Geochemistry of Gold Deposits in Anka Schist Belt, Northwestern, Nigeria

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ABSTRACT

Gold quartz veins have been identified associated with the rock formations of the Anka Schist Belt forming eight gold deposits that include Kuba I, Kuba II, Doka, Dumi I, Dumi II, Zurzurfa I, Zurzurfa II, Jameson and Kwali. The present study involves the use of major and trace elements to characterize some of the features that are diagnostic of their setting and origin. The gold mineralization is characterized by average composition that plot within the sedimentary-metamorphic field of Na_2O/Al_2O_3 - K_2O/Al_2O_3 discrimination diagram, suggesting a metamorphic origin for the gold mineralizing fluids. Characterization of the inter-elemens ratios of the lithophile elements K, Rb, Ba. Rb, and Sr revealed that they are similar to those of average metasedimentary rocks; further suggesting mineralizing fluids of metamorphic origin. The result obtained is similar to what has been reported from Zuru, Birnin Gwari and Kushaka schist belts; and many other areas of gold mineralization in the country and the world. The study has also shown that favourable geochemical factors exist for the discovery of a Cu, Pb and Zn deposits in the study area, and that the old Zurzurfa mines may be as prospective for these base metals as they were for gold.

INTRODUCTION

Man has tremendous esteem for gold since early times, and it is produced in many countries in Africa including Nigeria[1,2]. There are many areas of gold occurrence in Nigeria mainly associated with the schist belts which are composed of rocks like gneisses, schists, quartzites, amphibolites and granitoids[3,4,5,6,7,8,9,10,11]. Gold mineralization has been reported in the Anka Schist Belt (ASB) by earlier studies[12,13,14,15,16,17,18,19]. None of these early reports paid adequate attention to the geochemical characterization of the Anka gold prospects and their associated mineralization. Geologically, the Anka area is underlain by Precambrian migmatitic-gneisses and metasediments of the ASB into which are intruded Older Granites and amphibolites (Figure 1).

The metasediments comprise of phyllites, schists and quartzites; while the Older Granites consist of granodiorites and diorites. Additionally, there are volcanic rocks (e.g. dacites and rhyolites) that overlie and intrude the basement gneisses, metasediments and granitic rocks of the Anka area[20,21]. A brittle fault zone cuts the area consisting of sub-parallel phyllites and crushed and uncrushed quartzites, and forms part of the mapped Anka transcurrent fault which is interpreted as a possible Pan-African crustal suture[20,22,23].

Native gold is a relatively common mineral present in gold-quartz veins, in oxidized zones of many sulphide and hydrothermal deposits and in streams and rivers in most parts of the world. Hydrothermal gold deposits occur in orogenic belts that range in age from Precambrian to Late Tertiary. They are commonly found associated with stocks, batholiths and other igneous intrusions of intermediate to acid composition. The aim of the present paper is to describe the settings and present the major and trace element geochemical characterization of the gold prospects at the ASB

area as well as evaluate the potential for the discovery of Cu, Ag and Pb deposits in the study area.

EXPERIMENTAL

Mines and Samples Location

The Anka gold belt in NW Nigeria during its heydays boasted of six productive gold mines that cover several tens of km^2. The gold mineralization occurs at Kuba I, Kuba II, Doka, Dumi I, Dumi II, Zurzurfa I, Zurzurfa II, Jameson, Kwali and Kuba Mansur areas of the belt (Fig. 1). The gold workings at Dumi I and II, and Zurzurfa I and II are located near Tsareta area of the ASB. Outside this area are the Kuba and Mansur gold mines to the north-northeast (NNE). All of these six documented areas of gold occurrence are part of the Wangara golden land of[24,25] and are located along a silicified zone (the Anka transcurrent fault) that can be traced for about 15km within the area. The Anka gold deposits show considerable variety in the detail of their setting, but there is a very strong similarity running through the group as a whole.

The gold ore bodies mainly occur in quartz veins, veinlets and tiny stringers that abound in the country rocks that include phyllites, schists and quartzites. They have a sharp vein-wall rock contacts and the gold occurs in its native form as inclusions in minerals like chalcopyrite and galena. The veins do not always have a well developed wallrock alteration pattern, are marked by silicification, sericitization and carbonation. At the old open-pit mines, the miners often mined the soft (altered?) wall rocks which must have been gold bearing, leaving behind the main vein of a massive hard quartz body. The workings in the old gold mines found in the Anka area consist of elongated open pits aligned generally in a north-south direction, indicating that the mined auriferous quartz veins were also aligned in a N-S direction and conformed with the surrounding host rocks.

The mines were exploited in the 1940's and 1950's and the miners following the gold down until the pits became so deep that they had to abandon them due to difficulties. At present the narrow but deep open pits are slightly filled with water, especially in the rainy season. Most of the surface of the tailings is oxidized, because the mine is inactive evidenced by the formation of reddish brown iron oxide precipitates. Minor amounts of sulphide mineralization have been documented in the area, some occurring beneath lateritic covers[16,18].

Sample collection, preparation and analysis

Reconnaissance survey was first undertaken followed by a detailed geological mapping, trenching and sampling in places. Several representative rock and soil grab samples weighing 2-5 kg were collected from surface outcrops as were soils from old and current (artisanal) mines. The samples from the Zuzzurfa, Dumi, Kuba, Jameson, Kwali and Doka mines were labeled as ZG, DG, KG, JG, KW ND and DK respectively. The minerals in the samples were first studied and identified by hand specimen identification, binocular reflecting microscope inspection and thin section analysis using a polarizing microscope. Fourteen of the collected samples were prepared (crushing, grinding etc) at the laboratories of Department of Geology, Ahmadu Bello University (A.B.U.), Zaria. The samples were broken into smaller pieces with the aid of a hammer and altered material was removed by hand. The treated samples were then reduced to powders by pulverization and grinding, and used for the preparation of fused beads and pressed pellets. Lithogeochemical analyses of the samples were undertaken at the Geochemical Laboratories of University of Port Harcourt and the Institute of Agricultural Research (IAR), A.B.U. Zaria. The Chemical Analyses were done by a combination of X-Ray Florescence (XRF) and Atomic Absorption Spectrophotometry/Spectroscopy (AAS) techniques.

The samples were analysed for silicon, aluminium, iron, calcium, potassium, titanium and trace elements using sample from powders and the XRF technique. 0.50g of each of the sample

powder was mixed with $Li_2B_4O_7$ in a graphite crucible and fused at 1000^oC for 20 minutes and the fused beads cooled, weighed and fusion loss calculated. The above major elements were determined from the fused beads. For the trace elements determination, 10g of the powder from each sample was used to prepare pressed pellets using standard procedures, and the pellets dried at 110^oC for about 2 hours. Sequential XRF analysis on the pressed pellets was employed for the trace elements analysis. The limit of detection of trace elements is 2 ppm.

Magnesium, sodium, barium, manganese, zinc, lead, silver and gold were determined using AAS methods. Loss on ignition was calculated after each sample was ignited at 1000^oC for 30 minutes and allowed to cool, weighed and digested in a hot water bath using dilute HCL. The just listed elements (except silver and gold) were analyzed from the digest. Limit of detection of the major elements is 0.01% (100 ppm).

The silver and gold were determined by the routine 10g/aqua regia solution analytical method and AAS technique, as described below. The aqua regia ($HBr-Br_2$) is a 0.25N solution with respect to both HBr and Br_2 that was prepared by diluting 29ml of 47% HBr and 20ml Br_2 (99% Analar) to 1 liter with de-ionised water. The concentrated Hydrobromic acid carries bromine which attacks the gold and also provides the acidic medium necessary for the solubilizing the gold. Only concentrated nitric acid was used to dissolve the silver.

10.0 g of the sample powder was weighed and transferred to a crucible and roasted in a temperature-controlled furnace at $700-750^oC$ for 1 hour, after adding stock flux. The sample was allowed to cool and transferred into a polythene bottle. 20ml of the hot solution earlier prepared was then added to the bottle, shaken by a mechanical shaker for 1 minute and allowed to stay overnight. Another sequence of decomposition was undertaken with concentrated nitric acid only, in order to digest the silver. The gold and silver were determined directly in the solutions by flame AAS set at 242.8 and 328.1 nm, respectively (Table 1).

RESULTS AND DISCUSSION

Mineralogy and geochemistry

Mineralogically, the metallic minerals documented in the veins are pyrite, chalcopyrite, galena, smithsonite and native gold. Gangue minerals are predominantly quartz with minor amounts of muscovite (sericite), chlorite and carbonates mainly occurring in trace amounts. The chemical compositions and averages of the samples from the six mines are given in Table 1, and are not significantly different from each other; indicating a common ore-fluid. The Anka gold prospect is characterized by an absence of rocks with SiO_2 of less than 63%, high and variable potash/soda ratios; and high levels of several lithophile trace elements (Rb, Sr, Ba, Th) in the samples investigated. The chemical analyses show that, apart from minor amounts of TiO_2, MnO and CaO, the samples yield SiO_2, Al_2O_3, Fe_2O_3, MgO, Na_2O and K_2O/ as major components.

The excess CaO over MgO in some of the samples (ZG23, DG13, DG14 KG13, KG27 and KW27) suggests the presence of carbonate in these rocks, confirming hand specimen descriptions of those samples. On the other hand, samples from the quartz vein (ZG23, DG13, KG13, KW14) are quite siliceous (> 68% SiO2) pointing to the abundance of quartz. The presence of high alumina content in the samples (greater than 15%) is also noteworthy. In some of the samples, potash is greater than soda while, in others, the reverse is the case. This variation in the ratio of K_2O and Na_2O in the samples may be due to addition of materials through metasomatism[26]. The average loss on ignition (LOI) is in the range of 3.51-6.43% (Table 1).

The only trace elements measured include Ba, Rb, Sr, Ni, Cu, Pb (90-20 ppm), Zn, Ag, and Au. Two of the analysed samples from the Zurzurfa trenches (ZG11 and ZG23) gave elevated but widely varying concentrations of Cu, Pb, and Ag. The range of concentration of the main metals in the samples are Cu (267 – 5927 ppm), Pb (2985 -22173 ppm) and Ag (2 – 10 ppm).
A sample from the quartz vein at Zurzurfa with visible gold particles (ZG23) gave a Au value

Table 1: Geochemical composition of oxides (weight percent) and trace elements (parts per million) of representative rock samples from Anka gold prospects. $Fe_2O_3(T)$ - Total Fe.

| | ZURZURFA SAMPLES | | | DUMI SAMPLES | | | |
	ZG11	ZG15	ZG22	ZG23	DG13	DG14	DG21
SiO_2	64.58	63.74	63.02	68.15	68.14	64.55	65.88
TiO_2	0.73	0.72	0.63	0.64	0.47	0.62	0.69
Al_2O_3	15.94	19.48	17.79	18.11	16.29	18.17	17.90
$Fe_2O_3(T)$	5.74	4.21	4.94	3.50	3.26	2.98	3.98
MnO	0.03	0.01	0.08	0.02	0.01	0.04	0.00
MgO	1.43	0.83	1.28	0.02	0.05	0.44	0.58
CaO	0.86	0.02	0.59	0.42	0.72	0.59	0.32
Na_2O	3.33	3.88	3.25	2.78	2.68	2.93	3.09
K_2O	3.73	4.88	4.56	3.58	2.79	4.12	3.81
LOI	3.51	4.50	3.79	3.06	6.22	6.43	4.09
TOTAL	99.88	99.83	99.93	100.28	99.63	100.43	100.34
K	37300	48800	45600	35800	27900	41200	28100
Ba	976	1192	1087	966	789	1085	813
Rb	140	172	192	125	98	146	97
Sr	1062	1120	1108	1049	918	1075	881
Ni	42	11	6	12	16	21	31
Cu	5927	4112	5386	7412	456	267	314
Pb	21316	18498	17920	22173	3481	2985	4721
Zn	39	12	36	41	16	27	17
Ag	9	8	9	10	4	2	3
(ppb)							
Au	13	10	11	1173	11	8	0.7
(Ratios)							
Na_2O/Al_2O_3	0.21	0.20	0.18	0.15	0.16	0.16	0.17
K_2O/Al_2O_3	0.23	0.25	0.26	0.20	0.17	0.23	0.21
K/Ba	38	41	42	37	35	38	36
K/Rb	266	283	253	286	285	282	287
Ba/Rb	7.0	6.9	5.7	7.7	8.1	7.4	8.4
Rb/Sr	0.13	0.15	0.17	0.12	0.12	0.14	0.11

Table 1, (Cont): Geochemical composition of oxides (weight percent) and trace elements (parts per million) of representative rock samples from Anka gold prospects. $Fe_2O_3(T)$ - Total Fe.

	Sample Number						
	KUBA SAMPLES			JAMESON		KWALI	DOKA
	KG13	KG14	KG27	JG11	JG13	KW14	DK21
SiO_2	68.58	65.64	65.02	64.05	63.24	68.05	67.38
TiO_2	0.73	0.72	0.43	0.70	0.67	0.69	0.49
Al_2O_3	16.94	17.84	18.79	18.03	18.32	16.77	16.90
$Fe_2O_3(T)$	3.74	3.72	2.94	2.95	2.86	2.78	3.11
MnO	0.03	0.02	0.06	0.02	0.01	0.04	0.06
MgO	0.43	0.61	0.58	1.12	0.70	0.46	0.68
CaO	0.76	0.21	0.69	0.52	0.40	0.80	0.42
Na_2O	2.33	3.11	2.98	3.78	3.69	2.55	2.87
K_2O	2.66	3.79	4.21	4.58	4.49	3.84	4.31
LOI	4.01	5.07	4.53	4.46	6.00	4.63	2.09
TOTAL	100.21	100.76	99.93	100.21	99.75	100.61	100.31
K	26600	37900	42100	45800	44900	38400	43100
Ba	959	902	1085	1096	1089	985	1131
Rb	121	130	199	161	198	136	187
Sr	1052	920	1111	1091	1112	1063	1084
Ni	11	22	9	32	8	13	11
Cu	7627	412	5399	312	5436	1267	311
Pb	24920	8178	20218	3713	23131	2398	3811
Zn	19	21	31	19	26	21	19
Ag	10	5	7	3	9	9	6
(ppb)							
Au	13	15	6	8	5	2	0.8
(Ratios)							
Na_2O/Al_2O_3	0.14	0.17	0.16	0.21	0.20	0.15	0.17
K_2O/Al_2O_3	0.16	0.27	0.22	0.25	0.25	0.23	0.26
K/Ba	28	42	39	42	41	39	38
K/Rb	220	290	212	285	228	282	230
Ba /Rb	7.9	6.9	5.5	6.8	5.5	7.2	6.1
Rb/Sr	0.12	0.14	0.18	0.15	0.19	0.13	0.17

A sample from the quartz vein at Zurzurfa with visible gold particles (ZG23) gave a Au value of 1173 ppb while comparison of the results obtained from the different sites show six samples (ZG11, ZG15, ZG22, DG13, KG13, KG14) gave results close or between 10-13 ppb gold. The gold content of another four samples (DG14, KG27, JG11, JG13) falls between 5 and 8 ppb with one of the samples (KW14) giving a gold content of 2 ppb. These gold values indicate an average quality grade of gold deposit for the market. A gold grade of 0.8 ppm in samples DG21 and DK21 is, however, uneconomic, but is an indication of a good potential for economic gold grade within the mineralization.

The Zurzurfa samples are distinct in surprisingly having higher concentrations of Cu, Pb and Ag. This is reflected in the abundance of galena and secondary copper minerals (malachite and azurite) in the host quartzite and phyllite that abound in the area. Four of the samples (ZG12, ZG, 2G, ZG) show up to 5927-7412 ppm Cu, 17920-22173 *ppm* Pb and 9.0 *ppm* average Ag content. This is an indication of a likely very economic Cu and Pb deposits, as, even by today's standard, these grades of copper, lead and silver are economical. This occurrence deserves further attention in the form of core drilling. More importantly, the high base metal content indicates a correlation with the gold mineralization (hydrothermal alteration).

Origin of the Anka Gold Mineralization

The Anka gold mineralization is Precambrian in age and its origin is hydrothermal as observed from the wall rock alteration in a number of gold deposits in the area. The old quartz vein workings in the study area were probably emplaced during and as part of the metamorphic and tectonic processes that resulted in the formation of the Anka fault. Some of the controls on the formation of gold deposits have primarily been attributed to structural factors[27,28,29]. Some Australian gold deposits are sited in brittle-ductile and brittle faults of great lengths[30,31]. Everywhere in the world, the mineralizing fluids were possibly

of the same composition[29] and various theories have been proposed to explain the sources of gold-mineralizing fluids. These include mantle-lower crust degassing[32], metamorphic dewatering[28,33,34] and magmatism[35].

The average composition of the samples plots at the sedimentary-metamorphic field in the K_2O/Al_2O_3 diagram[36], suggesting a metamorphic origin for the gold mineralizing fluids (Figure 2). Similarly, there is variation in the ratio of K_2O/Na_2O in the samples possibly due to addition of materials through metasomatism. The nickel contents obtained from the whole rock analyses were also used to infer the origin of the mineralizing fluids. The chemical analyses revealed an average nickel concentration of about 24 ppm, indicating that the mineralizing fluids responsible for the quartz-veins are of sedimentary-metamorphic parentage[37,38,39]. However, according to these authors, a nickel concentration of about 100ppm suggests an igneous parentage. As a result other chemical parameters were integrated with field data to determine the nature of the gold mineralizing fluids[37,38,40].

The inter-element ratios of the large ion lithophile elements (LILE) K,Rb, Ba and Sr in the analyzed samples were used to further infer the nature of the gold mineralizing fluids[8,27,33]. These workers used the fractionation patterns of LILE in potassic alteration domains of vein gold mineralization as tracers of the source of K and Au. The K-Rb-Ba signatures of the mineralizing fluids were investigated in the studied samples (Table 1). The average and range of ratios of the lithophile element include those of: K/Ba = 38 (range: 28 – 42); K/Rb = 264 (range: 212-290), Ba/Rb = 6.9 (range 5.5 - 8.4), and Rb/Sr= 0.14 (range: 0.11-0.19).

The ASB samples are characterized by ratios of K/Ba, Rb/Sr, K/Rb and Ba/Rb that are similar to those of average crustal ratios. According to Holland[41] and Taylor and Co-workers[,42], the average crust has inter-element ratios of 285 for K/Rb; 36 for K/Ba; 7.8 for Ba/Rb; and 0.123 for Rb/Sr. Taken together, the geochemical features of the rocks suggest that the

Anka gold mineralization was structurally controlled, and the mechanism of gold transport and deposition is related to metamorphic processes[43,44,45]. In contrast magmatic sources of mineralizing fluids have lithophile element trend characterized by diminished K/Rb and Rb/Sr ratios[33,36]. The gold might have been derived from the reworking of Birrimian rocks which covers extensive areas[46] but are now known to be largely converted to gneisses and migmatites[47]. There seems to be no genetic link between the gold mineralization and nearby Older Granite intrusions (Figure 1) though heat from the intrusion might have remobilized the gold mineralizing fluids.

The dominant structural trend in the area is the NNE-SSW trending Anka fault along which gold-mineralising fluids were probably generated, channeled and deposited as gold-sulphide-quartz veins in the area. The brittle faulting is synchronous with gold mineralization and hydrothermal alteration at a number of other places in Nigeria[8]. It is pertinent to note that the origin of gold deposits in Nigeria have been ascribed to regional metamorphism[8,17] following the model of Boyle[44]. According to Department of Mines (Nigeria) Annual Reports[17], primary gold deposits are spatially associated with amphibolites and have no specific relationship with the Older Granites. Some of the gold-mineralizing fluids in NW Nigeria have been confirmed to be metamorphic in origin mainly through lithophile and rare earth elements characterization[8].
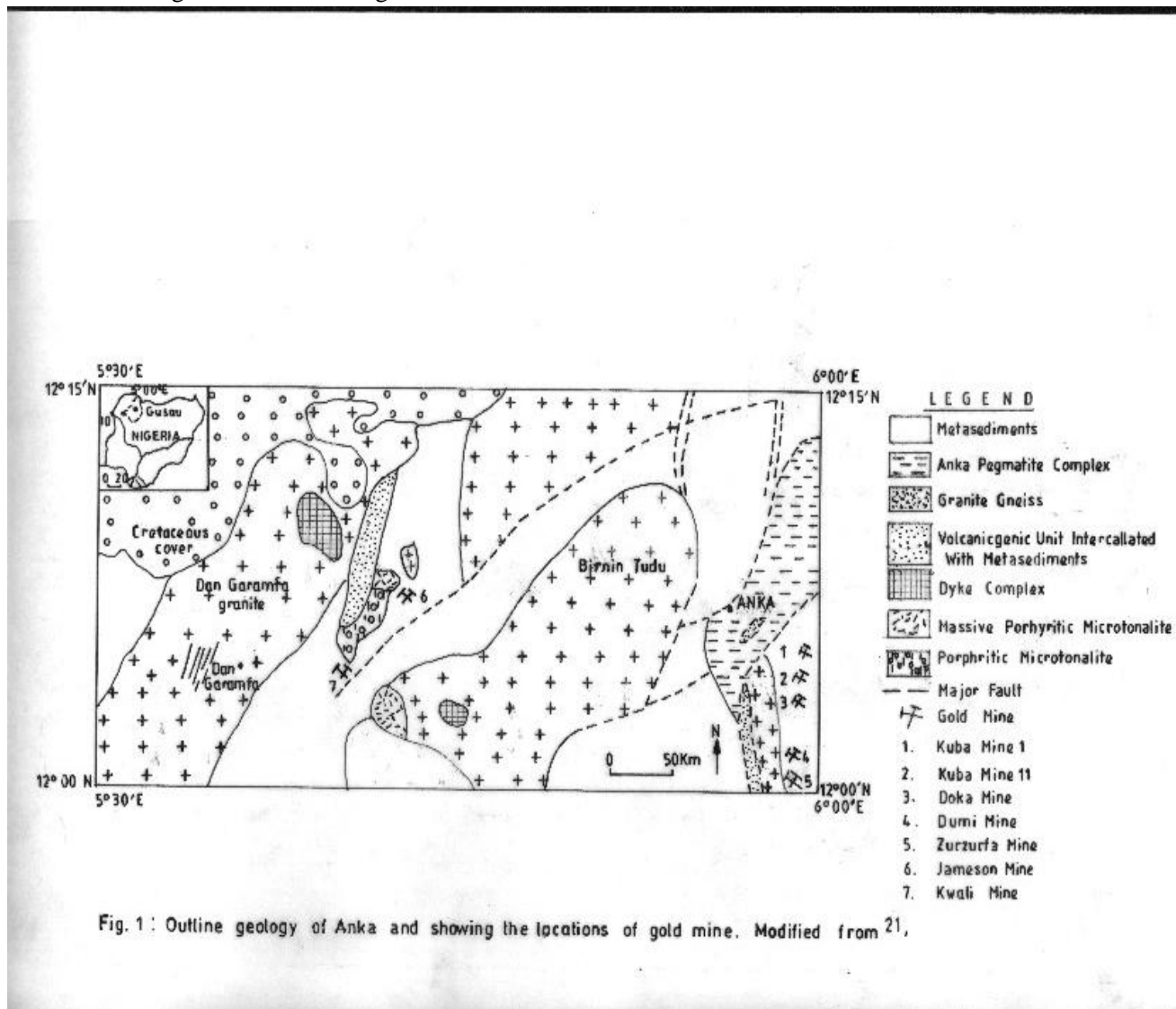

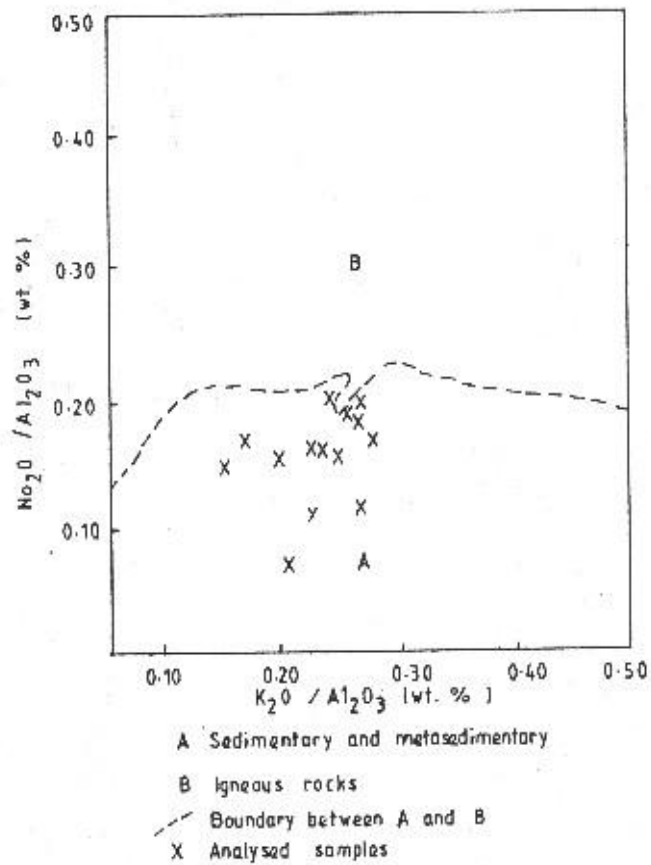Fig. 1 : Outline geology of Anka and showing the locations of gold mine. Modified from [21],

A   Sedimentary and metasedimentary

B   Igneous rocks

---   Boundary between A and B

X   Analysed samples

Fig.2: Na_2O/Al_2O_3 vs. K_2O/Al_2O_3 plot for metasedimentary rocks Uwet area (indicated field after 36)

CONCLUSIONS

The present study has confirmed the gold occurrences of ASB, as well as their overall mineralogical and chemical characteristics. The geochemical characterization of the ASB gold mineralization suggests a metamorphic origin for the gold mineralizing fluid which was generated and expelled during late brittle movements along the Anka fault, in line with those of[28,33,34]. A similar model was proposed by[8,49] to explain the metamorphic origin of the Au-minerallizing fluids at Bin Yauri (Zuru schist Belt) and Tsofon Birnin Gwari (Kushaka Schist Belt). This is also similar to what has been reported from many other areas of gold mineralization in the country and the world.

Economic concentration of gold mainly occur in veins[48,49,50] and it is used in industry, monetary and jewellery, which is one of the most popular and important uses of carat gold. Gold has been worked in the past on a big scale, and is still now been mined on a small-scale in the study area by traditional panning. Most of the gold deposits carry sulphide mineral like galena, pyrite, chalcopyrite and sphalerite that are rich in Cu, Pb and Ag. These three metallic deposits could be mine as associated ores during the exploitation of the gold deposit in the area.

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