Lithologic, Petrographic and Geochemical Search for By-passed Gold Mineralization within Mutumdaya Gold Field in Minna outskirts, North-Central Nigeria

Unuevho, O. M.[1], Ako, T. A.[2], Unuevho, C. I.[2*], Ejepu, S. J.[2], Akobundu, N. A.[2], Tahir, A.[1] and Jatau, B. S.[3]

[1]*PW Nigeria Ltd, Mining Division, Minna*

[2] *Department of Geology, Federal University of Technology, Minna*

[3] *Department of Geology and Mining, Nassarawa State University, Keffi*

[*] *Correspondence email:* c.unuevho@futminna.edu.ng

Abstract

By wildcat pitting, local artisanal miners established a lode gold mine within Mutumdaya in the Northern Nigerian Massif. The mine is now abandoned after a few years of mining. Wildcat pitting lacks the benefits of geoscientific investigations, and the mines so found remain unassessed discoveries. Some untapped gold mineralization does remain around such mines when abandoned. The mineralization constitutes by-passed gold mineralization. Lode gold mining will continue in Mutumdaya if by-passed gold mineralization is found within vicinity of the abandoned mine. This study identified by-passed gold mineralization prospects in immediate vicinity of the abandoned mine. This was achieved by searching for rocks that share similar lithologic, petrographic and geochemical attributes as rocks within the abandoned mine site. It involved surface lithologic mapping, thin section petrographic analysis, and elemental gold concentration analysis in rock samples, using X-Ray Fluorescence Spectrophotometer. The rock bodies were found to be kyanite schist, amphibole schist, quartz schist, and quartzite intruded by syntectonic biotite granite bodies. The quartz schist attained greenschist metamorphic grade, while kyanite schist and amphibole schist attained amphibolite facies metamorphic grade. The kyanite schist at the abandoned mine site contains 0.058 ppm gold concentration. This is 29 times average crustal gold abundance of 0.0000002 %. Outside the abandoned mine site, kyanite schist and amphibole schist contain 0.066 and 0.021 ppm gold concentration. They are respectively 33 and 11 times gold enriched. Gold was undetected in the quartz schist, quartzite and granite bodies. The kyanite schist outside the abandoned mine site is more enriched in elemental gold than the rock body that constitute gold ore within the mine. Apparently, rock bodies in the amphibolite metamorphic facies status constitute prospects for by-pass lode mineralization within the immediate vicinity of the abandoned gold mine. These prospects are at location 9°40'05"N, 6°48'50" E, and location 9°39'05"N, 6°48'40"E. Abandoned artisanal gold mines in the Northern Nigerian Massif and in other developing economies should be searched for by-pass lode gold mineralization, using integrated geoscientific methods.

Keywords: Wildcat pitting, by-passed gold mineralization, metamorphic facies, elemental gold concentration

INTRODUCTION

Informal artisanal mining dots the stretch of land from Minna through Gwada to Gurmana in North Central Nigeria (Kankara and Darma, 2016). Mutumdaya lies within Latitudes 9°39' 30" N to 9°40'12" N and Longitudes 6°48'35" E to 6°49'30" E on this stretch of land, where it constitutes part of the Basement Complex in the Northern Nigeria Massif (Figure 1). Main lithologic units within the basement complex are polymetamorphic migmatite-gneiss-quartzite complex of Archean to Middle Proterozoic age, Upper Proterozoic metasediments and metaigneous rocks, and Pan African intrusives generally called Older Granites (Woakes *et al.*, 1987).

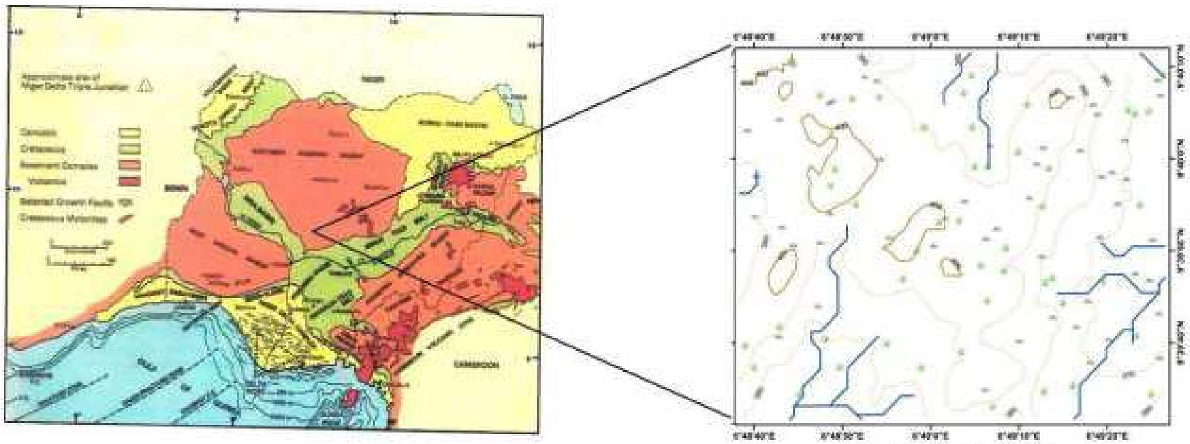

Figure 1: Location of Mutumdaya within Northern Nigerian Massif

According to McCurry (1989), Woakes *et al.* (1987) and Ajibade *et al.* (2008), the Archean to Middle Proterozoic rocks achieved high grade metamorphic status (upper amphibolite – granulite facies) while the Upper Proterozoic rocks belong to lower metamorphic grade (greenschist to low amphibolite facies). The Upper Proterozoic rocks form N – S trending schist belts. Their lithologic units include banded iron formation, schist, amphibolite and quartzite. The Older Granite intruded the Archean and Upper Proterozoic rocks during the Pan African orogeny (McCurry, 1989; Ajibade *et al.*, 2008; Obaje, 2013). The formation of ore deposits is often linked with hydrothermal fluids that commonly originate from igneous activity (Murphy, 2016; Revuelta, 2018). Thus, metamorphic rocks in the vicinity of igneous intrusives are potential ore deposit bearers. Most of the gold deposits in Minna lies within the Kushaka Schist Belt and adjoining Pan-African migmatite and granite bodies (Garba, 2002; Ajibade *et al.,* 2008). Mutumdaya gold field is within the Kushaka Schist Belt, and is regionally encompassed by Migmatite-Gneiss Complex, Older Granite and other schist belts (Unuevho, 2018).

Mining of lode gold deposits (gold mineralization within bedrock or weathered detritus) within Mutundaya gold field took place at a mine site located within Latitudes 9°39' 50" N to 9°39' 55" N and Longitudes 6°49'0" E to 6°50'0" E (Figure 2). This mine site together with its immediate vicinity constitutes the area studied, and covers a spatial extent of 3.3 km^2. Local artisanal miners found the mine by wildcat pitting. The approach lacks the benefits of geoscientific investigation, and this places the mine deposit among chance finds of Nwabufo-Ene and Mbonu (1988).

Figure 2: Lode gold mining at Location 9°39'55.3" 6°49'02.4" E

Figure 3: Mutundaya gold mine at location 9°39'55.3"N 6°49'02.4"E, presently in abandoned state

The mine is now abandoned (Figure 3), thereby creating a mining sustainability challenge in Mutundaya. Gold mineralization in mine found by wildcat pitting of artisans are unassessed discoveries. Some untapped gold mineralization does remain in the vicinity of such mines when abandoned. The mineralization constitutes by-passed gold mineralization. The term 'by-passed gold mineralization' is used in parallel sense to the term 'by-passed hydrocarbon deposit' employed in the petroleum industry to describe hydrocarbons trapped in inadvertently undeveloped reservoirs.

Identification of the by-passed gold mineralization will provide an opportunity for sustaining mining in the Mutundaya gold field. Searching for by-passed gold mineralization within immediate vicinity of an abandoned mine site found by wildcat pitting, requires lithologic, petrographic and geochemical characterization of the rocks at the mine site, and searching for immediate vicinity of the site with similar geoscientific attributes. This study pioneers in such rock characterization in Mutundaya gold field, and its objective is to identify by-passed gold mineralization in the mine's immediate vicinity. Establishing a host rock is an essential aspect of mineral prospecting. Gold mining in developing countries is significantly contributed to by artisanal miners, who are sparingly educated youth struggling to eke out livelihood by exploiting solid mineral resources. Like the Mutundaya gold field miners, they search for deposits by wildcat pitting. Consequently, there are chances of leaving behind by –passed mineralization in mine vicinity when the mines are abandoned. Thus the results of this study should be internationally significant in driving prospectors to deploy integrated geosciences techniques to investigate the vicinity of abandoned mines for possible by –passed gold mineralization.

Groves and Forster (1993) recounted that gold mineralization exists in geological settings that vary from sub-greenschist to upper amphibolite facies. They however remarked that at different localities, gold mineralization selectively occurs in lithologic units. This emphasizes that gold prospecting will be more successful at the local scale if metamorphic facies selected for its mineralization is identified (Sillitoe, 2006; Robert *et al*., 2007). Eskola (1920) first introduced metamorphic facies concept to differentiate rock associations within regionally metamorphosed terrains, using mineral assemblages that attained equilibrium at similar lithostatic pressure and temperature. Some of his metamorphic facies are greenschist facies and amphibolite facies. Bucher and Grapes (2011) as well as Penchuk (2021) defined metamorphic facies as metamorphic rocks that are genetically related in terms of lithostatic temperature and pressure. Winter (2020) emphasized that the prevalent lithostatic pressure and temperature constrain the mineral assemblage that develops during a metamorphic process. Sahin and Erkan (1999) used the presence of biotite, garnet, staurolite and orthoclase to differentiate metamorphic facies in Central Anatolia massif in Turkey. They associated kyanite and biotite with amphibolite facies. Mibel (2014) grouped quartz, feldspar and muscovite as comparatively universal minerals because they remain stable in wide temperature – pressure conditions, and as such inappropriate for facies definition. He emphasized the use of index minerals which he arranged in metamorphic upgrade direction as chlorite, biotite, garnet, staurolite, kyanite and sillimanite.

Groves and Forster (1993) also recounted that most gold deposits were discovered by combining basic surface geological mapping with either geochemical exploration or geophysical exploration or both. They stressed that many gold mines in Western Australia were discovered by drilling geochemical anomalies. According to Murphy (2016), the Prospector's Dictum is that gold is the best pathfinder for gold. Timkin *et al* (2016) employed lithochemical surveys to evaluate gold bearing potential in Akimov ore bearing area of Gory Atlas in the Russian Federation. They delineated gold-silver ore within the anomalous geochemical field. Noor *et al.* (2016) included petrography and X-ray fluorescence in their procedure for ascertaining facies of gold- hosted metamorphic rocks in Rock District of Malukul. Unuevho *et al* (2018) included lithochemical data, in the form of elemental composition, among the geoscientific data employed in the search for ore deposits in Garatu, North Central Nigeria. They established that spatial concentration of gold was above 900ppm, which far exceed the average crustal concentration (0.0000002%) within a considerable portion of the area.

METHODOLOGY

The first step towards achieving the study's objective was surface lithologic mapping. Lithologies of rock fragments obtained from the mine, and outcropping rock bodies within the mine site vicinity, were first identified in hand specimen, using texture and mafic colour index (MCI). The geographical co-ordinates of locations of the mine site and rock outcrops were obtained using Etrex version of hand held GPS (Geographical Positioning System). Six rock samples that represent the mine rock fragments and outcropping rock bodies within the mine site vicinity, were selected for thin section analysis and whole rock geochemistry. The six rock samples represent 3.3 km^2 spatial extent, which is the areal coverage of the studied mine's immediate vicinity. They constitute an average sampling density of about 2 samples per km^2. This is considered adequate in searching for by-passed gold mineralization within immediate vicinity of a once active gold mine. In thin section, the samples were examined with plane polarized light and cross polarized light of MEIJI manufactured petrographic microscope (N_p– 107B model and serial number 000341) to improve on rock identification made in hand specimen. The identified lithologic units were plotted on a topographic base map and the surface geological map was completed on 1:20,000 scale. Metamorphic facies were identified using Figure 4 as a template.

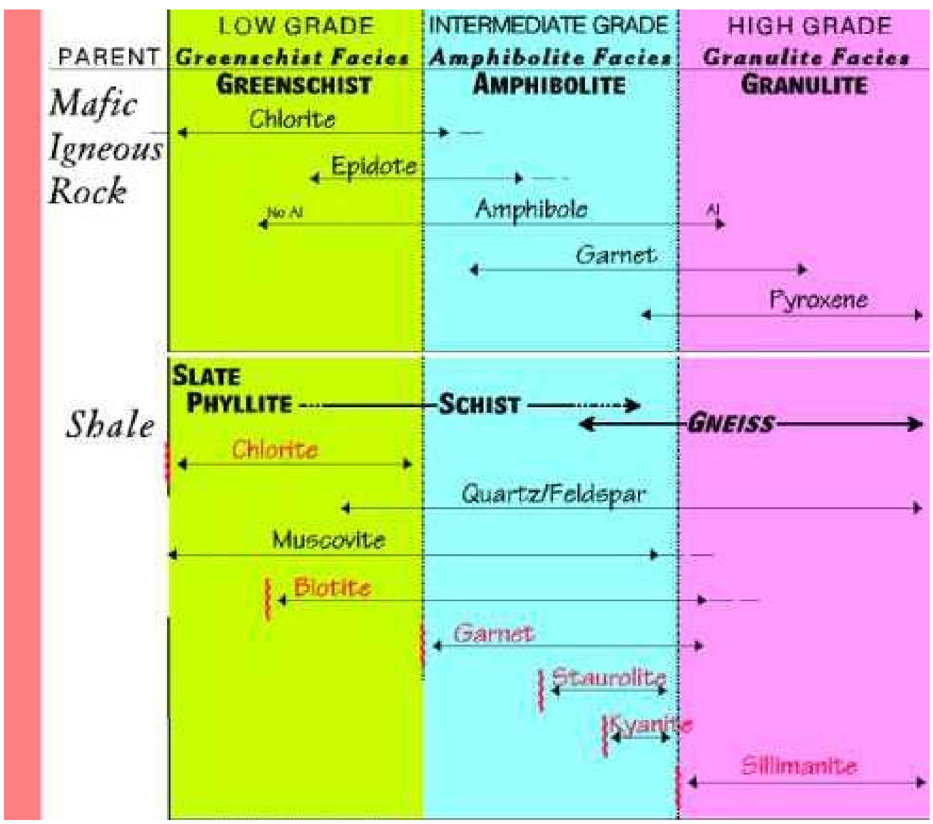

Figure 4: Template for metamorphic facies definition, using index minerals (Fichter, 2000)

Whole rock geochemistry of the representative lithologic samples was investigated at the geochemical laboratory of the Geological Survey Agency of Nigeria, Kaduna, using X- Ray Fluorescence Spectrophotometer, to obtain elemental gold concentration data. Each sample was pulverized and then homogenized in preparation for the elemental concentration determination.

RESULTS AND DISCUSSION

Figure 5 is a rock fragment dug up from the mine site. Quartz (Q), biotite (B), orthoclase (ORT) and kyanite (K) were seen in thin section view (Plates 1 and 2) of the sample (Sample 1) for the rock fragment. It was identified as kyanite schist in upper amphibolite metamorphic facies by virtue of observed schistose texture and presence of kyanite, in conformity with facies template given in Figure 4.

Figure 5: Kyanite schist at Mutumdaya mine pit (9°39'55.3" N; 6°49'0.24" E)

Its photomicrographs under plane polarized light (PPL) and cross polarized light (XPL) are plates 1 and 2 respectively.

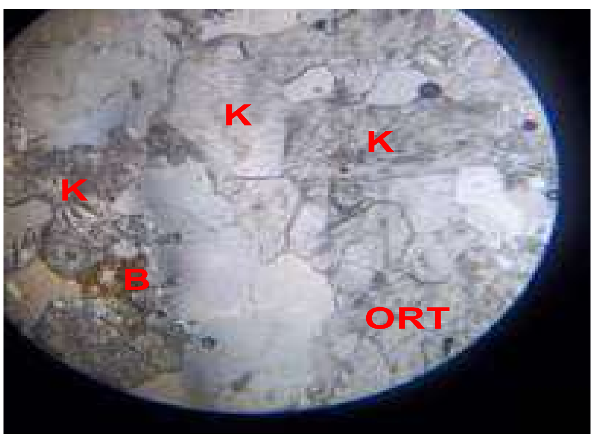

Plate 1: Photomicrograph (PPL) M40 for Sample1

Plate 2: Photomicrograph (XPL) M40 for Sample 1

Figure 6 is an outcrop at Latitude 9°39'52"N and Longitude 6º49'02"E, in the environs of the mine. Quartz, orthoclase and amphibole were observed in thin section (Plates 3 and 4) of its sample (Sample 2). It was identified as amphibole schist on account of its schistosity and dominant amphibole. The outcrop is in the amphibolite facies by virtue of the presence of amphibole, in with the facies template (Figure 4).

Figure 6: Amphibole schist at 9°39'52"N; 6°49'02"E

Plate 3: Photomicrograph (PPL) M40 for Sample 2

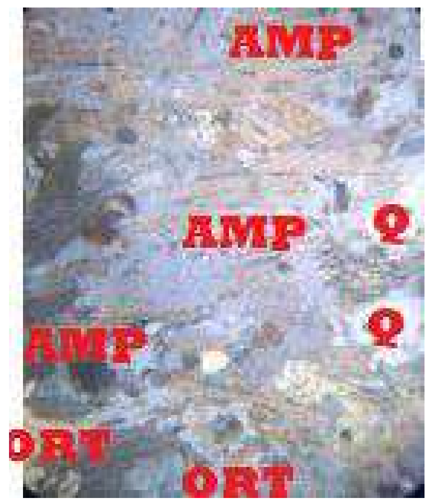

Plate 4: Photomicrograph (XPL) M40 for Sample 2

Figure 7 is a rock sample from a very poor exposure at Lat. N9°40'04" and Long E 6°48'50". Minerals observed in its thin section (Plates 5 and 6) are quartz, cummingtonite and kyanite (Sample 3). The schistose texture and presence of cummingtonite (an amphibole) and kyanite makes it amphibole schist in the amphibolite facies metamorphic grade.

Figure 7: Kyanite schist at 9°40'04"N and 6°48'50"E

Plate 5: Photomicrograph (PPL)M40 for Sample 3

Plate 6: Photomicrograph of sample 3 (XPL) M40

Figure 8 is a quartz schist outcrop at Latitude N 9°39'50.9'' and Longitude E6°49'3.7''. Photomicrographs (Plates 7 and 8) of a vein filling (Sample 4) in the schistose outcrop shows the presence of quartz, biotite and orthoclase. The combination of quartz, biotite and orthoclase places this rock in the upper greenschist facies, in conformity with the facies template in Figure 4.

Figure 8: Quartz schist outcrop at N9°39'50.9°49'3.7"E

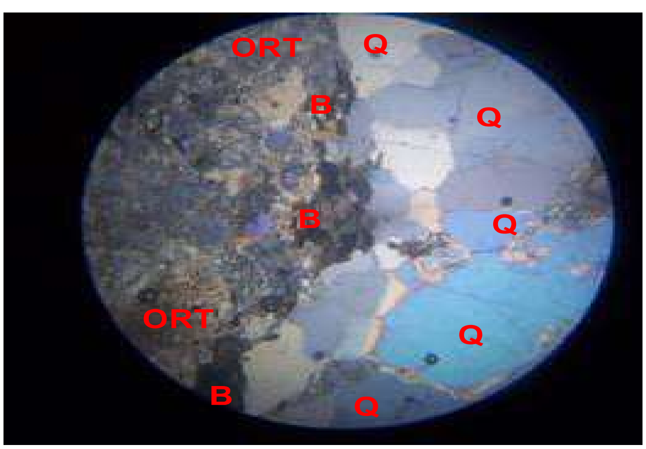

Plate 8: Photomicrograph of sample 4 (XPL) M40

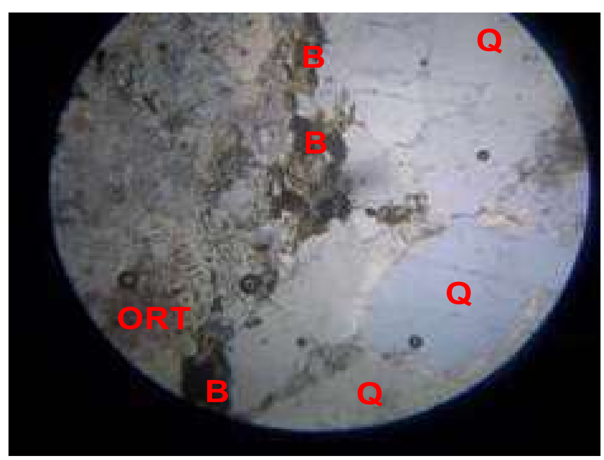

Plate 7: Photomicrograph (PPL) M40 for Sample 4

Figure 9 is quartzite outcrop at Lat. 9°40'01.4"N and Long 6°49'15.1"E.

Figure 9: Quarztite outcrop at Latitude N9°40'01.4"; Longitude E6°49'15.1"

The quartzite body is unferruginised, unlike most quartzite bodies in Minna and environs.

Both the schist and quartzite outcrops were intruded by medium to coarse grained biotite granite (Figure 10). The granite body is slightly foliated and therefore identified as syntectonic biotite granite.

Figure 10: Granite body at Latitude N9°40' 03.3" and Longitude E6°49'12.9"

Photomicrograph of the thin section from the granite sample – Sample 5 (Plates 9 and 10) - shows quartz, biotite and orthoclase.

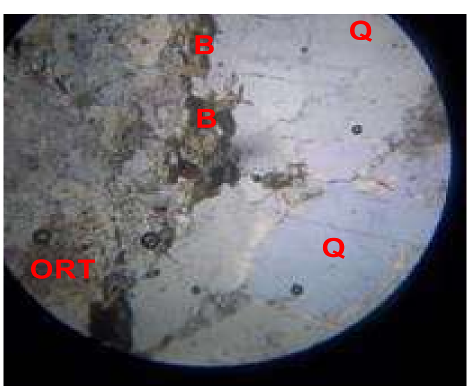

Plate 9: Photomicrograph of granite (PPL) M40 (Sample 5)

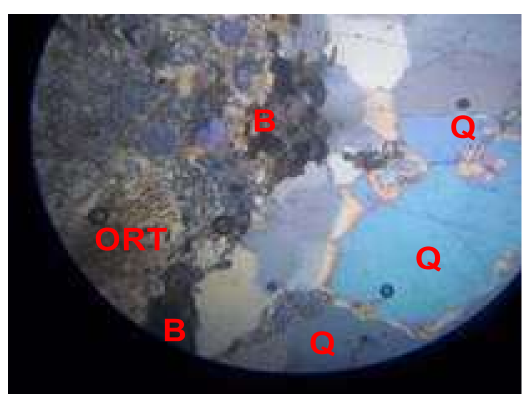

Plate 10: Photomicrograph of granite (XPL) M40

Figure 11 is the geological map produced from the lithological units.

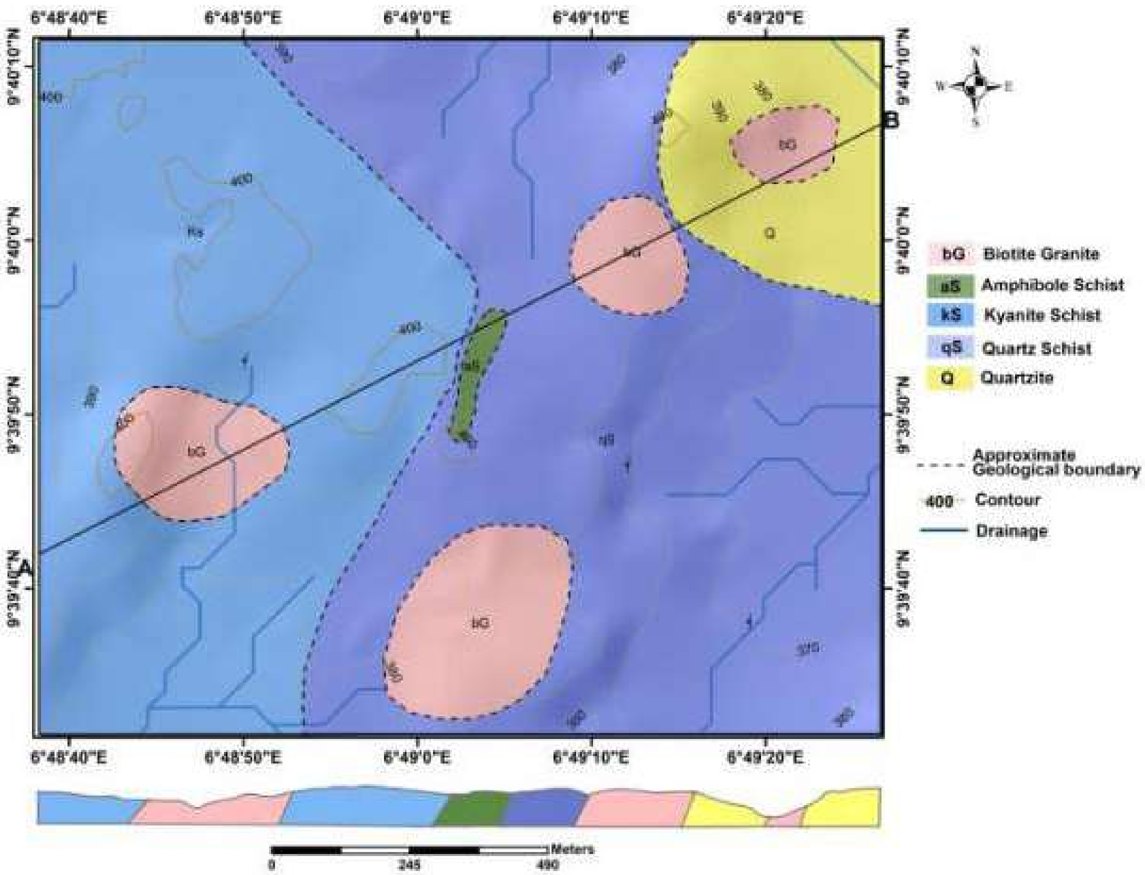

Figure 11: Geological map of Mutumdaya

Results of the X-Ray Fluorescence spectrophotometer analysis for gold concentration (in ppm) in the lithologic samples are presented in Table 1.

Table 1: Trace Element Concentration (in ppm) of some lithologic samples

SAMPLE	LATITUDE	LONGITUDE	Au	ROCK TYPE
1	9° 39'55.3"N	6° 49'0.24"E	0.058	KYANITE SCHIST
2	9° 39'05"N	6° 48'40"E	0.021	AMPHIBOLE SCHIST
3	9° 40'05"N	6° 48'50"E	0.066	KYANITE SCHIST
4	9° 39'50.9"N	6° 49'3.7"E	ND	UPPER GREENSCHIST FACIES SCHIST
5	9° 40'01.4"N	6° 49'15.1"E	ND	QUARZITE
6	9° 40'03.3"N	6° 49'12.9"E	ND	GRANITE

ND means Not Detected

The S1 sample is a kyanite schist fragment obtained from the exhausted mine site. The kyanite content places the schist in upper amphibolite facies metamorphic grade. Its elemental Au concentration is 0.058 ppm. This gives a gold enrichment factor of 29 when divided by an average crustal abundance of gold (0.0000002 %).

Rock sample S3 is from a schist outcrop at Latitude N9° 40'04" and Longitude E6° 48'50". The elemental Au concentration obtained for this sample is 0.066 ppm. Gold is 33 times enriched in this schist than its average crustal composition. Its enrichment factor (33) is higher than the enrichment factor (29) that characterise the rock fragment from the exhausted mines. Like rock fragments from the exhausted mine site, the S3 rock sample contains kyanite and thus is in upper amphibolite facies metamorphic grade. Elemental gold concentration is 0.032 ppm for the amphibole schist (sample 2) at Latitude N9° 39'52" and Longitude E6° 40'02". Gold is 15 times enriched in this rock body, which is also in the amphibolite facies. Thus all rock bodies in the amphibolite metamorphic facies status constitute prospects for by-pass lode gold mineralization within the immediate vicinity of the abandoned gold mine. Lode gold mineralization hosted in amphibolite facies have been reported by some workers, among whom are Ridley *et al.*(1998), Simard *et al.*(2013), and Kalinin *et al.*(2019). Gold was undetected in the schist outcrop in upper greenschist facies, as well as in the quartzite and granite rock bodies. Since gold is the best pathfinder for gold (Murphy, 2016), the quartzite, granite and upper greenschist facies schist in Mutundaya are barren of gold mineralization. Figure 12 shows positions of the abandoned gold mine and proposed new gold mine for by-passed gold mineralization in Mutundaya.

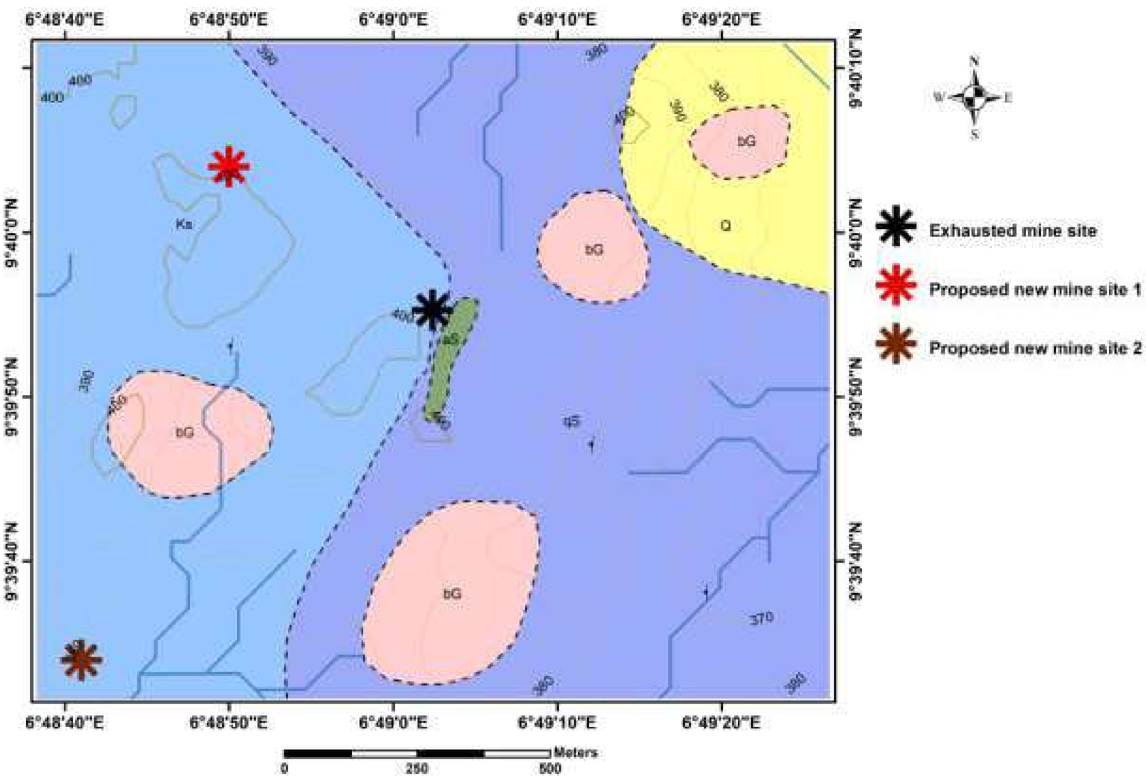

Figure 12: Locations of abandoned gold mine and proposed new gold mine for by-passed gold mineralization in Mutundaya

CONCLUSION

Textural and mafic colour index analysis of rock samples in hand specimen, as well as thin section petrographic analysis revealed the rock bodies within the mine and its immediate vicinity to be kyanite schist, amphibole schist, quartz schist, unferruginized quartzite and syntectonic biotite granite. Observed field relationship showed that the syntectonic biotite granite intruded the schist bodies and the quartzite. By virtue of kyanite being an index mineral, the kyanite schist achieved amphibolite metamorphic facies status. The presence of orthoclase and amphibole in the amphibole schist revealed that the schist attained the upper greenschist facies status. Elemental gold concentration varies from 0.032 to 0.066 ppm in the amphibolite facies schist, and is higher than the elemental gold concentration of 0.055 ppm in the mine rock body at some locations. The gold enrichment in these schist bodies ranges from 15 to 33 times higher than the average crustal elemental gold concentration. The schist in amphibolite facies metamorphic grade constitutes by-passed lode gold mineralization bodies within the immediate vicinity of the abandoned gold mine. It is recommended that all abandoned gold mines once operated by artisanal miners should be explored for by-passed gold deposits in the vicinity of the mines, in the Northern Nigerian Massif and in countries with significant artisanal mining, using integrated geoscientific methods.

REFERENCES

Ajibade, A.C., Anyanwu, N.P.C., Okoro, A.U. and Nwajide, C.S. (2008). The geology of Minna Area, Geological Survey Agency of Nigeria, Madol Press, Abuja112p.

Al-Sayid, K.Z. (2019). Geological and geochemical techniques.

Bucher, K. and Grapes, R. (2011). Petrogenesis of metamorphic rocks, 8th Edition, Springer-Verlag, Berlin, 419p.

Eskola, P. (1920). The mineral facies of rocks. Norsk. Geol. Tidsskr.6(1922), 143 – 194

Fichter, L.S. (2000). Barrovian metamorphism and metamorphic grade. Jmu geology.

Csmgeo.csm.jmu.edu/geollab/fichter/metarx/barrovian.htl

Garba, I. (2002). Late PanAfrican tectonics and origin of gold mineralization and rare- metal pegmatites in Kushaka Schist Belt, Northwestern Nigeria. J. Mining and Geology, v.8, 1-12.

Groves, D.I. and Foster, K.P. (1991). Archean lode gold deposits. In: Gold metallogeny and exploration. Springer, Boston. https://doi.org/10.1007/979-1-14613-0497-5-3

Haldar, S. (2018). Mineral Exploration, 2nd Edition, Elsevier, 370p.

Kalinin, A.A., Kazanov, O.V., Bezrukov, V.I. and Prokofiev, V. Yu. (2019). Minerals, 9(3), https://doi.org/10.3390/min 9030137

Kankara, I. and Darma, M.R. (2016). A review of gold metallogeny in Nigeria. International Journal of Research in Chemical, Metallurgical and Civil Engineering, 3(2), 49-57.

Mc Curry, P. (1989). A general review of the Geology of the Precambrian to Lower Paleozoic rocks of Northern Nigeria.In: Geology of Nigeria. Ed. Kogbe, C.A., 2nd Ed., pp13 – 37.

Mibel, G. (2014). Introduction to types and classification of rocks. Short Course IX on Exploration for Geothermal Resources. UNU – GTP and Kengen, Kenya

Murphy, M.E. (2016). The trace element chemistry of arsenopyrite and its potential use as an indicator mineral for gold deposit exploration in Australia. PhD thesis unpublished. The University of Western Australia, 357p.

Noor, M., Tonggirch, A. and Mulana, A. (2016). Type of gold hydrothermal deposits in Metamorphic Rock District, Buru Province, Malukul. International Journal of Engineering, 3, 39 – 45.

Nwabufo-Ene, K.E. and Mbonu, W,C. (1988). The metasedimentary belts of the Nigerian Basement Complex – Facts, Fallacies and new Frontiers. In: Precambrian Geology of Nigeria. Eds: Oluyide, P.O., Mbonu, W.C., Ogezi, A.E., Egbuniwe, I.G., Ajibade, A.C., Umeji, A.C., pp 35-65.

Obaje, N.G. (2013). Updates on the geology and mineral resources of Nigeria. Onaivi printing and publishing Co, Abuja, 213 p.

Panchuk, K. (2021). Physical Geology. First University of Saskatchewan Edition

Revuelta ,M.B. (2018). Mineral Resources, Springer Nature, Switzerland, 641p

Ridley, J., Groves, D.I. and Knight, J. H. (1998). Dold deposits in Amphibolite and Granulite Facies Terranes of Archean Yilgam Craton, western Australia: Evidence and implications of synmetamorphism mineralization. Doi:https//doi.org/10.5382/Rev/11.12

Robert, F., Brommeckar, R., Bourne, B.T., Dobak, P.T.,McEwan, C.T., Rowe, R.R. and Zhou, X. (2017). Models and Exploration models for major Gold Deposit Types. In: Proceedings of Exploration 07: Fifth Decennial International Conference in Mineral Exploration. Eds: Mikerett, B., 6991-711.

Sahin, M.B. and Erkan, Y. (1999). Nineral Res Expl., 121, 83-100

Sillitoe, R.H. and Thompson, J.F.H. (2006). Changes in Exploration Practice: consequences for discovery. Society of Economic Geologists Special Publication 12, 193-219.

Timkin, T., Voroshilov, V., Yanchenko, T. (2016). IOP conference : Earth Enviroon.Sci

430120B. Geology, geochemistry and gold-ore potential assessment within Akinmov ore-bearing zone, the Altai territory, Russia.

Unuevho, O.M. (2018). Geology and Geochemistry of Rocks around Mutundaya Gold Mine, Sheet 164SW, North- Central Nigeria. Unpublished BTech Geology Thesis, Federal University of Technology, Minna, Nigeria, 51p.

Unuevho, C.I., Oragba, F.U., Umar, B.S., Oduleke. R.B., Saliu, S., & Udensi, E.E (2018). Geological, Geochemical, and Geoelectrical Prospecting for Ore Mineral Resources in Garatu, North- Central Nigeria. *International Journal of Geology and Earth Sciences ,4(1)*,30-44.

Winter, J.D. (2020). Metamorphic Grades, Zones, Facies and Facies Series: in principles of

Igneous and metamorphic petrology. IUGS – SCRM: https/:www.bjs.ac.uk/scmr/home.html

Woakes, M., Rahaman, M.A. and Ajibade, A.C. (1987). Some metallogenetic features of the Nigerian Basement Complex. Journal of African Earth Science, 16(5), 655-664.