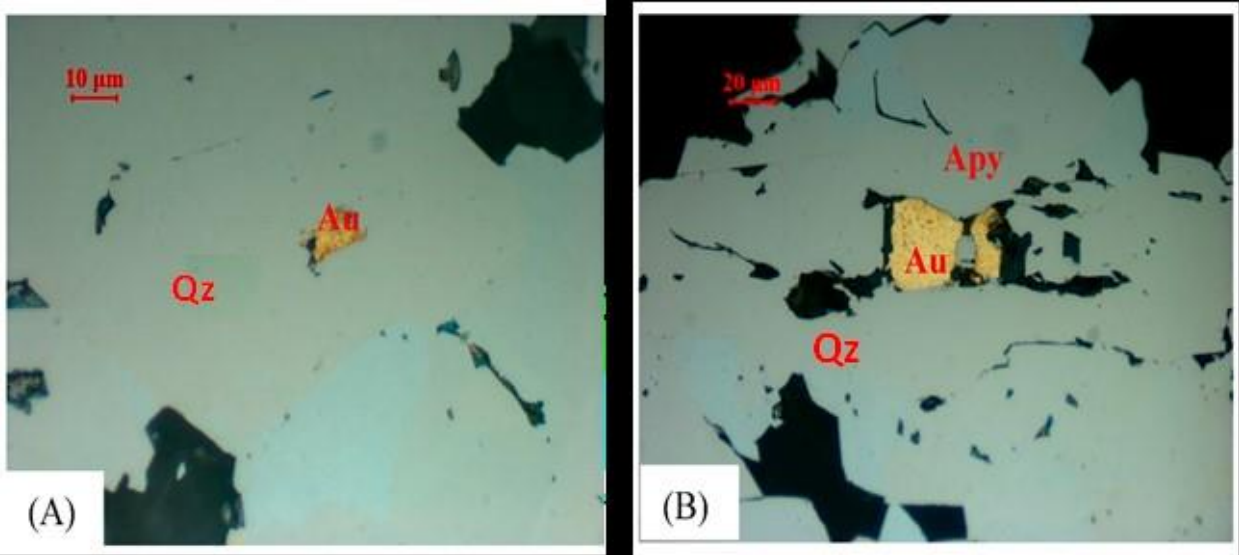


Plate 6(a & b): Photomicrographs (a & b) of gold grains embedded within quartz

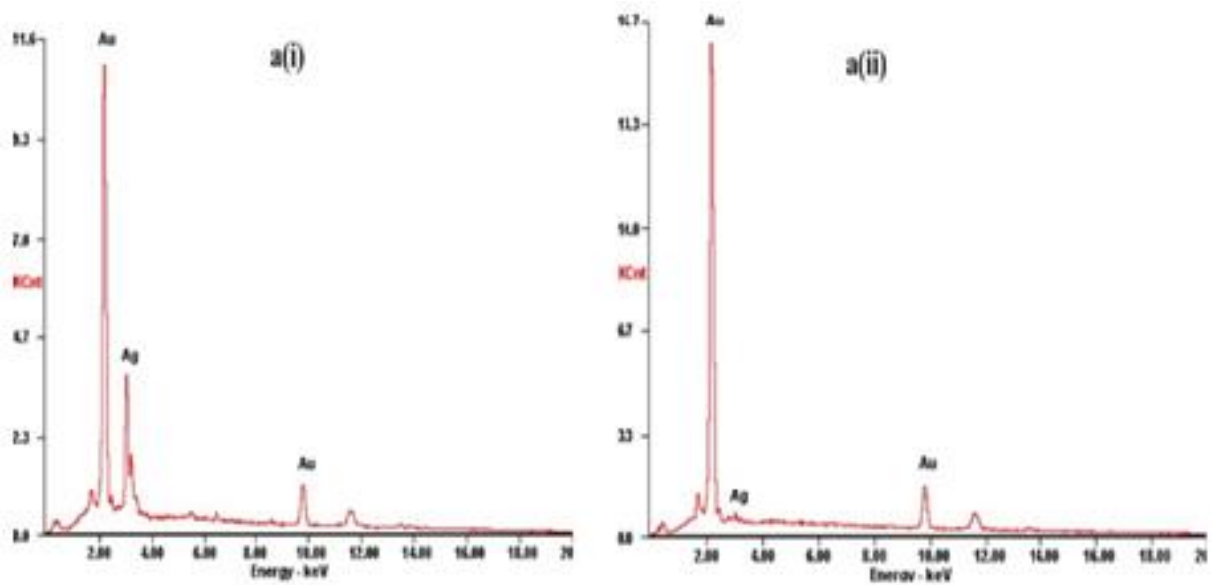


Figure 9: [a (i) and (ii)]: Diffractogram showing gold peak,

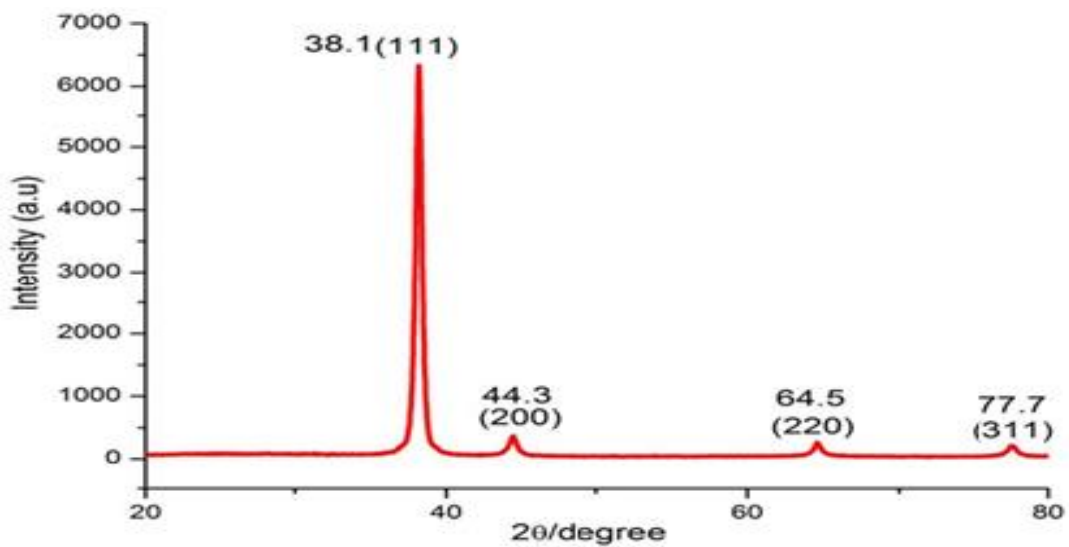


Figure 9: [b] Diffractogram showing intensities of gold

X-ray diffraction

The gold in the Dikko area is associated with arsenopyrite and quartz minerals as seen in Plate 6. The diffractograms (Fig. 9a) shows Ag in association with Au and (Fig. 9b) the four peaks that are characteristics of the intensity of gold, namely at 2 θ : 38.1, 44.3, 64.5, 77.7. This diffraction pattern describes the crystalline pattern and the crystallinity of a gold mineral.

Conclusion

The chemical and mineralogical characteristics studied here illustrate that Dikko gold-bearing rock ore samples have a significant gold content of 3.9 ppm, which is economical. Petrogenetic element indicators provided from this study give a mantle source origin. These results demonstrate that Cu correlates strongly with the Au of the studied area. Pb and Cu are pointer elements for Au. The integrated spatial interpretation showed that L2 stands out as the primary mineralized center, with very high Au (3.59 ppm), extremely high Pb, very high Rb/Sr and moderate Ba concentrations.

The Dikko gold-bearing ore is a distinctive mesothermal gold deposit that is formed as a hydrothermal mineralization. The pattern fits a mesothermal/orogenic gold model common in the Pan-African basement of North Central Nigeria with Gold-bearing fluids that ascend along N–S or NE–SW shear zones. The ore microscopy indicates that the gold grain is embedded within quartz crystals of the amphibolites, which is also associated with arsenopyrite and quartz minerals. Gold is also associated with silver (Ag) in the Dikko area.

Exploration strategy should be a focused detailed mapping, trenching, and drilling around L2. Extend soil/rock geochemistry grids between L2–L5–L7 to track alteration trends and conducting structural analysis to map the controlling shear zone.

Conflict of interest: The authors declare that there is no conflict of interest.

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