Field Characteristics of Quartz Vein-Type Gold Deposits in Part of Kushaka Schist Belt, North Central Nigeria

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Abstract

Gold deposits within the Kushaka schist belt of North-Central Nigeria are hosted within the meta-sedimentary basement rocks known as the schist. These meta-sediments have been largely intruded by the granitic plutons of Pan-African origin. Hydrothermal processes are believed to be largely responsible for the gold mineralization because the presence of lineament structures that extending from the granite outcrops and terminating in the schist. More so, faults, splayed veins, foliations and fractures hosted within the meta-sedimentary host rocks provided the needed pathway for fluid movement. The aeromagnetic data obtained from the Nigerian Geological Survey Agency (NGSA) on Minna Sheet 164 as part of the Nigeria-wide geological survey data carried out in 2007 was used alongside the Oasis Montaj and ArcGIS software. The aeromagnetic data was obtained using a proton precession magnetometer with a resolution of 0.01nT. The magnetic data was important for the structural mapping and the delineation of magnetic anomaly. One of the magnetic lineaments was found to be one of the veins being currently worked for gold. A total of 18 overburden soil samples were panned for gold along 10 pits at a weight of 2.5Kg each. A positive correlation was found between vein splays and the presence of gold in the overburden soil. Two classes of quartz veins were identified from the study. They are the foliated (mineralized) and the un-foliated or massive quartz veins. The quartz veins that have no structural elements were observed to be barren and un-mineralized. The pattern of gold mineralization was found in the areas that are fractured, vug filling types, vein splays, wall-rock alteration zones and dissemination in the overburden soil. The geochemical analysis of the soil concentrates, wall rock alteration and quartz veins are subjects of further research that are currently ongoing.

Keywords: Gold deposits, Kushaka schist belt, hydrothermal process, fractured quartz, aeromagnetic anomaly.

1. Introduction

Several works have been done in Nigeria that deal with gold mineralisation (Garba, 1992, Garba, 2003 and Kankara and Darma, 2010). Majority of the gold deposits are primarily found in metamorphosed rocks (schist) as deposits of epithermal origin or as orogenic deposits. Others are found as either alluvial or eluvial deposits. Quartz veins and systems of quartz veins in regions that have undergone poly-phase deformation or multiple deformations provide the primary source of gold mineralization (primary gold deposits) (Yannah *et al.*, 2015). This multiple deformation occurs in levels or stages. As the hot hydrothermal fluids from depth move into the structures that were formed in the host rocks as a result of the deformation and fill the favourable structures within the host rock, materials begin to precipitate and different types of mineralization may occur such as lodes, vein type deposits possessing varying characteristics (Catheline *et al.,* 1991).

Any quartz vein system is often characterized by a set of properties and it is these characteristics that enable exploration geologists to determine their economic importance (whether they are mineralized or un-mineralized). This study of the field characteristics of the mineralized zones is important for the fact that a repeated pattern can be observed from multiple cases of mineralization in similar geologic environment.

The important field characteristics that are relevant to this research include textural characteristics (mineralized and un-mineralized), structural characteristics, wall rock alteration and overburden soil characteristics. Wall rock alteration have a strong relationship with the hydrothermal processes (Kreuzer, 2006 and Vallance *et al.,* 2004). The amount of alteration obtained at any point is often proportional to the size of the veins or veinlets (Harraz *et al.,* 1992). This results in a wider alteration envelope where the veins are thicker and smaller alteration zones where the veins are thin. This paper is a documentation of the observed field of the mineralized quartz vein in part of Kushaka schist belt, North Central Nigeria.

2. Location and Regional Geology of the Study Area

The study area is within the Minna-Kushaka schist belt of Nigeria and located between latitudes 09° 36' 30" to 09° 36' 46.6"N and longitudes 006° 34' 35" to 006° 34' 50" in Niger State, Nigeria Figure 1).

The schist belts of the Nigeria are characterized by their distinctive, structural, petrological and metallogenic features (Elueze *et al.,* 2015). These belts principally occupy a North-South trending trough and are very common in the regions around western Nigeria (Oyawoye, 1972); important schist belts are also found in North-Central Nigeria.

Within the Minna sheet, three belts are occupied by medium-low grade meta-sedimentary and volcanic rocks (Ajibade and Wright, 1988). Each of the belts is considered as formations and named as such. They are the Birnin-Gwari, Kushaka and Ushami schist formations.

The Kushaka schist formation has received little attention until recent times and it is the activities of the artisanal gold miners that stimulated recent research interests (Ako *et al.,* 2013)

The formations of the schist belts characteristically form prominent strike ridges but the exposure of the rock formations to the surface is poor. The formations are also deeply weathered and large granitic rock bodies have intruded into the schists (Ajibade and Wright, 1988).

The area consists of rocks such as the meta-sedimentary rocks and meta-igneous rocks that have been subjected to the processes of deformation and metamorphism. These lithologies have been intruded by the Pan-African granitic rocks (Alabi, 2011).

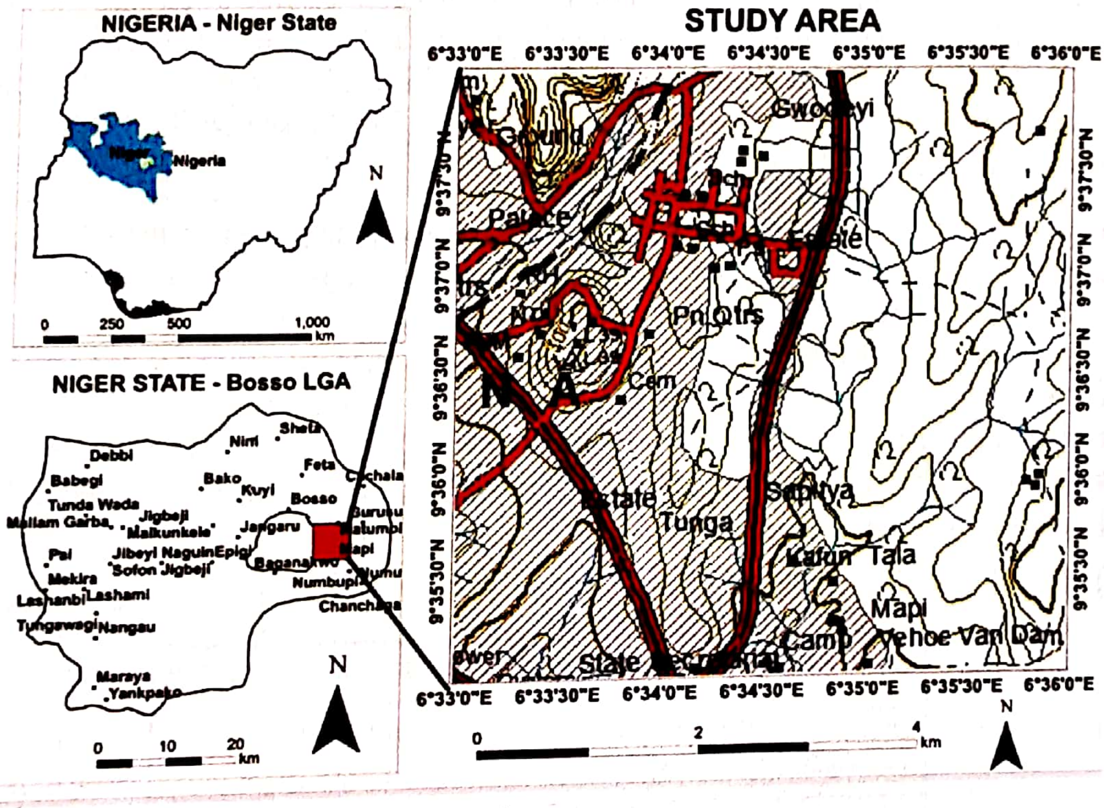

Figure 1: Map of Nigeria Showing the Study Area

3. Materials and Methods

This investigation was carried out at a site made up of mining pits excavated by artisanal miners within the area. The aeromagnetic data obtained from the Nigerian Geological Survey Agency NGSA on Minna Sheet 164 as part of the Nigeria-wide geological survey data carried out in 2007 was used. The aeromagnetic data was obtained using a proton precession magnetometer with a resolution of 0.01 nT. The airborne geophysical work was carried out by Fugro Airborne Surveys Limited, Canada. The data was obtained along a series of NE-SW tie-lines direction with a flight line spacing of 500 m and terrain clearance of 80 m. The average magnetic inclination and declination across the survey is -6.73° and -1.88° respectively. Other survey and equipment specifications are shown in Table 1.

The micro-levelled magnetic data covering the sheet (study area) was windowed out using the vertices coordinates in Oasis Montaj software. For the purposes of data presentation and interpretation the total field magnetic data is gridded using the minimum curvature gridding method (Briggs, 1974) with a cell size of 150 m, which represents about one quarter of the 500 m average line spacing. The total magnetic intensity field was International Geomagnetic Reference Field, (IGRF, 2009) corrected and super-regional field of 32000 nT was deducted from the raw data. A 3 x 3 convolution filter was passed over to the final grid to smoothen the grid image. This data was required for the enhancement and general understanding of the regional geology of the area. In this regard, the data was used to map contacts and structural features within the study area and improved definition of the potential of known zones of mineralization, their geological settings, and identifying new areas of interest.

The veins trend in a NE-SW direction and is concordant with the strike of the schist host rock along its foliation plane. Some of the mining pits were also randomly excavated at other places to intersect suspected cross cutting vein systems in the area under study. The characteristics of the mining pits such as the length, the breadth and the depth are often determined by the size and other structural characteristics of the quartz vein intrusion such as the angle of dip and the depth to which it extends. In some pits, where the quartz veins are favourably structured for gold mineralization, the veins have been completely removed or excavated and some have been abandoned while others are being worked or reworked.

Table 1: Specifications for the Acquisition of Aeromagnetic Data for the Exploration Area

SURVEY SPECIFICATIONS	
Magnetic Data Recording interval	0.05 seconds
Radiometric Data Recording interval	1 second
Sensor Mean Terain Clearance	80 meters
Flight Line Spacing	500 meters
Flight Line Spacing (Infil)	250 meters
Tie Line Spacing	5000 meters
Tie Line Spacing(infil)	2500 meters
Flight Line Trend	135 degrees
Tie Line Trend	225 degrees
EQUIPMENT SPECIFICATIONS	
Manetomete3 x Scintrex CS2 Cesium Vapour	3 x Scintrex CS2 Cesium Vapour
Data Acquisition System	FASDAS
Magnetic Counter	FASDAS MAG FPGA
Radar Altimeter	KING KR405B
Barometric Altimeter	DIGIQUARTZ
Radiometric Crystal Volume-Up	2048 cu inch
Radiometric Crystal Volume-Down	512 cu inch
Radiometric Crystals	GPX 1024/256
Radiometric Data acquisition	GR 820-3
NAVIGATION SPECIFICATIONS	
Flight Path track	Digital
Flight Path Navigation	Novatel 3151 R/Omnister RTDGPS
Flight Path Recovery	Digital
Flight Path Processing	Real Time Defferential GPS
PLOTTING SPECIFICATIONS	
Projection	Universal Transverse Mercator
Spheroid	WGS 1984
Central Meridian	9 Degree East
Central Scaling Factor	0.9996
Datum	WGS 1984
X Bias	500 000 Meters
Y Bias	0 Meters
Grid Mesh Size	125 Meters
Aircraft Supplied by	FUGRO Airborne Surveys
Aircraft	Cessna Caravan 208B ZS-SSB & PR-FAS
Data Acquisition by	FUGRO Airborne Surveys
Data Processing by	FUGRO Airborne Surveys

The pits were excavated along a large quartz vein intrusion in a basement schist host rock. The measured properties of the pits were the lengths which ranged from lengths of about 1.23

meters to about 4 meters, and the breadth ranged from 0.76 meters to about 4.5 meters and depths of about 10 meters were also recorded.

The main geologic features that formed the area of interest for this research are the quartz vein intrusion and the weathered alteration zones. The overburden soil materials were also studied on the field the data were also logged during the process of characterizing the pits. The soil profile for each pit was identified and logged if it has not been disturbed or destroyed. It is logged using colour, thickness and grain sizes. The samples were collected systematically using the channel chip sampling method. A 4-litre plastic container was used to collect an average of 2.5 kilogrammes of soil samples for each horizon in each of the pits was panned for gold. No geochemical tests were carried out on the soil samples. The samples were only collected for their availability and for reference purposes in further researches. In each pit, the geologic features of interest are treated accordingly so that in each domain, the quartz veins are characterized based on colour, texture, structure, colour, dimension and orientation of other structural elements such as the foliations in the veins and their mineralogy. The data collected from the pits were logged systematically and plotted on a linked graph sheet. Thirty five (35) samples were collected in total and eighteen (18) of these samples are made up of soil overburden and each weighed about 2.5 kilogrammes and 0.004 m^3 in volume, ten (10) samples from the quartz vein, five (5) samples from the alteration envelopes, three (3) samples constituted the schist host rock and two others from the granitic intrusions within the area were used for the petrographic analysis.

The method that was adopted in order to achieve the set objectives includes a phase system that is common to most geosciences research which is field mapping.

During field mapping, a compass/clinometer was used for the collection of structural data such as the strike and dip of rock outcrops, joints values and directions and other structural. Global positioning system (GPS) was used to take bearings and accurate positions where measurements were taken in the field.

The overburden soil profile samples that were lumpy and coarse may not readily yield gold grains and the gold grains may remain trapped within the uncrushed soil. All the overburden soil samples were therefore crushed using mortar and pestle. Sensitive measuring scales were also utilized within the laboratory to make accurate measurements of the recovered gold grains and other samples.

For each trench, a certain number of samples were taken depending on the available sampling media. In some of the trenches, the original soil profile has been disturbed and therefore taking samples from these zones will not be able to provide accurate data for research. The target sampling media include the wall-rock alteration, the quartz vein, alteration selvages and the overburden materials for all the soil horizons present in each pit where they are undisturbed. The samples that were taken from the field are from the alteration zones which represent one of the primary targets for this research. Different soil horizon samples were also taken, and these were all treated individually giving regards to individual horizon thickness and grain size distribution.

The quartz veins were sampled by cutting or chipping off representative samples using a geologic hammer in each of the trench and then they are wrapped separately in a sample bag and labelled correctly with the trench number. The wall-rock alteration samples were collected from either side of the quartz vein intrusion to the required volume and weight and thoroughly mixed to ensure the homogeneity of the samples collected. The required weight and volume of the samples for the purpose of this research are at least 2-3kg for the soil samples, 2-3 kg for the wall rock alteration samples and at least 1-2kg for the quartz vein samples.

The overburden samples were taken from the different soil horizons within each pit using the channel chip sampling method along the length and breadth of the trenches so as to get samples that are representative of each trench. Details of this field method are contained in the work of Vishiti *et al.* (2015).

4. Results and Discussions

4.1 Field Observations

The field mapping shows that the study area is composed of three main rock types as shown in the geologic map in Figure 2. These rocks are the schists, intrusive granites and the migmatites. The schists have been weathered but the structures have been preserved. The schist has been intruded by the rocks of granite composition and the intrusions are believed to have driven the hydrothermal system that resulted in the mineralization of gold. The quartz veins intrude into the schist formation and run parallel to the NE-SW trend of the host schist. In other areas as well, the quartz intrusion has split up in many individual veinlets to form a horsetail structure and these areas are highly mineralized with gold representing one of the targets for the miners so that the number of samples taken from each pit or trench was controlled by the presence of the sampling media.

The quartz veins found in the study area occur within a foliated basement rock (schist) and they vary in their orientations. The orientations are strongly controlled by the strong foliation within the schist. Within pit 1, the evidence of a cross cutting quartz vein was observed. The early formed veins are associated with the first phase of deformation called D1 while the late formed veins are associated with the post deformation processes are called D2. The main quartz vein currently being explored for gold is associated with the second phase of the deformation which is due to the emplacement of the rocks of granitic composition within the schist and the vein strike in a NW-SE direction dipping at an angle range between 45° to 90° E. The late formed quartz veins associated with the D2 intersects and crosscut the early formed veins at an angle of 90° and strike in a NE-SW direction dipping at angle of 45° SE.

The cross-cutting vein is an indicator of more than one episode of vein intrusion and deformation of the host rock within the study area. The cross-cutting vein have a relatively shallower angle o dip between 30 - 45° SE while the early formed veins are characterized by a relatively steeper angle of dips ranging between 45 -90 ° E.

The quartz veins occur as an intrusions and strike in the same direction as the strike of the host rock. They also occur as cross cutting intrusions that are discordant to the strike of the host rock. The concordant vein are characterized by very high angles of dip ranging between 45° to 90° while the cross cutting or discordant veins occur at 90° to the strike of the host rock (schist) and the discordant veins and are characterized by low angles of dip ranging from 30° to 45°.

The veins show large variation in their thicknesses and exhibit sharp contacts with the alteration zone with steep angle of dip and are found to be standing almost vertical at some point (pits). In some of the pits, the quartz veins are highly weathered and fragmented. Mining pits have been excavated along the direction of strike of the veins. The veins are not continuous in outline but are characterized by splay structures and horsetail structures where the veins split into several systems of veins similar to the tail of a horse and continue again as one vein. The veins are banded and foliated and are characterized by brittle structures like fractures and joints (Figure 3)

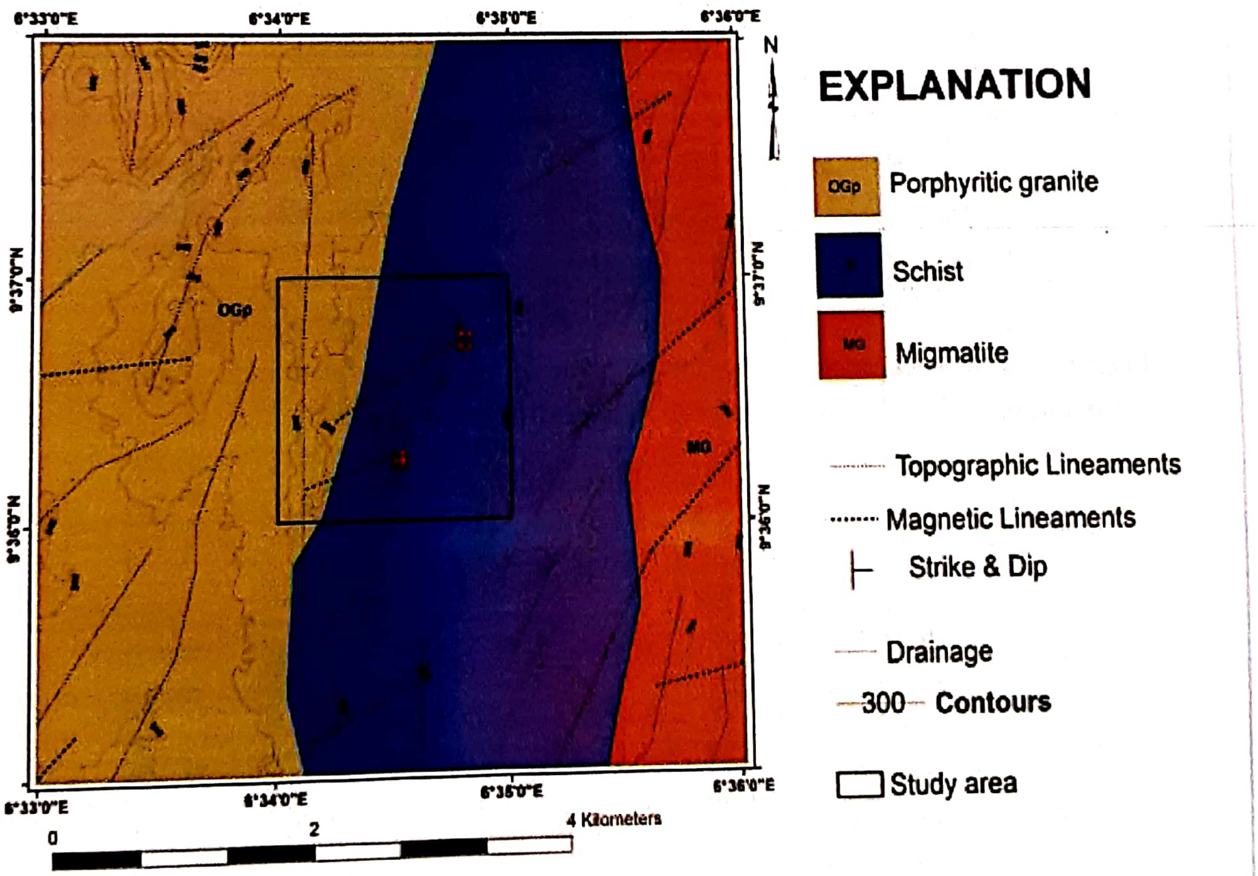

Figure 2: Structural Map of the Study Area Super-imposed on the Geological Map

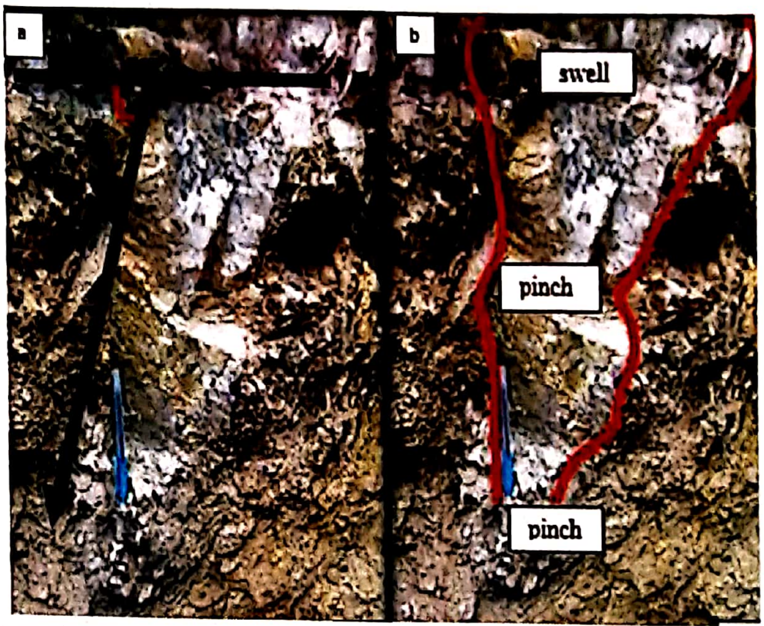

Figure 4: **(a)** Foliated quartz vein with the plane of foliation perpendicular to the strike of the vein **(b)** Fractures within the quartz veins with pinch and swell structure.

The structured quartz veins are characterized by the banding or foliation of differently coloured layers and tend to be more mineralized than the massive veins while the massive veins have no distinctive structures and are mainly barren. Textural zoning was observed with the alternation of dark, smoky, pink coloured quartz and the darker seams of hematite (Yannah *et al.*, 2015) the banding and foliation in the veins occur parallel to the strike of the vein. Some observed characteristics in the quartz vein are either associated with mineralization or not and a simple method proposed by Yannah *et al.*, (2015) have also been used in classifying the different morphologies observed in the quartz veins (Figure5).

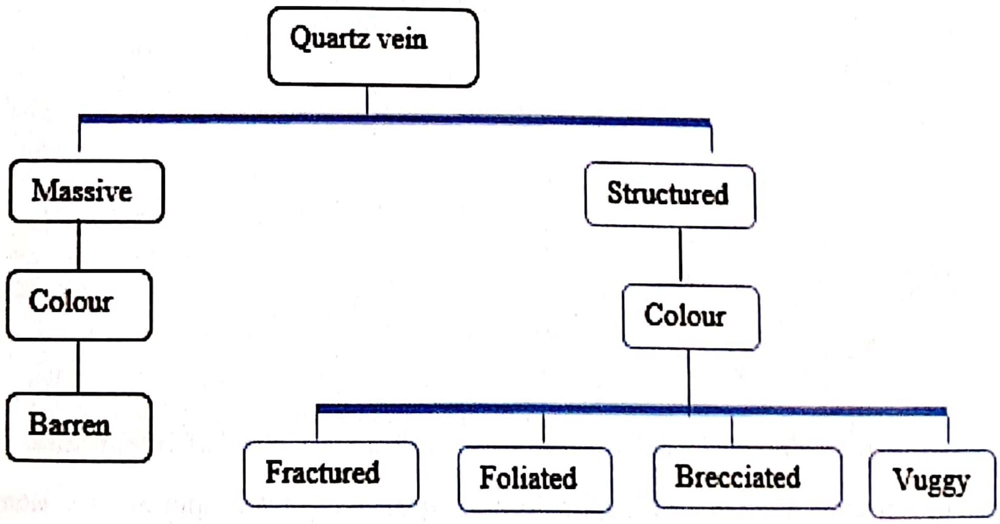

Figure 5: Flowchart diagram describing the systems of quartz veins within the study area (modified after Yannah *et al.*, 2015).

4. 2. Quartz Vein Textures

The most common quartz vein textures observed in the area under study are the associated with the primary growth textures as outlined below:

i. Massive texture: these types of quartz vein intrusion have a generally homogeneous feature with no evidence of fracture, shearing or banding.

ii. Crustiform texture: these types of quartz veins have the appearance of banded crusts. They are characterized by alternating parallel to sub-parallel layers called bands. The bands are differentiated based on variation in texture, mineralogy and colour; usually, the crustification occur symmetrically extend from one side of the host rock to the other side (Adams, 1920).

4.3. Quartz Vein Structures

In some of the pits such as pits 7 and 10, the quartz veins have split up into many individual veinlets to form a horsetail structure and these areas are highly mineralized with gold and they represent one of the targets for miners (Figure 6).

Figure 6: Horsetail structure or the splay formed when a single vein split into a system of veins.

There are two varieties of quartz veins that are recognized; there are those which do not host gold mineralization and the gold hosting quartz veins. The gold hosting quartz veins are the most common within the study area but only a few were observed in the field due to their removal (mining) by artisanal miners. The gold hosting veins are either foliated, brecciated or un-foliated veins containing vugs (Figure 7). The selvages formed by the quartz stringers are also mineralized. These mineralized stringers have been characteristically defined by brittle structures such as fractures and brecciation. The splay of a single vein into systems of veins is called stringers and these stringers are believed to have a composition that is similar to that of the primary quartz vein (Suh, 2008).

The presence of vugs is a texture which indicates that at the time of formation of the vein, the pressure of the hydrothermal fluids was equal to or greater than that of the lithostatic conditions (Robert *et al.*, 2005). More so, the preserved nature of the vugs indicates the low-pressure condition at the time of the vein formation.

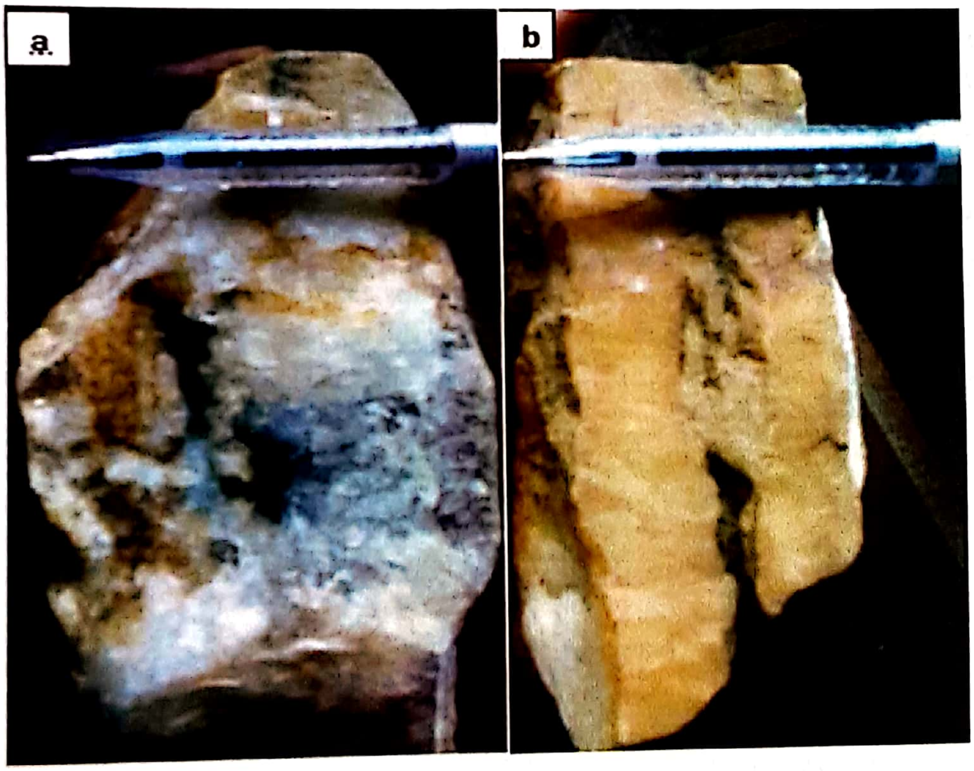

Figure 7: (**a**) and (**b**) are un-foliated quartz vein samples characterized by the presence of vugs while (**c**) Brecciation of the quartz veins. These structures are all associated with gold mineralization.

4.4 Field Observation of the Wall-Rock Alteration

Quartz veins usually cause portion of the rocks bounding their surfaces to undergo chemical changes called alterations. Within the studied area, the alteration occurs in a direction that is concordant with the strike of the vein and a zoning pattern of alteration that is lateral and symmetrical on both sides of the veins in thickness and colour change. This indicates that the process of alteration began almost instantaneously when the hydrothermal fluids entered the host rock (Yannah *et al.*, 2015). The pattern of alteration is controlled by the vein so that the size or thickness of the veins correlates positively with the thickness and size of the alteration envelope or zone (Figure 8).

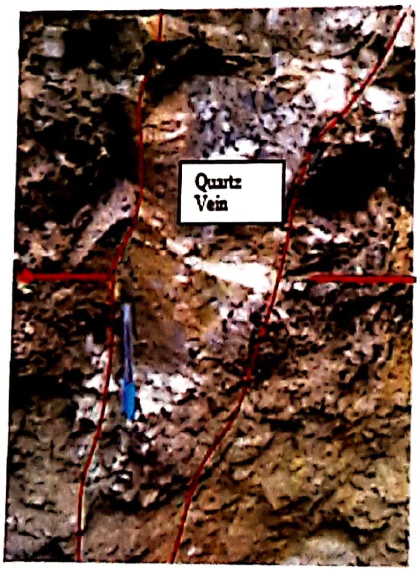

Figure 8: Quartz vein intrusion with the alteration zones occurring symmetrically on both hanging and the footwall.

This has the effect that where the veins are massive and thick, the alteration zones are relatively wider and thicker than the points where the veins are thinner. The alterations show variation in colour from pit to pit and the colour ranges from very dark to dark and reddish brown. The pits where the veins splays or forms the horse tail structures, the alteration are more reddish brown than dark. The altered wall rocks vary in their angles of dip from pit to pit and are largely controlled by the angle of dip of the veins.

The observed alteration zones are characterized by lateral changes which grades out into the host rock. In pits where the alterations are preserved, the zone of ferruginization is observed to be in direct contact with the vein. This is the thinnest zone with dark brown colour having a clayey texture and from this point, there is an outward gradational change into a bleached wall rock called the bleached zone, the zone of bleached rocks consists of minute particles of quartz grains. Bleaching of wall rocks in an alteration event is an indication of an alteration caused by hydrothermal processes (Yannah *et al*., 2015). The bleaching of rocks from an alteration often results from the processes of replacement of potassium feldspars by the residual titanium oxides (Ti-Oxide) (Vallance *et al*., 2004) and it may also result from sericitization (Sibson and Scott, 1998). This zone of bleached rocks in turn grades into an outer region that is light brown in colour. No geochemical analysis was carried out on the host rock and the intrusive granitic rocks and the soil samples but from the petrographic studies. The absence of gold from the intrusive granites and the schist host rocks is an indication of the absence or poor mineralization in the rocks and that the gold mineralization was from the vein intrusion.

4.5 Field Observation of the Overburden Soil

Within the study area, the gold grains have been reworked insitu. This conclusion was possible due the observed correlation between the presence of gold in the soil and characteristics of the veins. The soil overburden in the area were sampled and panned to detect the presence of gold in the soil. Some of the soil horizons host gold while gold was not found in others. A positive correlation also exists between finding gold in the soil horizons in pits where the veins are massive with no structures and not finding gold in soil where the veins are characterized by structural elements.

For each of the pits, 2.5kilogrammes of undisturbed samples were collected where from each soil horizon. This soil was washed and panned, the lighter soil fractions were removed and the heavy mineral fractions that remained were checked for gold using a magnifying hand lens. If gold grains were detected, they are removed and weighed and properly documented. Gold grains were obtained in all the three (3) soil horizons in pits 3 and 7 noting that in these pits, the vein exhibits no structural characters such as fractures but rather they are massive with wider alteration envelopes. A summary of the soil horizon panned and the pits where gold recovery were made is presented in Table 2. Subjecting the three (3) soil profile samples to grain morphological analysis in further studies combined with the observed correlation can prove beyond doubt that the gold grains are not from an alluvial source but are weathered and worked insitu. From the results, it was concluded that the insitu weathering of the rocks resulted in the formation of the soil in the area and that the gold was also from the quartz veins because it can be assumed that the processes of weathering of the rocks were also responsible for the dispersion of geochemical materials such as the gold in the soil.

The area is characterized by moderate soil cover with about 2-3 meters in thickness and up to 4 meters in some places creating a limitation on the access to veins and the altered wall rocks directly. Three major soil horizons are easily observable from the wall cutting within the pits (Figure 9).

Table 2: Summary of the soil profile is presented below showing the presence or absence of gold grains from the panned soil samples.

Pit Number	Sample position (Horizon)	Weight of the soil sample in Kg	Gold recovery (Yes or No)	Weight of the gold in g/2.5kg of soil
Pit 1	Horizon A	XX	XX	
	Horizon B	2.5	No	
	Horizon C	2.5	No	
Pit 2	Horizon A	2.5	No	
	Horizon B	2.5	Yes	0.006
	Horizon C	2.5	Yes	0.0032
Pit 3	Horizon A	2.5	Yes	0.0081
	Horizon B	2.5	Yes	0.0073
	Horizon C	2.5	Yes	0.0082
Pit 4	Horizon A	2.5	No	
	Horizon B	2.5	Yes	0.003
	Horizon C	2.5	Yes	0.005
Pit 5	Horizon A	XX	XX	
	Horizon B	XX	XX	
	Horizon C	XX	XX	
Pit 6	Horizon A	XX	XX	
	Horizon B	XX	XX	
	Horizon C	XX	XX	
Pit 7	Horizon A	2.5	Yes	0.009
	Horizon B	2.5	No	
	Horizon C	2.5	Yes	0.004
Pit 8	Horizon A	XX	XX	
	Horizon B	2.5	No	
	Horizon C	2.5	No	
Pit 9	Horizon A	XX	XX	
	Horizon B	2.5	No	
	Horizon C	2.5	No	
Pit 10	Horizon A	XX	XX	
	Horizon B	XX	XX	
	Horizon C	XX	XX	

The XX indicates removed or disturbed soil horizon, 'No' indicates no gold recovery and 'Yes' indicates gold recovery.

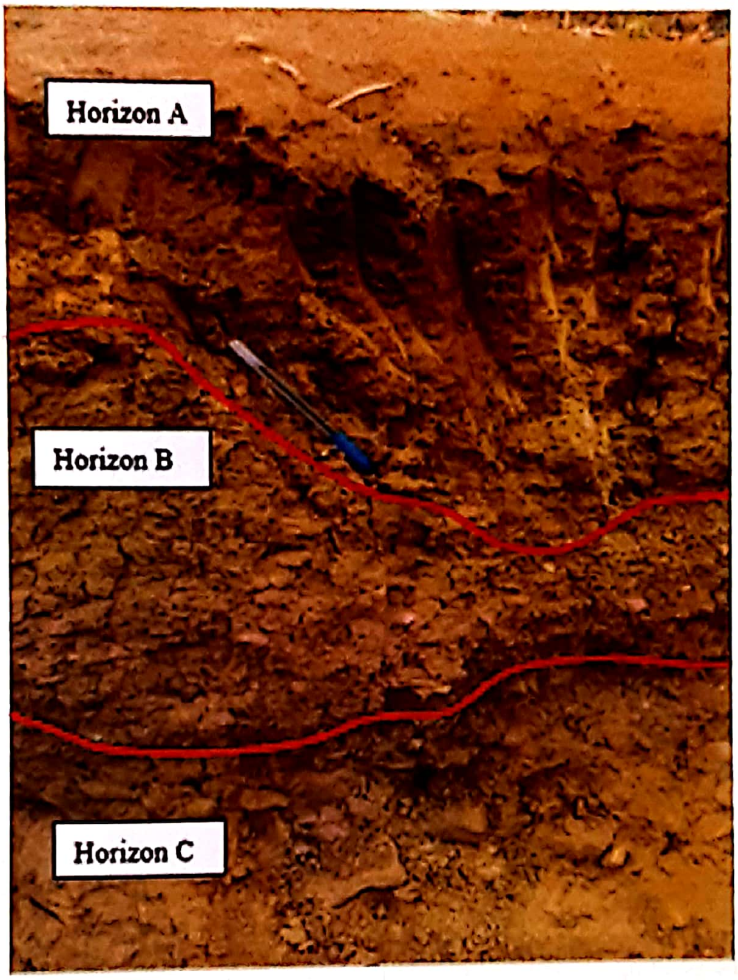

Figure 9: The prevalent soil profile within the study area showing different thickness and texture of the soil horizons.

The first horizon (Horizon A) is made up of nodular soil materials with a relatively finer grain compared to the other horizons. The second horizon (B) is made up of angular clasts and gravel sized rock fragments and the third horizon consists of the bed rock materials that have been crushed into fragments. The grain sizes of the soil materials for each of the horizons increases downwards to the unaltered bedrock.

Some of the horizons host gold mineralization and there seems to be a correlation between zones where the veins splays to form horsetail structures and the soil horizons that host gold. The gold content of the soil was determined in the study area by panning 2.5 kilograms of the soil sample for each horizon (Figure 10).

Figure 10: (a) the panning of the soil samples (b) heavy mineral fractions and (c) concentration of the heavy mineral fractions containing gold recovered from the panning.

4.6 Overview of the Structural Geology

A close observation of the super-imposed map of structures and geology show a concordant alignment of structural features. The topographic lineaments agree with the magnetic lineament in orientation in the NE-SW direction as shown in Figure 2 presented above.

Within the map, the boxed quadrant represents the specific area of interest for this research. Two important structural anomalies were identified using magnetic data. The magnetic lineament shown as a in the map represents the quartz vein currently being mined for gold and only a fraction of the extent of the vein have been noticed. A little north of vein **a**; is a yet undiscovered anomaly

(b) that may also be a high yield mineralized vein. Other important anomalies are observable and are all important points for further research.

The anomalies (both topographic and magnetic) can be observed above as they extend from the granite into the schist and from the migmatite into the schist. This might be an indication that not only magmatic processes, but metamorphism may have also played a part in the vein formation and mineralization.

The schist lies centrally between the granite and the migmatite serving as a receptacle for the hydrothermal fluids being that it is characterized by structures that are favourable for the movement of hydrothermal fluids. One of such structures is the weak foliation planes in schist. The veins in the schist appear to strike parallel to the foliation plane of the schist and exhibiting similar dip angles. That is, the dipping angle of the quartz vein is controlled by the angle of dip of the host schist.

The joint directions recorded from the granite outcrops were used in the construction of a Rosette diagram. The principal joint direction in the diagram shows an alignment with both the topographic and magnetic lineaments in a NE-SW direction (Figure 11).

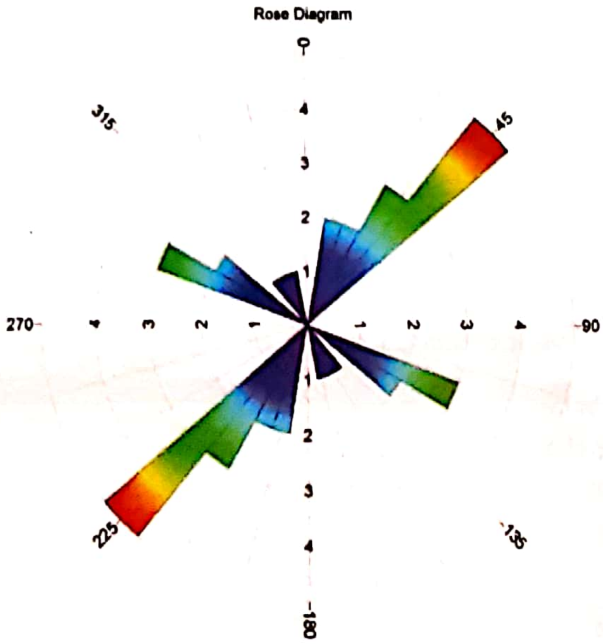

Figure 11: A Rose diagram used for visualizing the principal joint directions.

5. Conclusion

Field work within part of the Kushaka schist belt indicates that the mineralization is structurally controlled and that the style of mineralization is the gold-quartz vein type. The presence of faults within the schist could have served as the conduit or pathway for the movement of hydrothermal fluids and precipitation of materials (Oluyide, 1988 and Adeleke *et al.*, 2014). The other assumption can be that the hydrothermal fluids and the metals they carry in them may have resulted from the dehydration of rocks during metamorphism or other deep seated crustal or mantle generated thermal processes (Goldfarb *et al.*, 2005). The indication of metamorphism is given by the presence of the migmatite within the study area suggesting that metamorphism and magmatism may have played roles in the vein genesis and evolution. Only isotopic studies of the fluid inclusion in the quartz vein can resolve this problem in further research.

The presence of gold in the overburden soil was also detected from panning of soil samples. The presence of the gold grains within the soil horizons were found not to be in a random manner but rather controlled by the morphology of the vein. That is, at points where the quartz veins are characterized by structures such as foliation, fracture, banding, brecciation and splays, gold grains are virtually absent from the superficial layers (Horizons A, B and C) but at the points where the quartz veins are massive without structures, gold grains are presents in the overburden soil. This correlation indicates that the gold in the soil is not from an alluvial source; rather, it has been reworked insitu by geologic processes. It can also be concluded that the absence of structures associated with mineralization within the quartz vein at the time of formation may have resulted in the dissemination of gold grains into the surrounding environment.

The alteration was driven by the quartz veins which are hosted in the fracture within the schist. Several intrusions of granitic rocks are common within the Nigerian schist belts as they are also found within the Kushaka schist belt and the study area such as the Minna Batholith.

The granitic intrusions are capable of driving hydrothermal processes through the presence of magmatic fluids or recirculating ground water (Suh, 2008) this can contribute to the formation of the vein, alteration and their evolution.

Within the Nigerian schist belt, there are practically little or no gold mineralization where these granitic intrusions are absent but because the absolute conclusion on whether the granitic intrusions are wholly responsible for the formation and evolution of the vein is a highly debated topic and for the purpose of this research, it is only safe to state that the granitic intrusion may have been responsible for the formation and evolution of the vein but Adeleke *et al.* (2014) was able to detect anomalous gold content in the soils close to the plutons of syenite at 5700 ppb to 266 ppb, and this is a strong indication that plutonism can in fact carry mineralizing fluids for the gold enrichment. A close study of the geologic map show that both the topographic and magnetic anomalies occur mainly between different rock types within the study area. For instance, in figure 2 above, anomalies (a) and (b) can be seen striking from the granite into the schist. The mineralizing fluid responsible for the formation of the quartz vein may have been the product of magmatism from the granite intrusions or from metamorphic dewatering of rocks during the formation of the migmatite or both. This fault outlined by the magnetic anomaly represents the pathway for the movement of the hydrothermal fluids and the subsequent formation of the vein. During the field work and ground-truthing, the lineament A was found to be one of the gold rich veins although b and other lineament features as shown in the map are yet undiscovered to the artisanal miners.

The observed alteration zones have been weathered. A positive correlation has also been found between the thickness of the quartz veins and the thickness of the alteration margin. Thicker and more massive veins produce the largest alteration haloes relative to the points where the vein is thinner. Gold grains were also found at the points where the alteration margins are larger.

Geochemical analysis of samples from the quartz vein, wall rock alteration and overburden soil concentrates, gold micro-chemistry and morphological analysis of the gold grains and investigation of the other identified anomalous zones within the study area are subjects of further research.

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