

Geology and genesis of gold-bearing quartz veins at Bini Yauri and Okolom in the Pan-African domain of western Nigeria

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Received 21 September 1987; accepted in revised form 26 December 1987

Key words: dewatering, fluid inclusions, goldveins, metamorphism, remobilization, schist belts

Abstract

The Bini Yauri and Okolom primary gold occurrences are localized within the Precambrian to Lower Paleozoic schist belts of western Nigeria. These belts consist of gneisses, migmatite, quartzite, mica schist, phyllites, amphibolite, and granite which represent suites of metasedimentary, metavolcanic and intrusive rocks that are infolded into the Nigerian basement complex. Gold-bearing veins in the Bini Yauri lode occur as lenticular bodies within altered mica schists at the contact zone with a granite porphyry. At Okolom, the veins are hosted in sheared zones within a sequence of silicified biotite gneiss, amphibolite and schist. Vein contacts in the two deposits are generally sharp, steeply dipping at ca. 80° E and commonly contain stockworks and discordant stringers adjacent to the wall rocks. Vein constituents are essentially quartz, sericite, chlorite, albite, tourmaline calcite, magnetite and hematite. These are commonly intergrown with pyrite, pyrrhotite, chalcopyrite, arsenopyrite, galena, sphalerite and argentite which altogether may constitute up to 3% of the vein systems. Alteration minerals like sericite, chlorite, epidote, calcite and quartz are common in wall rocks adjacent to veins. The alteration minerals are commonly associated with quartz, magnetite, ilmenite, hematite, zircon, rutile and limonite. Fluid inclusion studies in vein quartz reveal a bimodal distribution of filling temperatures which suggests at least 2 temperature regimes centred on 170° C and 240° C up to a maximum of 320° C during mineral deposition. Salinity estimates for the ore fluid average 1.5 equivalent weight percent NaCl and ore precipitation appears to have taken place at a minimum depth of about 1.4 km.

Our study of the contacts, shape, petrography and fluid inclusion aspects of the Bini Yauri and Okolom vein systems suggests that gold mineralization in the two localities and in the Nigerian schist belts in general may have evolved as a result of the metamorphic dewatering of thick sequences of clastics, shales and their associated volcanic rocks within the Precambrian to Lower Paleozoic basement complex. Several stages of remobilization and reconcentration of vein constituents appear to have taken place during succeeding thermotectonic events.

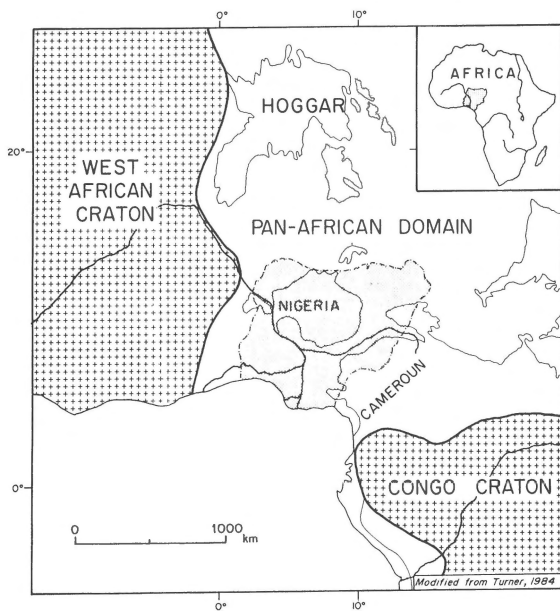


Fig. 1. Location of Nigeria in the Pan-African domain of West Africa.

Introduction

The gold-bearing quartz veins at Bini Yauri and Okolom represent two examples of the series of primary gold occurrences within the Precambrian to Lower Paleozoic schist belts of Western Nigeria. The Nigerian schist belts are linear domains of metasedimentary, metavolcanic and intrusive igneous rocks in the Pan-African mobile belt which separates the West African craton from the Congo craton (Fig. 1). Primary gold occurs in the schist belts from the Ilesha area in the southern part through Bini Yauri in the middle part, and in the Maraba area in the northern part of the belts (Fig. 2) (Woakes & Bafor, 1982). Primary gold in these locations and adjacent prospects occurs dominantly in quartz-mica veins, quartz-sulphide veins, quartzofeldspathic veins and in the alteration halos surrounding the veins. Gold mining in the schist belts has been mostly confined to eluvial occurrences adjacent to and several metres away from known primary occurrences. Intermittent mining from alluvial, eluvial and gold quartz veins pro-

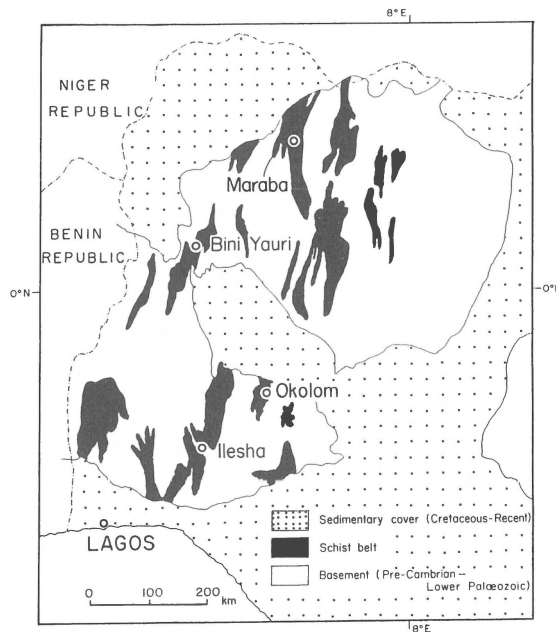


Fig. 2. Positions of Bini Yauri and Okolom in the Nigeria schist belts.

duced over 12,000 kg gold according to post-colonial mining records.

Despite the importance of the Nigerian gold-bearing schist belts, information about the geological details of the primary gold-bearing quartz veins is generally lacking. Previous reports of Russ (1933), Truswell & Cope (1963), De Swardt (1981) and Woakes and Bafor (1982) have given some general descriptive information on the mineralization of parts of the schist belts with little emphasis on their genetic aspects. The objective of the present paper is to describe in some detail the geology and genetic aspects of two major gold-bearing districts which have seen intermittent mining in a wide varieties of lithologies. The Bini Yauri veins consist of quartz veins primarily in mica schist and the Okolom veins are in a sequence of biotite gneiss, amphibolite and talc tremolite schist. A detailed description of the geology, mineralogy and fluid inclusion aspects of these deposits is followed by discussion and interpretation of the nature of the ore forming fluids at Bini Yauri and Okolom in particular and the schist belts in general. This study

is a part of an on-going project on metallogeny in Nigeria initiated in the Department of geology, University of Ilorin.

Geological setting

Bini Yauri and Okolom lie within the northwestern and southern parts of the northerly trending schist belts respectively (Fig. 2). In these general areas, the major groups of rocks are predominantly metasediments and metamorphosed mafic and ultramafic igneous bodies that are distributed within an ancient gneiss-migmatite complex. These metasediments and metavolcanics are deeply infolded into Precambrian basement gneisses and migmatite and intruded by granitic plutons during the Pan-African (600 ± 100 Ma) orogeny. The Precambrian gneisses and migmatite bear imprints of Liberian (ca. 2500 Ma) and Eburnean (ca. 2000 Ma) tectonic events (Oversby, 1975) although the enclosed metasediments and mafic volcanic rocks are assigned to Upper Proterozoic (Turner, 1983). Earlier authors (Grant et al., 1972) reported imprints of the Kibaran event (ca. 1200 Ma) within some parts of the schist belts. The regional foliation trend and principal lineaments in the schist belts are generally north-northeast and the metamorphic grade in the metasediments is dominantly that of greenschist, although high grade zones (e.g. lower to upper amphibolite facies) are common within the older gneiss-migmatite complex. These schist belts have been compared with the greenstone belts in Archean geological settings (Wright & McCurry, 1970). Although the Nigerian schist belts do have many features in common with Archean greenstone belts especially with respect to their size, synclinal structures, low metamorphic grade and the presence of volcanic and clastic rocks and their associated banded iron formation and gold mineralization, they are characterised by the predominance of metasediments and lesser volumes of volcanic rocks compared with Archean greenstone belts.

In the Bini Yauri area, (Fig. 3) gneisses and schist are intruded by a porphyritic 'older granite'. The granite body is associated with sheared con-

tacts along the southwestern and eastern margins. Prominent foliation trends is generally to the north. At Okolom (Fig. 8), a suite of biotite gneiss is interlayered by a variety of mica schist/talc schist and a mafic complex composed mostly of amphibolite. The mafic complex is confined to an antiformal axis within the biotite gneiss.

The geotectonic setting of the basement rocks and the infolded schists has been a subject of controversy in recent years in terms of plate tectonic models. One argument suggests a Himalaya-type collision between the West-African craton and an active margin on the east. During the proposed collision in mid to late Proterozoic time the Eburnean (2200 ± 200 Ma) gneisses and metamorphic rocks were reactivated (Black et al., 1979). Supracrustal rocks were infolded to form the north-south linear schist belts and the schist belts were later intruded by granitoid rocks of Pan-African (ca. 600 Ma) age. Rahaman (1981) suggested that the Pan-African (600 ± 100 Ma) event involved the opening and closing of a volcanic island arc that developed to the east of the West-African Craton. Mafic rocks of the schist belts are thought to have been derived from two different magmatic sources; one with ocean floor affiliations and the other with island arc characteristics. Ocean closure is thought to have caused the intrusion of the Pan-African (600 ± 100 Ma) granite.

Apart from these models, Olade & Elueze (1979) considered the schist belts as parts of a Proterozoic succession that was developed within an ensialic mobile belt as a result of extensional tectonics involving crustal thinning, doming and rifting. The geological characteristics of rock assemblages in the schist belts are compatible with an ensialic mobile belt on a thin Proterozoic crust which provided access to magmatic materials from upper mantle levels. Metamorphosed mafic-ultramafic sills and flows (presently amphibolite) and their associated metasediments (schists, phyllites) banded iron formation, impure clastics and volcanoclastic sequences in these belts are believed to be products of volcanic eruptions and sedimentation of a mid to late Proterozoic aulacogen (Olade & Elueze, 1979). Although age relationships of the lithologies in the schist belts is still controversial as

the imprints of the Kibaran event (ca. 1200 Ma) are represented in some parts of the belts (Baer, 1981). Ogezi (1977) suggested that the ensialic reworking of the crust centred at the 600 ± 100 Ma period is particularly significant in the evolution of the schist belts.

Petrography

Gold-bearing quartz veins at Bini Yauri and Okolom are hosted in many lithologies. These include fine-grained mica schists in Bini Yauri area and biotite gneiss, amphibolite and talc-tremolite schist in the Okolom area.

The Bini Yauri veins are lenticular quartz bodies localized in the contact zone between a mica schist and porphyritic granite (Fig. 3). The veins vary from 0.5 cm to 0.5 m width along a strike length of over 2 km (Fig. 4). Vein contacts are generally sharp and steeply dipping at ca. 80° E. Vein stockwork and discordant stringers are commonly distributed along the southwestern sheared contact of the porphyritic granite (Fig. 3). Mineralogy and texture of the porphyritic granite is similar to the older granite suite of Pan-African (ca. 600 Ma) age.

Two types of mica schist are distinguished around the intrusive body; an altered schist and an unaltered variety. The altered schist is host to the Bini Yauri veins. Alteration is confined to within approximately 50–250 m of the granite contact. The rock is light to dark green in colour, well foliated and consists of very fine grained alignments of quartz set in a matrix of altered feldspar, sericite, chlorite, calcite, epidote and rutile. Sericite represents up to 70% of the altered schist. The sericite has almost completely replaced plagioclase feldspar to a large extent. Quartz, together with altered feldspar and sericite form excellent compositional laminations (Fig. 5). Granular quartz occurs as conformable and disconformable veinlets (Fig. 6) giving the rock a stockwork appearance. In some cases, quartz tourmaline veinlets crosscut the schistosity (Fig. 7).

Sulphide minerals occur in concordant and discordant quartz-sericite veins and the quartz-tourmaline veinlets. Pyrite is commonly scattered

throughout the altered schist. The common sulphide minerals in the veins include pyrite, pyrrhotite, arsenopyrite, chalcopyrite, marcasite, sphalerite and galena. Pyrite, pyrrhotite, chalcopyrite, sphalerite and marcasite occur as euhedral to subhedral grains in many instances while ilmenite occur as irregular grains, streaks and overgrowths on pyrite. Blebs and irregular grains of galena are common in some veinlets and pyrite is a common replacement of chalcopyrite and pyrrhotite. The pyrite in turn is commonly coated or entirely replaced by limonite. Magnetite grains in the veinlets are commonly intergrown with hematite which appear to have formed as a result of martitization. The magnetite grains contain up to 0.4% Cr_2O_3 . The sulphide minerals represent less than 3% of the vein constituents. Free gold rarely occurs in the veins although high gold values occur with increasing content of sulphide minerals. Small ($4 \mu\text{m}$) inclusions of gold were observed in chalcopyrite in some instances. Gold values in the quartz veins average 7 g/tonne over considerable sections of drill core.

The unaltered schist approximately 70 m or more away from the granite/schist contact is generally weakly foliated with minor development of quartz veins and segregations compared with the altered rock. Sericite in the rock is less than in the altered schist as most feldspars in the rock are unaltered. Indeed the quartz and feldspar grains in the unaltered rock lack any preferred orientation. The unaltered schist may be pyritic but with no significant gold content. Our petrographic studies suggest that silicification and sericitisation of the schist are related to shearing which accompanied sulphide and gold precipitation.

At Okolom, gold-bearing quartz veins and lenses are confined to a sequence of silicified biotite gneiss, amphibolite and talc tremolite schist (Fig. 8). The veins run north-north-east crosscutting the north-south foliation of the gneiss, schist and amphibolite for about 800 m and continue intermittently for 3 km along strike. The veins are generally steeply dipping, pinch and swell and may be 2 m wide in outcrops. Most of the vein systems are confined to a centrally located antiform, occupied by amphibolite and talc schist within the biotite

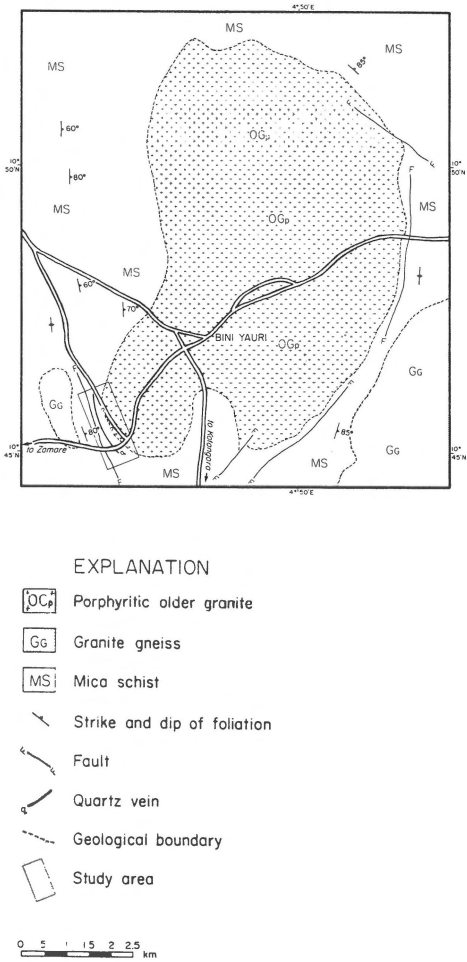


Fig. 3. Geological map of the Bini Yauri area. Boxed area is shown in Fig. 4.

gneiss. Vein contacts are strongly sheared and the contact zones consist of quartz, sulphide stockworks and stringers. The wall rocks adjacent to vein contacts are typically altered with a remarkable development of sericite, chlorite, tourmaline, zircon, rutile and hematite. Where quartz veins have been extensively fractured, plates of muscovite and fibres of tourmaline are common. Fractured milky quartz in the veins and adjacent wall rock commonly contain pyrrhotite, pyrite, marcasite, chalcopyrite and argentite in order of decreasing abundance. These sulphide minerals represent only about 2% of the vein constituents and they are

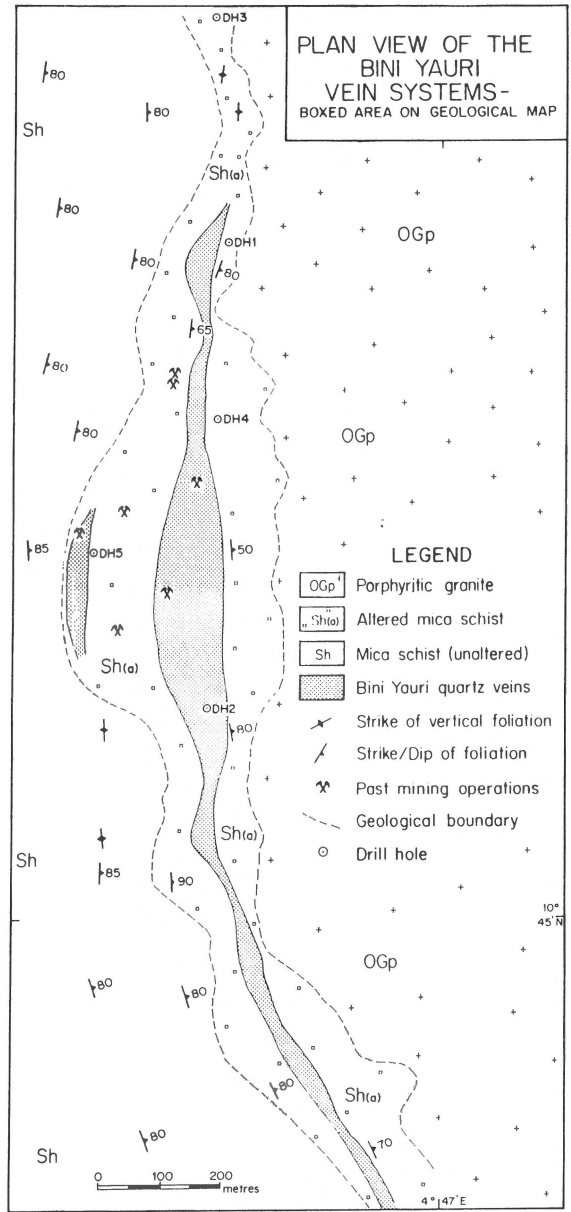


Fig. 4. Plan view of the Bini Yauri vein systems.

commonly associated with magnetite, ilmenite, zircon and rutile. Native gold is rare in polished sections although panning of weathered altered wall rock and vein material reveals very fine-grained gold.

Biotite gneiss is the predominant wall rock for the veins. Foliation shows shallow dips and gener-

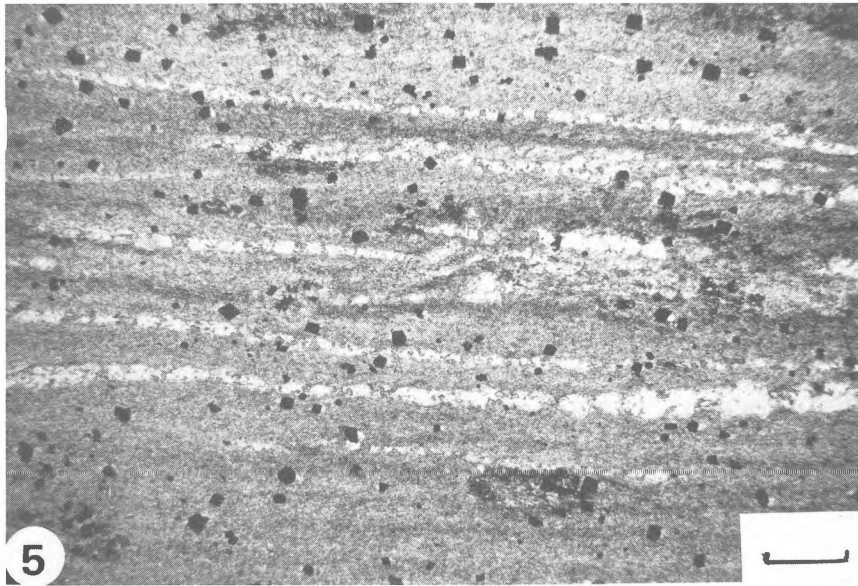


Fig. 5. Finely laminated pyritic schist with distinct compositional laminations. Notice the conformable quartz layering (white bands) partly deformed at the centre. Transmitted light, bar scale = 2.5 mm.

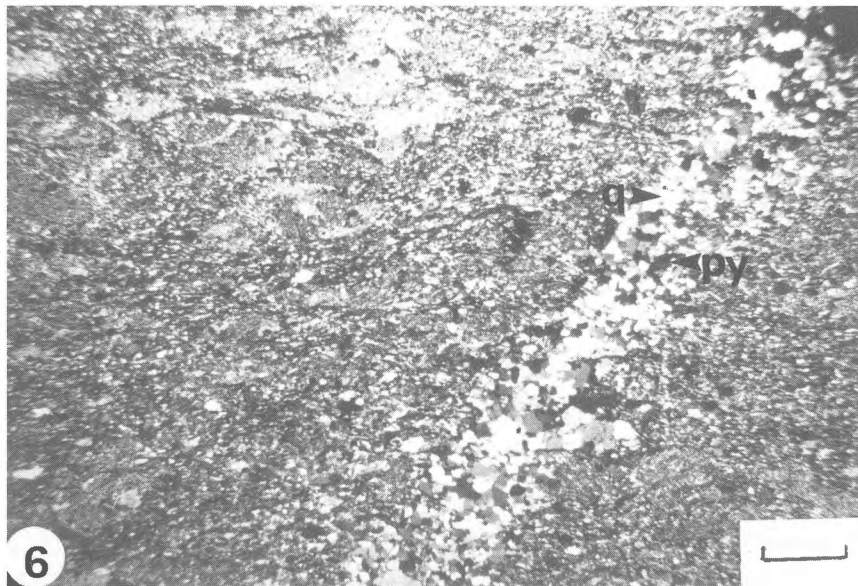


Fig. 6. Crosscutting quartz sulphide veinlet in an altered schist, q = quartz; py = pyrite. Transmitted light, bar scale = 2.5 mm.

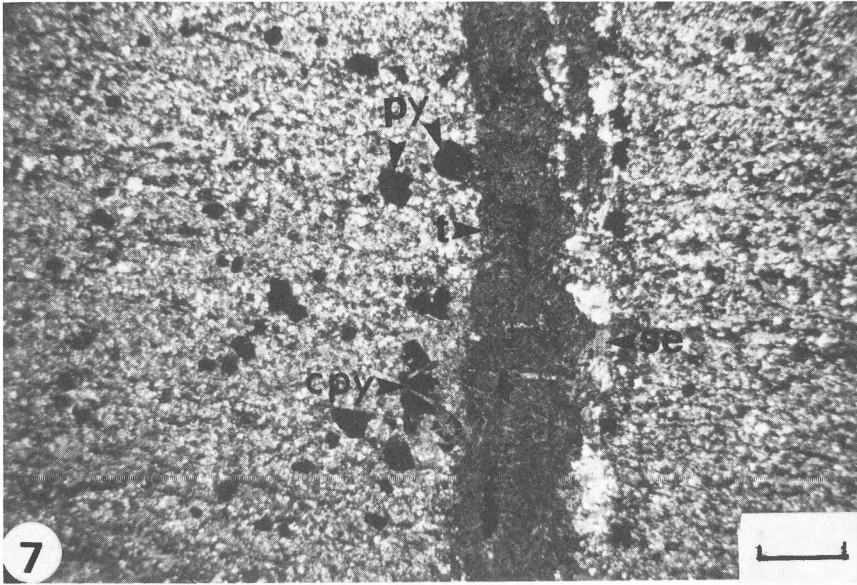


Fig. 7. Crosscutting tourmaline – sericite – sulphide veinlet in altered schist. Notice the growth of sericite on the wall of the veinlet. Later fractures in the tourmaline are filled with sericite; t = tourmaline, se = sericite, py = pyrite, cpy = chalcopyrite. Transmitted light, bar scale = 2.5 mm.

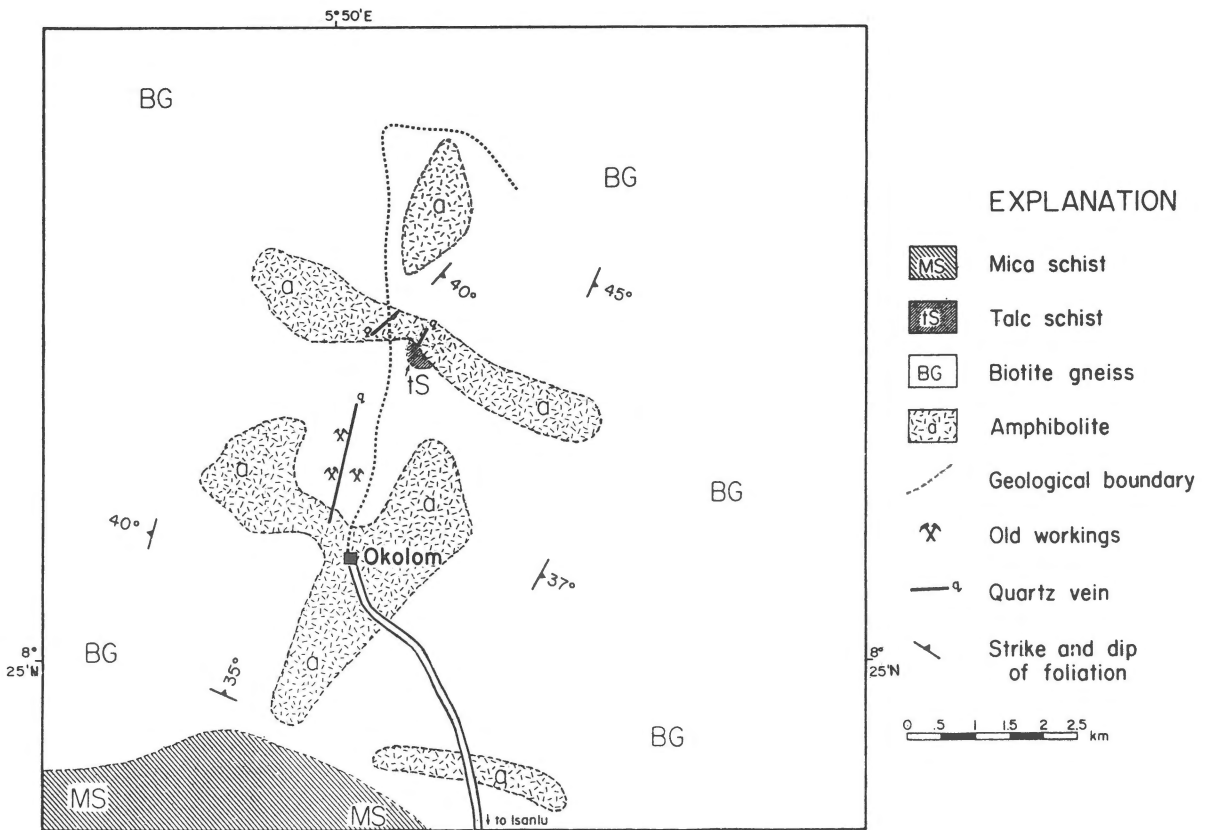


Fig. 8. Geological map of the Okolom area.

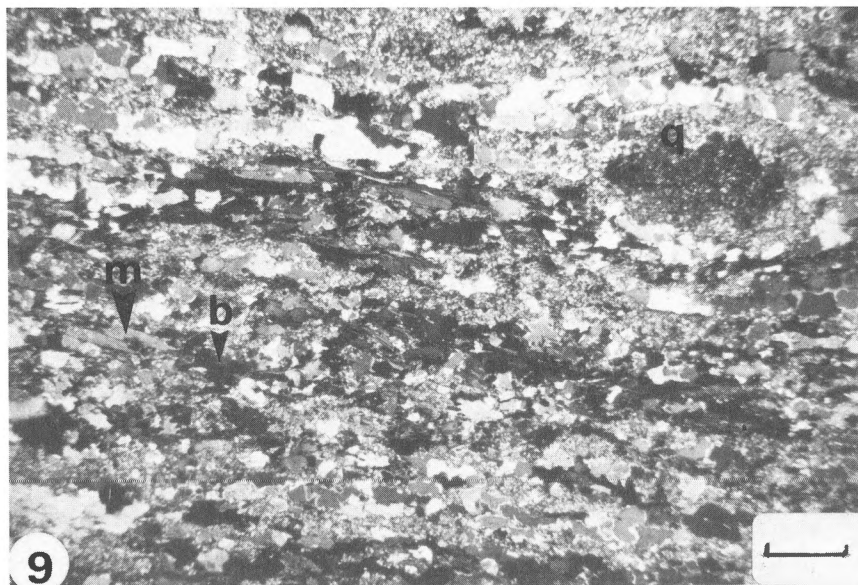


Fig. 9. Silicified biotite gneiss; host rock for the Okolom veins in crossed polars. Notice the lath shaped crystals of biotite and muscovite defining lineation and cryptocrystalline quartz in pressure shadows; b = biotite; m = muscovite; q = quartz. Bar scale = 2.5 mm.

ally northerly trends. The rock consists of lath-shaped biotite, altered feldspar, hornblende, magnetite, ilmenite, rutile, chlorite and sericite (Fig. 9). The rock is highly silicified adjacent to the quartz veins and commonly contains pyrite.

This observation together with the remarkable development of quartz sericite, chlorite and tourmaline in the wall rocks adjacent to veins suggest that silicification, sericitization and chloritization processes accompanied sulphide and gold mineralization. Talc tremolite schist and amphibolite within the gneiss are extremely retrograded with the extensive development of chlorite replacing hornblende. Veins in the talc tremolite schist and amphibolite consist of similar sulphide and oxide minerals as those in the biotite gneiss although magnetite content in the amphibolite may be up to 5%.

Fluid inclusion study

Fluid inclusion studies were carried out on twelve samples of quartz-chlorite-sericite veins, quartz-sulphide veins and quartzofeldspathic veins of Bini Yauri and Okolom. Of the three groups of vein

systems, the quartz-sericite-chlorite veins and quartz-sulphide veins were the most useful for inclusion work as the quartzofeldspathic veins, which are generally hematite-bearing, contain no usable inclusions. Fluid inclusions in quartz are generally ovoid, tubular or irregular in shape. They range from 4 μm to 35 μm in their longest dimensions and all have two phases, a liquid phase and a vapour phase. The vapour phase varies from 2 to 12 volume percent but commonly is about 5%. Some of the inclusions are distributed mostly along the crystal growth zones while others are confined to the network of fractures in quartz. Some isolated inclusions are randomly distributed away from growth and fracture zones. This suggests that at least some of the inclusions studied are primary.

Homogenization temperature (T_h) by vapour disappearance were recorded from 49 inclusions in the Bini Yauri and Okolom veins through the use of a video-equipped U.S.G.S. gas flow heating/freezing stage in the Economic Geology laboratory of Dr. Marcos Zentilli at Dalhousie University, Halifax, Canada. Reproducibility was better than $\pm 1.5^\circ\text{C}$ within the temperature range measured.

A bimodal distribution of temperature with a

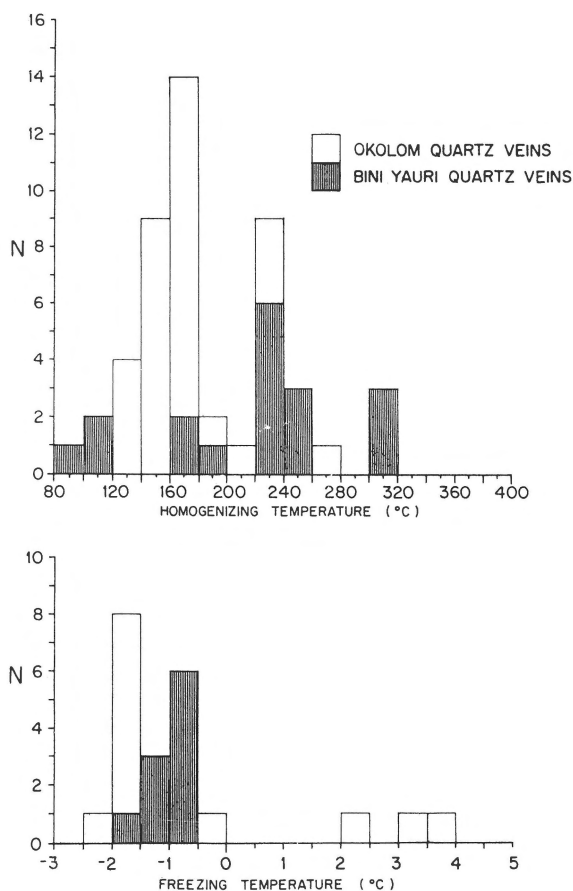


Fig. 10. Fluid inclusion homogenization and freezing data for the Bini Yauri and Okolom veins.

low temperature mode between 160 and 180°C and a higher temperature mode between 220 and 240°C were identified in the two localities (Fig. 10). The high temperature (220–240°C) mode appears to be more pronounced in the Bini Yauri vein systems while the low temperature mode (160–180°C) prevailed at Okolom (Fig. 10). It is interesting to note that the two populations are represented in both deposits. The two homogenization temperature populations are interpreted as representing at least two episodes of shearing, mineral deposition and recrystallization in the veins.

In the Bini Yauri sulphide-bearing quartz veins, the homogenization temperatures range from 222°C to 319°C, suggesting that sulphide precipitation took place over this temperature range.

Successive shearing probably led to the redistribution and recrystallization of vein minerals at lower temperatures. It is thought that late quartz veining and recrystallization took place at temperatures as low as 90°C in the Bini Yauri vein as recorded in the secondary inclusions in matrix quartz grains in the altered schist. Many of the inclusions in the matrix quartz grains are monophasic types and appear to have formed at very low temperatures.

Freezing data

Most of the freezing temperatures measured from 22 inclusions are between -0.5 and -1.9°C . Freezing temperatures of 2.9°C to 4.0°C noted in a few inclusions represent formation of clathrate, which indicate the presence of CO_2 . This clathration commonly leads to double freezing (Collins, 1979). Crushing experiments confirm the presence of a highly compressed gas, probably CO_2 , in the inclusions. From the freezing temperatures, a salinity of 0 to 2.8 equivalent weight percent NaCl with an average of 1.5 wt% NaCl is estimated for the ore bearing fluid using the formula of Potter et al. (1978).

The homogenization temperatures are uncorrected for the effects of pressure as stratigraphic thicknesses and level of erosion in the Nigerian schist belts is presently unknown. However, if the mineralizing solution is assumed to have gained access into dilatant fracture networks of the host gneisses and schists through extensive fracturing at Bini Yauri and Okolom, a minimum hydrostatic pressure equivalent to a depth of 1,400 m (140 bars) would have prevented the ore forming solution from boiling at the maximum temperature and average salinity attained (Haas, 1971). This may lead to an addition of 10–15°C as corrections to our homogenization temperatures.

Discussion and conclusions

Earlier workers on the genesis of gold deposits, e.g., Emmons (1937) and Lindgren (1933), have emphasized that most gold veins are epigenetic and

are of igneous hydrothermal origin. This is due to the close spatial association of gold veins to igneous intrusions in many parts of the world. While this thought dominated for several decades, increasing knowledge has widened the number of theories proposed. A syngenetic 'exhalative' model was advocated for the stratiform and stratabound gold lodes in Archean greenstone belts of South Africa, Canada and Western Australia (Hutchinson, 1975; Anhaeusser 1976; Ridler, 1976) on the basis of their lenticular forms and volcanogenic affiliations. Dehydration accompanying burial and metamorphism was invoked to have formed the auriferous lodes at the Kerr Addison, Dome and McIntyre deposits within the Archean Abitibi greenstone belt of the Canadian superstructural province (Kerrich & Hodder, 1982). Recent work on gold deposits within metamorphosed turbidite sequences (e.g., Meguma Terrane of Nova Scotia, Canada) has also emphasized the importance of metamorphic dewatering and shearing processes in the generation of turbidite hosted gold veins (Henderson et al., 1986). Despite these theories, Macdonald & Hodgson (1986) have also recently emphasized the importance of a magmatic component for the ore forming fluid in the Archean gold districts.

Field evidence at the Bini Yauri deposit suggests that the gold-quartz veins occur at the sheared contact of the Pan-African porphyritic granite while the Okolom veins are distributed within shear zones traversing biotite gneiss, amphibolite and schist. This distribution pattern is comparable with the setting of the auriferous quartz veins of the Ilesha area (Fig. 1) where veinlets are localized along fractures, folds and foliation planes at the contacts of gneisses, schist and amphibolite (Elueze, 1986). The quartz veins in the Ilesha district are usually laminated and commonly contain sulfide and oxide minerals similar to those in the Bini Yauri and Okolom veins. This lack of lithologic preference for the gold-bearing veins in the Nigerian schist belts and the occurrence of the veins within shear zones cross-cutting several lithologies suggest that vein formation accompanied the deformation of the Nigerian basement complex. Evidence for age relationships of the veins in the study areas is tenuous as the available field and petro-

graphic evidence suggests several stages of quartz veining and recrystallization. From the homogenization and freezing data it is observed that the mineralizing fluids at Bini Yauri and Okolom had a relatively low salinity with very minor quantities of NaCl and a significant but unquantified CO₂ content. These fluids may have been derived from the metamorphic dewatering of the primary sedimentary rocks and their associated volcanics and volcanoclastics in the Precambrian to Early Palaeozoic rifts within this part of the Pan-African mobile belt. The proximity of granitic intrusions to veins as observed at Bini Yauri suggest that magmatic fluid or recirculated groundwater may be part of the ore constituents at some stage of vein evolution and accompanying alteration.

The available evidence supports metamorphism and shearing as the major processes involved in the gold mobilization and propagation in the Nigerian schist belts as suggested for the auriferous lodes formation at Kerr Addison, Dome and McIntyre deposits in the Canadian Abitibi greenstone belt (Kerrich & Hodder, 1982), and the gold districts of the Meguma Terrane in Nova Scotia, Canada (Henderson et al., 1986). Gold and sulfide precipitation in these settings appears to be post peak metamorphism and the primary source is likely to be from detrital gold and metal ions contained in the enclosing rocks. These characteristics may have significant bearings on the exploration for gold in the Nigerian schist belts and similar geological settings.

Acknowledgements

We would like to thank the Deputy General Manager (Exploration) of the Nigeria Mining Corporation, Dr O.M. Ojo for his encouragement and useful discussions on this ongoing project. Professor Marcos Zentilli of the Department of Geology, Dalhousie University, Halifax, Canada is thanked for logistic support and for allowing the use of his U.S.G.S. gas flow heating/freezing stage for our micro-thermometric determinations during a study visit by the senior author to Dalhousie University. Drs Anthony Annor and Peter Baer of the Depart-

ment of Geology and Mineral Sciences, University of Ilorin are thanked for their valuable comments on the aspects discussed in this paper. This research was made possible through the financial support to the senior author from a CIDA/NSERC research fellowship. We thank Doug Meggisson and Cassey Ravenhurst of Dalhousie University for help with drafting and editing.

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