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Research Article

PETROGRAPHY AND GEOCHEMISTRY OF BIRIMIAN GOLD MINERALISATION IN SIGUIRI BASIN, GUINEA

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ABSTRACT
Mineralised zone of Koulekoun gold deposit in Guinea is underlain by tonalite and metavolcanic rock which had undergone greenschist facies metamorphism. Gabbro is entirely barren and post-date metamorphism. Two generations of pyrite – fine pyrite 1 with corroded margins occurs in tonalite and mainly found along quartz veins and associated with arsenopyrite; pyrite 2 is coarse grained, euhedral and disseminated in metavolcanic rock. Silica in tonalite is slightly higher, soda is elevated but total iron oxide and magnesia are lower in tonalite than in the metavolcanic ore. There are no significant variations in TiO_2, Al_2O_3, P_2O_5, MnO, K_2O and SO_3 values. Gold (microscopic) possibly occurs as an inclusion in arsenopyrite as it strongly correlates with arsenic – a suggested pathfinder in gold exploration at Koulekoun.

Keywords: *Petrography, Geochemistry, Birimian, Gold Mineralisation, Siguiri Basin, Guinea*

INTRODUCTION
The Koulekoun deposit lies in the Siguiri Basin of the Birimian in the West African craton which consists of the Reguibat shield and the Man shield and made up of Archaean and Palaeoproterozoic granitic rocks. The West African craton is bounded to the north by the Anti-Atlas, to the west by a mobile zone of West Africa, and to the east by the mobile zone of Central Africa (Figure 1). The West African craton has remained stable for nearly 2.0 Ga and is largely covered by sedimentary rocks of Neoproterozoic and Palaeozoic age, namely, the Tindouf basin in the north and the Taoudeni basin in the central part (Bessoles, 1977).
Birimian rocks form a substantial part of the Man shield (Bessoles, 1977) which occupies the southernmost third of the West African craton (Figure 2). The Man shield comprises a western domain consisting of Archaean rocks of Liberian (ca. 2.75 Ga), Leonian (ca. 2.95 Ga) and pre-Leonian (ca. 3.1 Ga) age (Wright, 1985), and an eastern domain (Baoule-Mossi domain or Birimian/Eburnean province) composed chiefly of Birimian rocks of Palaeoproterozoic age, which were affected by a major tectonothermal Eburnean event around 2.1 Ga. The Birimian rocks were folded, metamorphosed and invaded by granitoids during the Eburnean event (Bonhomme, 1962).
Modern geochronological studies in Burkina Faso, Côte d'Ivoire, Ghana, Mali, eastern Mauritania and Senegal indicate that the Birimian rocks were formed over a maximum time interval of c. 2.25 to 2.05 Ga (Taylor *et al.*, 1988, 1992; Abouchami *et al.*, 1990; Liegeois *et al*., 1991; Boher *et aI*., 1992; Hirdes *et al*., 1992; Davis *et al*., 1994 and Hirdes *et al*., 1996). The Man shield stretches over several countries in West Africa including Burkina Faso, Ghana, Guinea, Liberia, Mali, Niger, Senegal, Sierra Leone and Togo (Figure 2).
The Birimian rocks comprise of evenly spaced belts of volcanic rocks separated by successions of sedimentary rocks into which most of the granitoids have been intruded. Woodfield (1966), Leube *et al.*, (1990) and Hirdes *et al.*, (1993) stated that the Birimian rocks comprise of basaltic and andesitic lavas interlayered with volcanogenic turbidites, with rare rhyolitic and dacitic lavas and pyroclastic rocks and some clastic sedimentary rocks. Thick sedimentary rock successions fill the basins between the volcanic belts and are intercalated along strike with the volcanic rocks. Greywackes and argillites are the dominant regional lithologies. Chert, ferruginous chert and carbonate rocks may be common at the transition between volcanic and sedimentary successions.

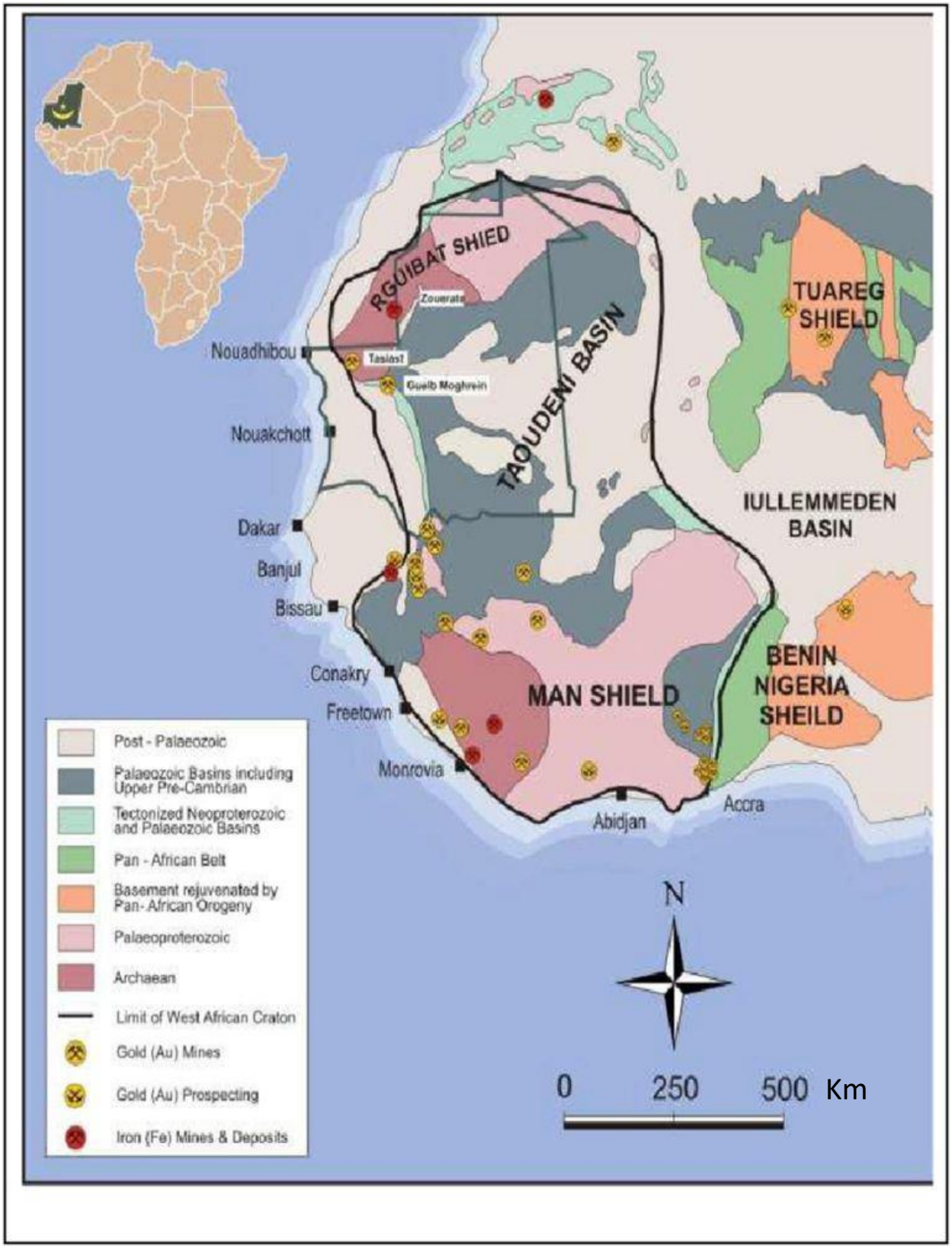


Figure 1: Geological Map of Western Africa Showing Basement Rocks and Basins (Modified after Boher *et al*., 1992)

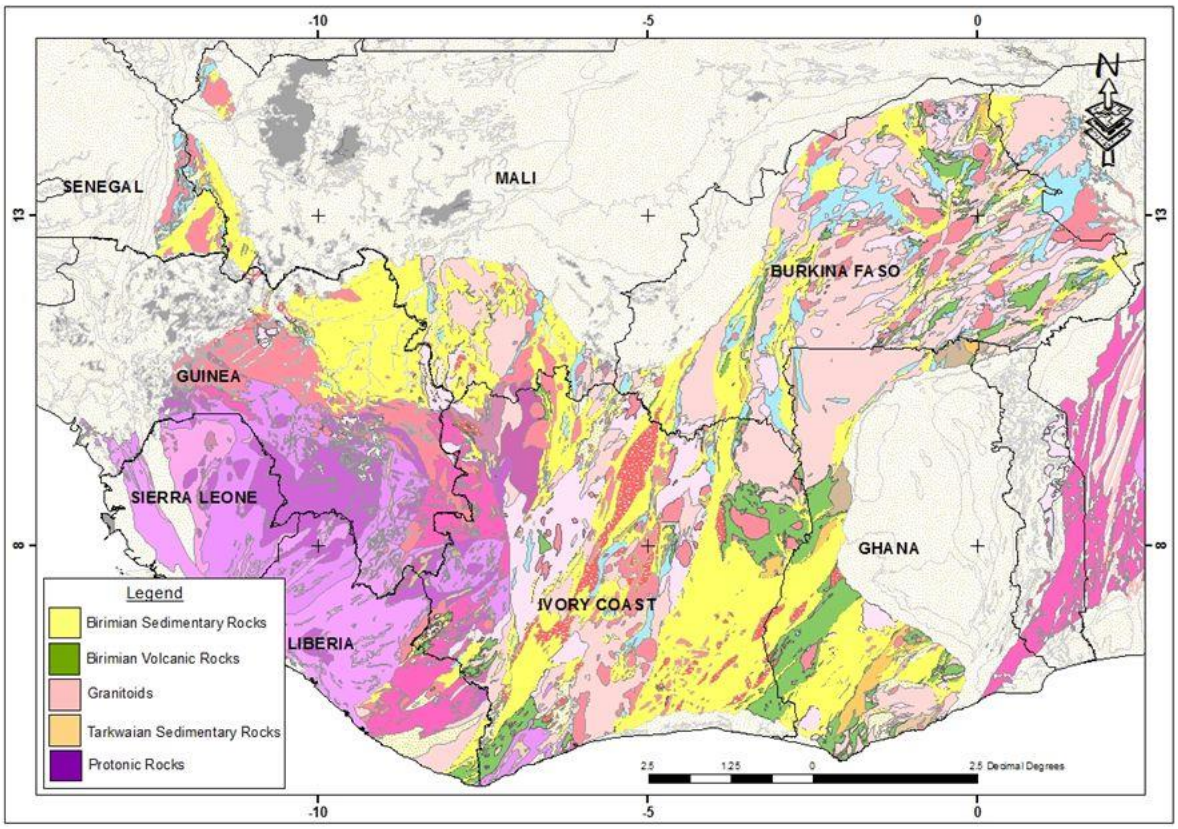


Figure 2: Regional Geology Map of West Africa Showing the Man Shield (Modified after Milési *et al*., 1992)

Leube *et al*., (1990) and Hirdes *et al*., (1993) suggested that the volcanic and sedimentary rock sequences were originally lateral facies equivalents. Sylvester and Attoh (1992) estimated the thickness of the Birimian rock sequence to have originally been 4000 m to 12000 m, although they are now highly attenuated.

The area of interest lies within the northeastern part of Guinea which falls in the Birimian at Siguiri Basin (Figure 3). The basin contains sedimentary and volcanic units with the western border bounded by the Niandan volcanic suite which forms a northwest-southeast trending mountain range that separates the Siguri Basin from the Archaean basement.

The study area is dominated by sedimentary units which had been subjected to lower greenschist facies metamorphism. The principal rock types include; granite gneiss complexes, flysch-type formations with minor volcanic rocks, fluvio-deltaic formations and plutonic rocks.

The rocks at Koulekoun are folded and faulted volcano-sedimentary rocks, metamorphosed and intruded by porphyritic dyke that had been further intruded by a younger, sub-horizontal dyke. The weathered profile extends to depths of up to 80m and capped by duricrust.

The volcano-sedimentary rocks generally strike 030° and are near vertical dip of 70° varying dip direction from NW to SE. The intrusive porphyritic dyke dips 60° - 70° to the east and strikes north-west (about 330°).

In neighbouring Burkina Faso, primary gold deposits are associated with deformed quartz veins with pyrite or tourmaline in Palaeoproterozoic Birimian rocks of metagabbro-diorite, metagranite and metabasalt with tholeiitic affinities (Béziat *et al*., 2008). In Ghana, gold is found in the Lower Proterozoic Birimian and Tarkwaian supracrustal rocks of the West Africa craton (Dzigbodi-Adjimah, 1993).

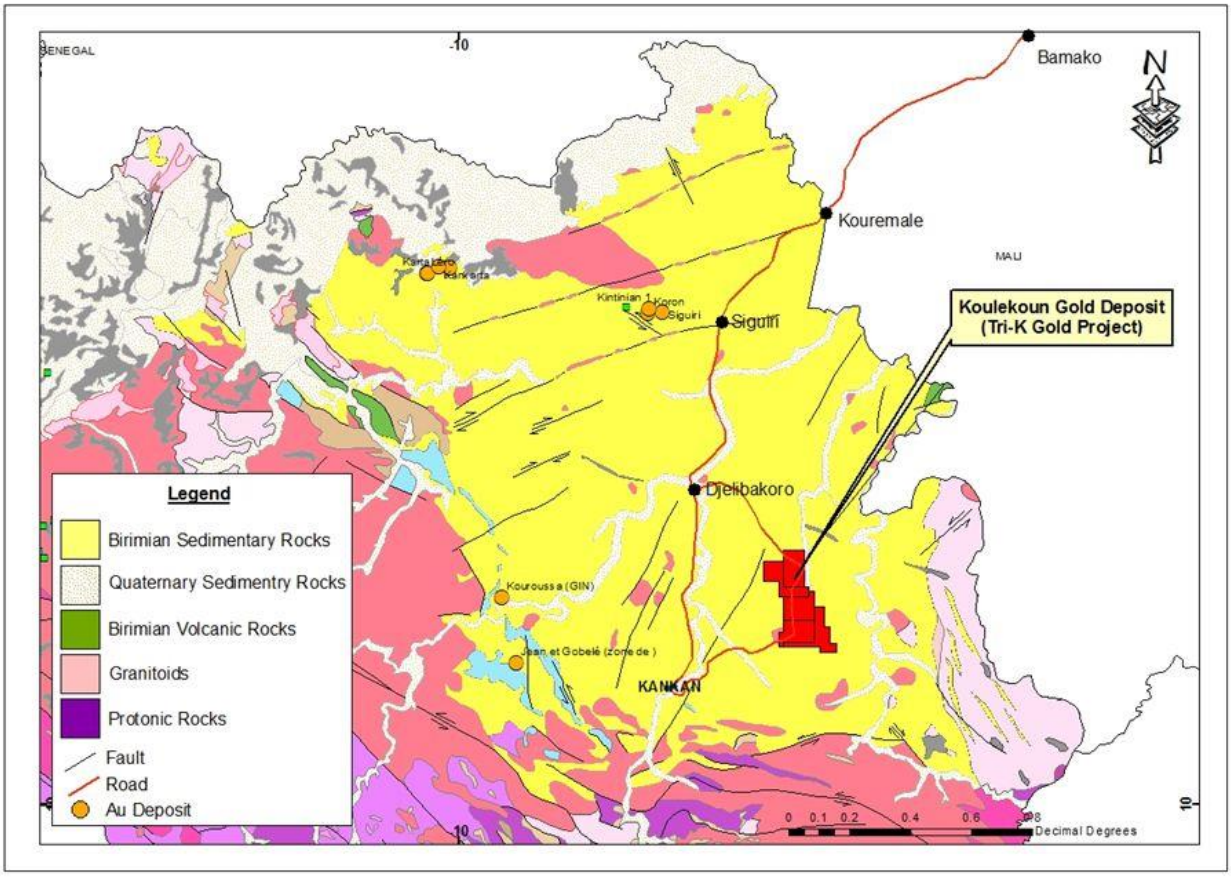


Figure 3: Regional Geological Map of Siguiri Basin Showing Koulekoun Deposit

Gold mineralisation in the Birimian of Guinea is found mostly in turbidities and lesser volcaniclastic sequences that had undergone mainly lower greenschist facies metamorphism with majority of gold deposits aligned on volcanic belts (Leube *et al.*, 1990). In the Siguiri basin, most gold deposits are found within sedimentary formations as e.g. Siguiri and Lefa gold mines (Anon., 2009). Gold mineralisation found in the Birimian units of the Siguiri basin is related to late tectonic plutonism and hydrothermal events that have remobilised gold along fractures and fault zones (Anon., 2009). This style of mineralisation is generally found in regionally metamorphosed terrains that have experienced considerable deformation. Hence, Birimian gold deposits within the Siguiri basin are invariably strongly structurally rather than lithologically controlled (Steyn, 2012).

MATERIALS AND METHODS

Methods Used

Seven (7) drill holes located at the western portion of the Koulekoun exploration license at varying depths (150m – 600m) intersected host rocks and the mineralised (ore) zone which were then selected for petrographical and geochemical studies. Most of the holes were drilled at an azimuth of 270° and 55°dip to target the NW mineralised porphyritic dyke that strikes 330° and dips to the east or drilled at an azimuth of 135° to target a NE dipping dyke. Initial logging followed by sampling of halved cores was carried out to assay for gold. Re-logging and sampling was done on the archived half cores at the core shed to establish rock types, alteration and mineralisation.

Fresh samples, representing the various lithologies from the study area were selected for petrographical investigation and XRF analysis. Eleven (11) samples of tonalite and four (4) from the mineralised metavolcanic rock were taken for thin and polish section preparation and transmitted and reflected light

microscopy at the University of Mines and Technology, Tarkwa and Ghana Geological Survey Department, Accra.

Mineral abbreviations used were after Whitney and Evans (2010). Thin and polish section studies were conducted with SM Lux Leitz microscope.

All samples were analyzed geochemically for major oxides and trace elements using X-ray fluorescence (XRF) analytical method at the Ghana Geological Survey Department. Gold (Au) was analyzed with conventional fire assay-atomic absorption spectrometry (FA-AAS).

The basic procedure for fire assay involved the mixing of a powdered 50g sample with sodium carbonate (ash), borax (sodium borate), litharge, flour and silica. A foil of lead (Pb) or silver (Ag) was usually added as a collector.

The mixture was then fired at a temperature ranging from 1000 – 1200°C to obtain a lead button which was then removed by cupellation at 950°C. The resultant gold pellet was digested with aqua regia mixture and the solution analyzed by atomic absorption spectrometre using gold standards.

RESULTS AND DISCUSSION

Results - Petrography

Tonalite

Tonalite is the main gold mineralised rock at Koulekoun. The rock is greenish grey, medium to coarse grained, porphyritic and has quartz carbonate veins. The phaneritic minerals are mainly plagioclase and quartz phenocrysts. In thin section, there is irregular alignment of plagioclase, amphiboles, sericite, quartz, chlorite and opaque minerals (Table 1). Amphibole is the only primary mineral. Secondary minerals are chlorite, epidote, sericite, quartz and plagioclase. Late metasomatic quartz overprint on metamorphic fabric and is associated with irregular aligned plagioclase and sericite.

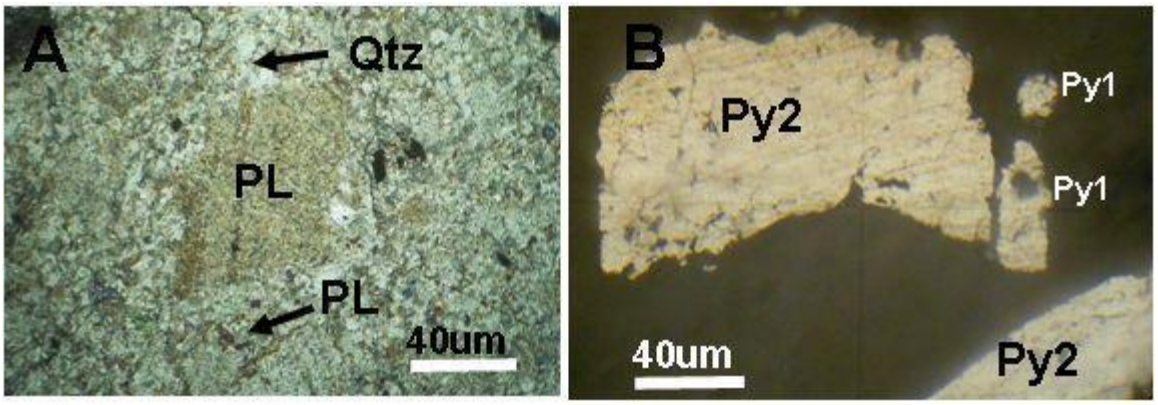
Chlorite might have been derived from breakdown of primary ferromagnesian minerals like pyroxene and hornblende during hydrothermal processes.

Plagioclase is colourless, fine grained, irregularly aligned and shows rare albite twining at 35°. Breakdown of plagioclase could account for sericitisation and silicification in the rock. Amphibole is fine to medium grained, subhedral, pleochroic from yellowish green to green, shows extinction at 51° and partially altered to chlorite. Quartz phenocryst is colourless, stained with alteration minerals and exhibits wavy extinction.

Pyrite and arsenopyrite are the main ore minerals. Whilst pyrite is fine grained, subhedral to euhedral and disseminated or occurs along fractures and around quartz veins, arsenopyrite is euhedral and mainly disseminated in the rock.

Table 1: Modal Percentage of Tonalite Ore at Koulekoun

Sample No.	**KL 3**	**KL 6**	**KL 7**	**KL 9**	**KL1 1**	**KL1 2**	**KL1 3**	**KL1 7**	**KL1 8**	**KL2 0**	**KL2 1**	**KL2 8**
Quartz	40	40	20	25	30	20	20	20	25	25	40	20
Plagioclase	30	30	45	45	40	45	45	45	45	40	30	35
Chlorite	5	5	2	2	4	2	2	2	2	10	6	7
Sericite	10	10	20	13	10	20	13	17	10	14	10	20
Epidote	4	4	4	2	2	4	5	5	2	5	4	5
Amphibole	3	3	2	2	2	4	5	2	2	2	2	2
Carbonate	5	5	4	6	5	3	5	4	9	2	3	6
Opaque	3	3	3	5	7	2	5	5	5	2	5	5
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**



Figures 4: Photomicrographs of Thin Section of Tonalite Showing A - Large Mineral Grains of Plagioclase, Amphiboles, Pyroxene in Crossed Polarised Light (Sample KL12); B - Subhedral Porphyroblastic Pyrite (Py2) in Plane Polarised Light

Metavolcanic Rock

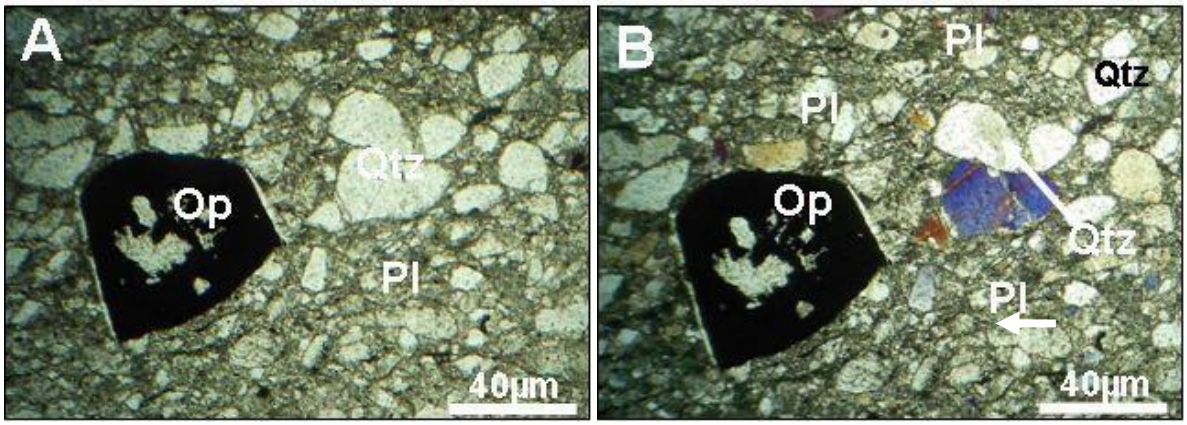
The rock in hand specimen is dark grey, fine to medium grained and composed mainly of alteration minerals and anhedral quartz and feldspar. In thin section, it is sub-angular with weak foliations (Figure 4A). The rock is composed of secondary quartz, plagioclase, chlorite, sericite, epidote and opaque minerals (Table 2).

Two types of plagioclase occur. Granular variety is sub rounded and partially altered to sericite and quartz whereas tabular variety is subhedral, fine to medium grained and shows irregular alignment. Quartz is medium grained, subangular to subrounded, poorly sorted, fractured and clouded by alteration minerals of sericite, chlorite, epidote and shows undulose extinction (Figures 5A and 5B). Chlorite occurs along fractures. It is pale green; fine to medium grained, weakly pleochroic and twisted. Opaque minerals (pyrite and arsenopyrite) are of fine dust to coarse grained and have varying shapes. Pyrite is pale yellow, and has high reflectance (Figures 6B and 7). Its shape varies from anhedral to euhedral and it is isotropic. Arsenopyrite is white or creamy, has low reflectance and takes a good polish. It is disseminated and varies from anhedral to euhedral (Figure 6A).

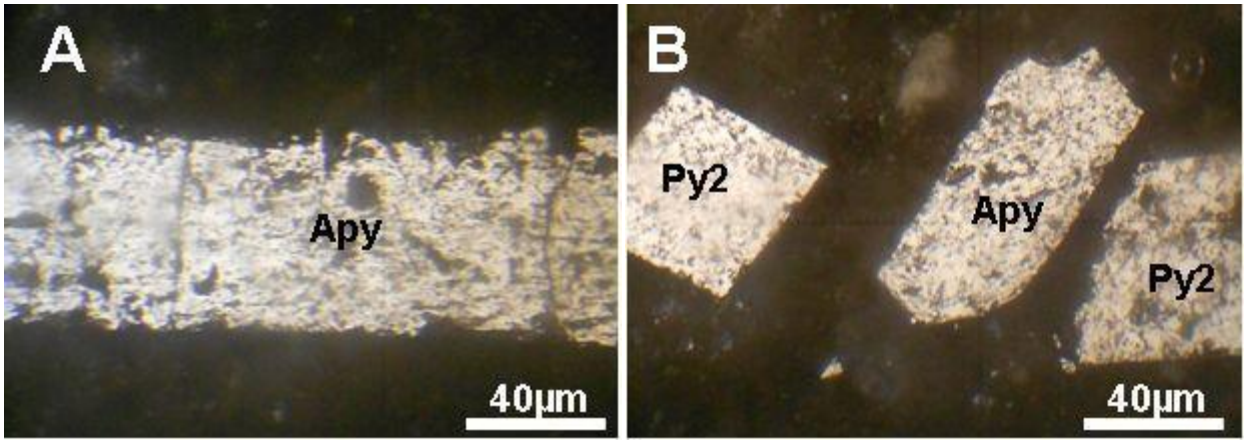
Two generations of pyrite occur. First generation pyrite is fine to medium grained, subhedral to anhedral and has corroded margins (Figure 6B). It occurs mainly along quartz veins and fractures. Second generation pyrite is euhedral to subhedral and disseminated in the rock (Figure 6B). Arsenopyrite occurs in the metavolcanic rock as medium grained and euhedral (Figure 6B). Pyrite maybe brecciated and exhibit annealed grain growth (Figure 7B).

Table 2: Modal Percentage of Metavolcanic Rocks

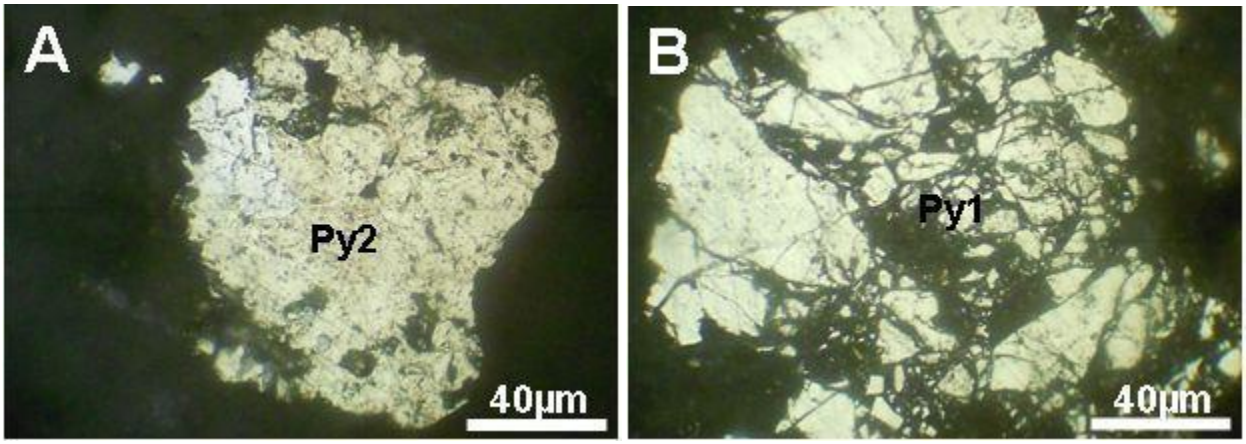
	Hanging Wall			**Ore Zone**				**Footwall**				
Sample No. KL-	**2**	**4**	**5**	**8**	**14**	**15**	**19**	**16**	**23**	**24**	**29**	**30**
Quartz	30	30	30	35	35	35	30	40	40	40	30	30
Plagioclase	35	35	35	30	30	30	35	30	30	30	35	35
Chlorite	15	20	20	20	20	20	20	18	18	18	15	15
Sericite	13	8	8	5	5	5	5	5	5	5	13	13
Epidote	5	5	5	5	5	5	5	5	5	5	5	5
Opaque	2	2	2	5	5	5	5	2	2	2	2	2
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**



Figures 5: Photomicrographs of Thin Section of Metavolcanic Rock Showing Coarse Plagioclase and Quartz Overprinted by Opaque Mineral (Sample KL 16) A - in Plane Polarised Light; B - under Crossed Polarised Light



Figures 6: Photomicrographs of Polish Section of Metavolcanic Rock under Plane Polarised Light Showing A -Euhedral Arsenopyrite (Apy) with Minor Corroded Margins; B - Disseminated Euhedral Pyrite (Py2) and Arsenopyrite



Figures 7: Photomicrograph of Polished Section of Metavolcanic Rock under Plane Polarised Light Showing A - Subhedral Porphyroblastic Pyrite (Py2) Overprinted by Gangue Minerals and Corroded at the Margins B - Brecciated Pyrite (Py1) Overprinted by Gangue Minerals and Corroded at the Margins

Geochemistry

Major oxides of tonalite in wt% shows SiO_2 ranges from 65.44 – 70.02. This is slightly higher in mineralised metavolcanic rock, TiO_2 (0.10 – 0.61), Al_2O_3 (18.55 – 21.43) values are very close in both rocks. Total FeO (0.96 – 3.53) is lower in the tonalite ore (0.96 – 3.53 at an average of 1.87 wt%) than metavolcanic ore (3.05 – 5.23 at an average of 4.05 wt%). In tonalite MnO values range from 0.03 – 0.07 wt% comparable with metavolcanic rock. MgO (1.40 – 3.42) has lower values in tonalite (1.40 – 3.42, mean 2.31 as against 3.04 – 4.71 at a mean of 3.96 wt% in metavolcanic rock. CaO ranges from 0.46 – 3.81 wt% in tonalite and 1.18 – 2.97, at a mean of 2.06 wt% in mineralised metavolcanic rock. Na_2O (4.66 – 8.07) is elevated in tonalite ore (4.66 -8.07 at a mean of 6.76 wt%) than in the metavolcanic ore (2.66 – 6.06, average 4.43 wt%). Values recorded for K_2O (0.99 – 205.00), P_2O_5 (0.06 – 0.24) and SO_3 (0.06 – 0.91) do not vary significantly (Table 4).

Discussion

The metavolcanic rock and tonalite on the Koulekoun deposit contain chlorite, epidote, sericite and secondary quartz which were introduced into the rocks during greenschist facies metamorphism. Two generations of pyrite occur - first pyrite (Figures 4B, 7B) has corroded margins and occurs mainly along quartz veins and fractures whereas second generation pyrite is disseminated. First generation pyrite and arsenopyrite have close association with gold mineralisation. In the metavolcanic rock and tonalite, pyrite is brecciated (Figure 7B). Gold (Au) is strongly correlated with arsenic (As), and moderately correlated with barium (Ba). Hence, arsenic (As) which is a pathfinder for gold (Au) in the Birimian could also be used as a pathfinder in the search for gold on the Koulekoun deposit.

Table 3: Summary statistics of major oxides in the ore zone at Koulekoun deposit

Rock Type	**Tonalite (N=11)**			**Metavolcanic Rock (N=4)**		
Oxide (wt %)	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
SiO_2	65.44	77.02	69.35	70.05	80.25	73.15
TiO_2	0.10	0.61	0.33	0.34	0.61	0.53
AI_2O_3	18.55	21.43	19.87	13.00	22.66	17.58
FeO_T	0.96	3.53	1.87	3.05	5.23	4.05
MnO	0.03	0.07	0.05	0.06	0.08	0.07
MgO	1.40	3.42	2.31	3.04	4.71	3.96
CaO	0.46	3.81	1.99	1.18	2.97	2.06
Na_2O	4.66	8.07	6.76	2.66	6.06	4.43
K_2O	0.99	3.28	2.61	1.10	4.38	2.53
P_2O_5	0.06	0.24	0.13	0.13	0.23	0.17
SO_3	0.06	0.91	0.40	0.13	1.43	0.85

Conclusion

Koulekoun gold deposit in Guinea is hosted by a non-mineralised metavolcanic rock which had been intruded by tonalite (the main gold mineralised rock). These rocks exhibit greenschist facies metamorphism evident by chlorite, epidote, sericite along foliation accompanied by late quartz. Pyrite, arsenopyrite and magnetite are the main ore minerals. Two generations of pyrite occur in tonalite and metavolcanic rock such that first generation pyrite is fine to medium grained with corroded margins whiles the second generation pyrite is euhedral to subhedral and disseminated. First generation pyrite and arsenopyrite have close association with gold. Though gold was not visible in hand specimen and in polish section analyses, assay results for gold range from 0.5 – 27ppm. Since arsenopyrite is the only arsenic bearing mineral and associated with pyrite, gold (Au) may occur as inclusion in arsenopyrite and/or pyrite. Moderate correlation of gold with arsenic, makes arsenic a pathfinder in gold exploration at Koulekoun. Silica in tonalite ore is slightly higher, Na_2O values are elevated but total FeO and MgO are lower in tonalite ore than in the metavolcanic ore with no significant variation in TiO_2, Al_2O_3, P_2O_5, MnO K_2O and SO_3.

Table 4: XRF Results in Hanging Wall, Ore Zone and Footwall on the Deposit

Zone	**Hanging Wall**			**Ore Zone**				**Footwall**				
Oxide wt%	**KL 2**	**KL 4**	**KL 5**	**KL 8**	**KL 14**	**KL 15**	**KL 19**	**KL 16**	**KL 23**	**KL 24**	**KL 29**	**KL 30**
Na_2O	4.97	2.74	4.09	3.47	2.66	5.52	6.06	5.78	4.92	4.82	4.13	3.69
MgO	4.86	4.18	4.78	4.34	3.76	3.04	4.71	3.48	3.41	2.94	2.89	3.94
AI_2O_3	22.09	29.99	23.91	22.66	13.00	18.61	16.04	20.69	18.38	18.11	20.53	26.75
SiO_2	56.20	48.21	55.66	56.25	71.25	65.05	63.03	61.36	64.25	65.55	62.21	50.59
P_2O_5	0.23	0.15	0.17	0.13	0.16	0.14	0.23	0.12	0.16	0.12	0.14	0.28
SO_3	0.03	0.98	0.13	0.95	0.89	0.13	1.43	0.18	0.14	0.12	0.04	0.06
K_2O	3.49	6.56	4.09	4.38	2.17	2.48	1.10	2.80	2.45	2.44	4.07	5.37
CaO	1.37	1.34	1.79	2.65	2.97	1.18	1.43	1.63	2.12	1.65	1.07	1.61
MnO	0.05	0.05	0.06	0.07	0.08	0.06	0.06	0.06	0.08	0.07	0.05	0.07
FeO_{total}	5.98	5.00	4.95	4.37	3.05	3.55	5.23	3.60	3.98	3.35	3.98	6.87
TiO_2	0.64	0.78	0.70	0.60	0.34	0.57	0.61	0.46	0.51	0.44	0.63	0.80
Co ppm	43.40	40.40	48.60	47.00	30.60	32.90	37.90	29.90	32.50	32.20	39.10	50.80
Ni	35.30	32.30	28.00	23.10	7.90	24.40	24.70	13.90	17.10	16.10	23.50	40.70
Cu	32.50	30.80	34.50	36.30	13.60	12.70	35.70	4.50	11.70	10.80	18.60	43.10
Zn	55.10	52.30	60.40	36.60	13.50	28.80	91.30	29.60	35.10	32.50	36.80	51.30
Ga	15.90	19.50	18.00	16.30	8.90	11.30	10.90	14.80	12.90	12.20	13.10	20.20
As	13.90	50.50	334.20	4653.00	3041.00	175.70	128.10	454.60	729.60	76.30	51.70	94.50
Br	1.00	1.00	0.60	7.30	7.70	1.00	0.70	1.40	1.40	0.50	1.00	0.40
Rb	98.20	1771.10	115.80	102.70	50.10	64.80	30.50	75.20	67.90	70.90	112.20	145.20
Sr	194.00	130.50	215.30	259.10	206.30	230.30	238.80	235.60	276.50	247.70	179.40	162.40
Y	16.60	16.10	12.60	10.60	7.00	12.10	11.50	7.70	11.80	10.40	11.50	18.70
Zr	129.80	149.10	143.20	121.60	141.80	157.00	179.10	156.20	223.40	156.50	142.40	120.80
Nb	6.30	8.00	8.80	6.00	4.00	5.30	6.40	6.40	5.50	5.10	5.90	7.40
Sb	1.50	3.80	2.30	5.80	1.50	1.50	5.20	3.60	1.50	3.20	3.80	3.70
Cs	3.70	4.10	1.50	1.50	1.50	6.10	1.50	4.10	1.50	7.10	1.50	5.20
Ba	598.70	734.30	612.10	559.70	278.10	374.30	291.10	506.60	487.30	508.80	618.80	753.10
La	23.50	32.00	23.30	15.40	12.90	32.30	29.00	31.80	32.10	29.30	24.20	22.50
Ce	48.40	57.00	41.20	35.40	17.40	53.70	54.80	60.00	61.40	53.60	45.30	42.80
Pr	5.00	5.00	5.00	14.50	5.00	13.60	5.00	5.00	5.00	28.70	5.00	5.00
Nd	14.10	8.20	5.20	5.00	5.00	5.00	5.00	12.20	11.40	32.90	50.00	20.20
Pb	4.80	3.90	6.40	7.40	4.50	1.90	23.10	4.60	5.00	3.30	5.40	1.30
Th	4.70	5.20	5.30	3.40	2.90	4.80	4.70	5.10	4.60	3.30	4.10	5.60

REFERENCES

Abouchami W, Boher M, Michard A and Albarede F (1990). A major 2.1 Ga Event of Mafic Magmatism in West Africa: An Early Stage of Crustal Accretion. *Geophysical Research* **95** 605 – 629.

Anon (2009). Report on the Geology of Lefa Gold Mine, Guinea, Lefa Gold Mine, unpublished 8.

Bessoles B (1977). *Geologie de l'Afrique – Le craton Ouest Africain*, (Memoire B.R.G.M., France, Europe) 403.

Beziat D, Dubois M, Debat P, Nikiema S, Salvi S and Tollon F (2008). Gold Metallongeny in the Birimian Craton of Burkina Faso (West Africa). *Science Direct* **50** 215 – 233.

Boher M, Abouchami W, Michard A, Albarede F and Arudt NT (1992). Crustal Growth in West Africa. Proceedings at 2.1 Ga. *Journal of Geophysical Research* **97** 345 – 369.

Bonhomme M (1962). Contribution à l'étude Géochronologique de la plate-forme de l'Ouest Africaine. In Leube, A., Hirdes, W. Mauer, R., and Kesse, G. O. (edition), *The Early Proterozoic Birimian Supergroup of Ghana and Some Aspects of its Associated Gold Mineralisation*, *Precambrian Research* **46** 139 –165.

Davis DW, Hirdes W, Schaltegger U and Nunoo EA (1994). U-Pb Age Constraints on Deposition and Provenance of Birimian and Gold-Bearing Tarkwaian Sediments in Ghana, West Africa. *Precambrian Research* **67** 89 – 107.

Dzigbodi-Adjimah K (1993). Geology and Geochemical Patterns of the Birimian Gold Deposits, Ghana, West Africa. *Journal of Geochemical Exploration* **47** 305 – 320.

Hirdes W, Davis DW and Eisenlohr BN (1992). Reassessment of Proterozoic Granitoid ages in Ghana on the basis of U/Pb Zircon and Monazite dating. *Precambrian Research* **56** 89 – 96.

Hirdes W, Davis DW, Lüdtke G and Konan G (1996). Two generations of Birimian (Paleoproterozoic) volcanic belts in north eastern Côte d'Ivoire (West Africa): Consequences for the Birimian controversy. *Precambrian Research* **80** 173 – 191.

Hirdes W, Senger R, Adjei J, Loh G and Tettey A (1993). Explanatory notes for the geological map of Southwest Ghana 1:100000. Bundesanstalt für Geowissenschaften und Rohstoffe (BGR). *Geologisches Jahrbuch, Reihe B, Haft* **83** 139.

Leube A, Hirdes W, Mauer R and Kesse GO (1990). The Early Proterozoic Birimian Super group of Ghana and Some Aspects of its Associated Gold Mineralisation. *Precambrian Research* **46** 139 –165.

Liegeois JP, Claessens W, Camara D and Klerkx J (1991). Short-Lived Ebumean Orogeny in Southern Mali: Geology, Tectonic, U-Pb and Rb-Sr Geochronology. *Precambrian Research* **50** 111 – 136.

Milési JP, Ledru P, Feybesse JL, Dommanget A and Marcoux E (1992). Early Proterozoic Ore Deposits and Tectonics of the Birimian Orogenic Belt, West Africa. *Precambrian Research* **58** 305 – 344.

Steyn JG (2012). Structural geology and controls of gold mineralization in the Siguiri Mine, Guinea, West Africa Stellenbosch University.

Sylvetser PJ and Attoh K (1992). Lithostratigraphy and Composition of 2.1Ga Greenstone Belts of the West African Craton and their Bearing on Crustal Evolution and the Archean Proterozoic Boundary. *Journal of Geology* **100** 377 – 399.

Taylor PN, Moorbath S, Leube A and Hirdes W (1992). Early Palaeoproterozoic Crustal Evolution in the Birimian of Ghana; Constraints from Geochronology and Isotope Geochemistry. *Precambrian Research* **56** 97 – 111.

Taylor PN, Moorbath S, Leube A and Hirdes W (1988). Geochronology and Crustal evolution of the Early Proterozoic Granite-greenstone terrains in Ghana, West Africa. *In: International Conference and Workshop on the Geology of Ghana with Special Emphasis on Gold*, programme and abstracts, Accra, 43-45.

Whitney DL and Evans BW (2010). Abbreviations for Names of Rock-Forming Mineral. *American Mineralogist* **95** 185–187.

Woodfield PD (1966). The Geology of the 1/4o field sheet 91, Fumso, N. W. Ghana, *Ghana.Geological Survey Bulletin* **30** 1 – 66.

Wright JB (1985). *Geology and Mineral Deposits of West Africa*, (Allen and Unwin, London, UK) 189.