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# The Hydrothermal Alteration Activity Related to the Orogenic Lode-Gold at Kplessou, Toumodi, Cote d'Ivoire

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**Abstract:** The southern part of the Fettèkro greenstone is known to host orogenic gold deposits. It is the case of Kpléssou in the region of Toumodi where gold has been mined since colonial times, in the 1900s, from its auriferous quartz plus calcite veins. Therefore, this gold potential has attracted the artisanal and small gold miners. The objective of this study is to highlight the characteristics of the geological formations and their mineralization from the distal to the proximal zone in order to deeply undertand the associated hydrothermal alteration footprints. In the fulfillment of this objective, field work has been undertaken at Kpléssou then followed by discussion with artisanal miners to elucidate the gold hosts and favorable structures. This step has been used to sample three mineralization zones: distal, intermediate and proximal. These samples served as the basis for the laboratory work realized at the University of Man. Petrographically, we notice the basalts, sericitoschist and various shales impregnated by the aurifeous veins of quartz and carbonates. The basalt and sericitoschist have undergone a ductile deformation resulting to their folding and schistosity and a brittle deformation which forms the veins. A strong hydrothermal alteration has affected the lithologies: sericitisation, chloritisation, carbonatation and sulphidation. Gold mineralization is epigenetic in the basalt, post-magmatic and is associated with sulphides lining the quartz + ankerite veins. However in the sericitochist where sulphides are disseminated, the mineralization is admitted as syngenetic, synmetamorphic and prekinematic. This mineralization in Kpléssou shows that it is an orogenic lode-gold type.

**Keywords:** Orogenic Lode-Gold, Artisanal Miners, Fettèkro Greenstone Belt, Kpléssou, Côte d'Ivoire

## 1. Introduction

The volcano-sedimentary furrow of Fettèkro - Toumodi is a major gold producer in Côte d'Ivoire. In its southern part, this greenstone belt hosts the gold deposits of Bonikro [1, 2, 3]; Hiré [4]; Agbahou [5], Dougbafla [6] and the prospects (Bandama: [7, 8]) proving by that the gold potential of its birimian formations. The characterization of its deposits has brought to light their relation with the class of orogenic gold [2, 9]. These discoveries follow the mining work begun since the colonial period when the "Kokumbo Company Limited" exploited gold in the region of Toumodi. This area is known for its three mineralizations and these gold veins, two types of which have been highlighted since the colonial period [10]. Also, it is accepted that this birimian furrow has undergone bimodal magmatism [11] and the presence of NS-oriented shear corridor with senestre endeavour [12]. This presence of gold is also associated with a boom in artisanal mining activities [13] especially in Kpléssou where petro-structural, hydrothermal activity and metallogenic characterizations of the gold mineralization remain to be elucidated. This is the main objective of this work, which is based on samples taken from

the gold panning wells of Kpléssou. Thus, the characteristics of geological formations and their mineralization will be highlighted in order to improve knowledge on the methods of implementation of gold mineralization (origin) of the department of Toumodi. More specifically, it will be a question of establishing the relationship between gold and the Eburnan orogeny through the processes of magmatism, metamorphism and deformations.

## 2. Geological Context

Kpléssou is a village in the department of Toumodi which is about 198 km in the north of Abidjan (Figure 1). The geological history of this region inscribes it in the Baoulé-Mossi (Eburnean) domain located on the Man Ridge belonging to the West African craton (Figure 2).

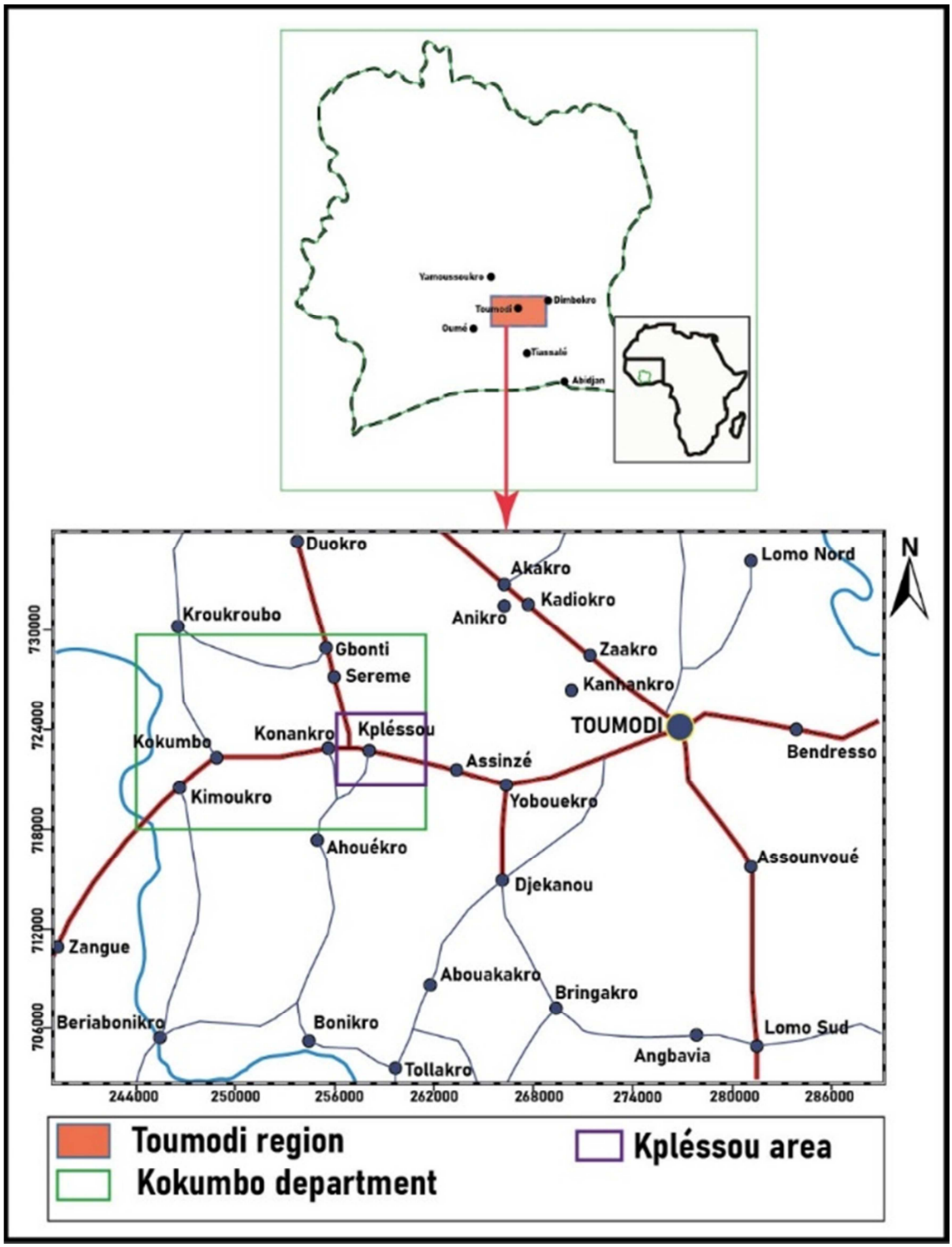



***Figure 1.*** *Localisation of the study area [12] within the Côte d'Ivoire geographic map.*

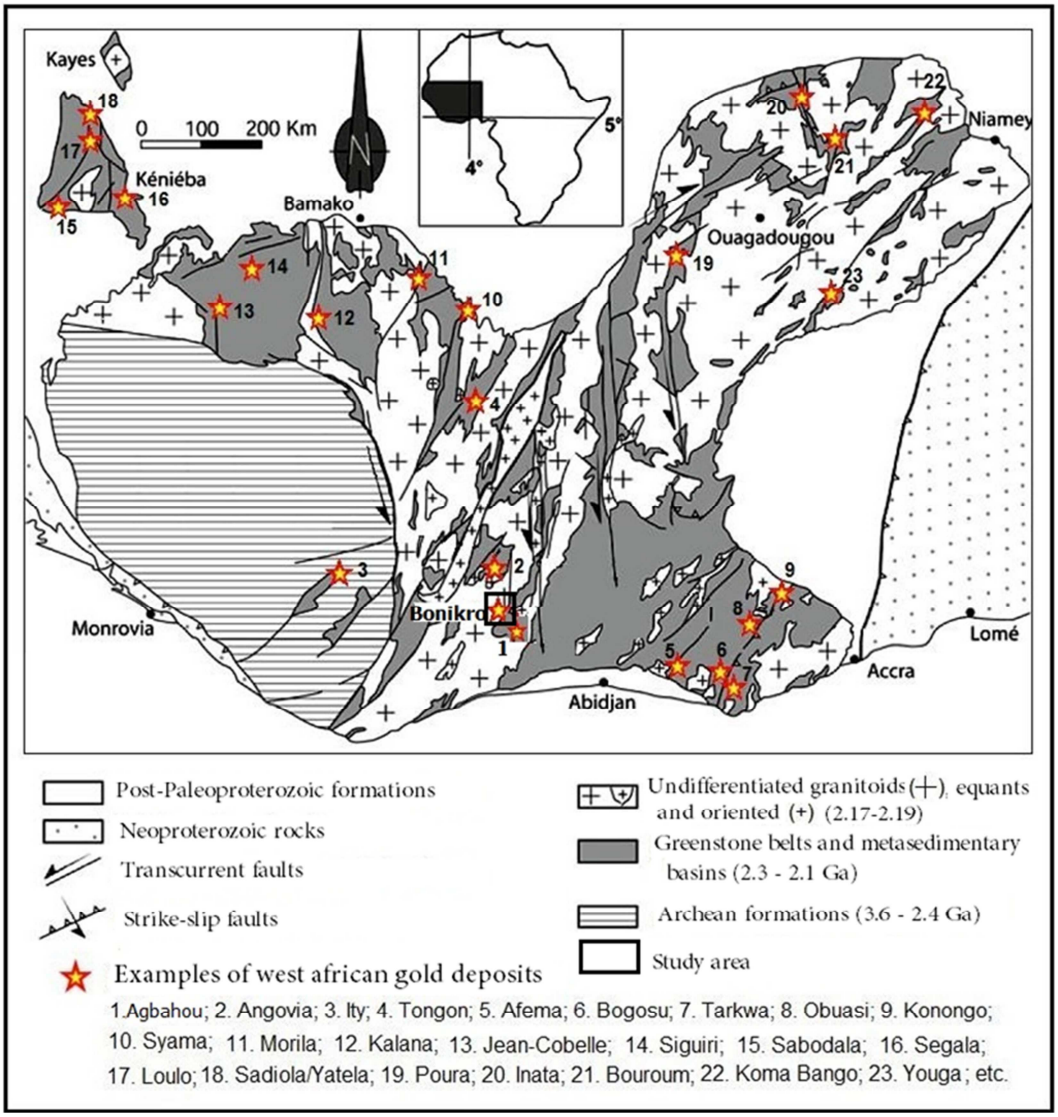



***Figure 2.*** *West african geological Map and examples of gold deposits showing the study area in the southern Fettèkro greenstone belt ([5] modified).*

This proterozoic age domain was structured during the eburnean orogenic cycle dated between 2.5 and 1.6 Ga which corresponds to the establishment of the Birimian formations ([6, 11]). The Toumodi-Fettèkro furrow is considered as a volcano-sedimentary basin in a sialic substratum, with tholeitic and calco-alkaline lavas. After observing a good part of the furrow [14] reports the existence, of a peneplaine comprising formations with little metamorphic (various schists), based on more metamorphic formations (quartzites, micaschists, para-amphibolites and amphibolic schists). To this are added some points of granitoids and calco-alkaline granitoid gneiss. Depending on the geochemistry of the major elements, he distinguishes a domain of calco-alkaline lavas and a domain of tholeitic lavas, with predominance of calco-alkaline rocks. Thus, the rocks of this furrow are mainly tholeititic and calco-alkaline metavolcanites, calco-alkaline granitoids and others with a tonalite-trondjhemite-granodiorite affinity (TTG), pyroclastic volcano-sediments, detrital sediments and neutral to ultrabasic rocks [11, 1, 15, 5]. When studying the northern part of this furrow, [16] observes that the beginning of the Birimian is marked by a siltstone to sandy siltstone episode, surmounted by a plutono-volcanic episode covered by acid pyroclastites and some sedimentary formations. It describes the effectiveness of a second series, subsequent to the tangential deformation, is affected by open folds, slightly turned towards the West-Northwest. This set is intruded by various granitoids, some of which are later than the folding phase. The polygenic character to these formations is admittes from the work on the conglomerate formations of the Anikro region [17] in the sense that the rocks consist of granitoid pebbles, quartz, bedded sediments, very few basic volcanoclasts and, above all, a predominance of ribboned, vacuolar, or amygdular felsic volcanites. The variation of the dip directions: sometimes SE, sometimes NW and NE, highlights a synclinal structure, where we observe intersecting stratifications. The characteristics of conglomerate formations make it possible to hypothesize that the volcanic activity of the region has undergone several phases [17]. It would therefore be a polyphase volcanic activity, very explosive in sub-

aeronautical and shallow sub-aquatic environment. The folding would have occurred during the Eburnean tectono-metamorphic event. According to [18], volcano-sedimentary formations and plutonites are intersected by N-S to NE-SO oriented quartz veins and veinlets sets that contain in places sulphides (pyrite, chalcopyrite) and gold. In the Kokumbo sub-department, near Kpléssou, gold mineralization would be of three types [10] named as filonian type (veins or quartz lenses), the residual type and the colluvionary and alluvial type; in addition, the metallic paragenesis associated with gold would be pyrite, scheelite, stibine and mispickel. Finally, a significant supergene alteration would have allowed the reconcentration of gold in a lateritic cover of about 50 to 70 m thick. It would seem that gold mineralization is related to the tectonic phenomena of the Eburnan orogeny and granitization. Sonnendrucker, 1968 highlights the basic nature of the host rock. It became evident to [19] that the Kokoumbo sector mineralization is primary and consists of gold and sulphides, mainly pyrite and chalcopyrite. He describes at Kokumbo two phases of sulphide mineralization because of the mineralization disseminated both in the veins of quartz or calcite and in their host rocks (greenstone and sericitoschist). The bonikro and Agbahou gold deposits located in the southern part of the Fettèkro-Toumodi furrow such as Kpléssou have highlighted that hydrothermal alterations such as sericitization, carbonation, epidotization, chlorinitization and sulphudation have played an important role in the establishment of gold deposits [2, 3, 20]. In addition, these deposits have clearly indicated their link with the orogenic gold model.

# 3. Material and Methods

This study was carried out in two successive phases: field phase and laboratory phase. The field phase held mainly on the part of the Kokum hill outcropping at kpléssou and made it possible to study and collect eight samples on the old quarries and on artisanal mining wells under operation. Thus, different samples composed of rocks, laterite and veins associated with gold were used for the second phase of this work. This phase began with the making of six thin sections at the Laboratory of Geology, Mineral and Energetic Resources of the University Félix HOUPHOUET-BOIGNY, Abidjan. This was followed by petro-microscopy and microstructural studies on a Jeulin-type polarizing microscope combined with an Amscope camera. The mineralogical assemblages observed made it possible to refine the petrographic determinations carried out in the field. This phase was completed by analyses of gold and its accompanying sulphides and synthesis at the School of Geological and Mining Sciences of the University of Man.

# 4. Results

At the top of the Kokumbo Bocca hill outcropping at Kpléssou of coordinates 6°3'55.26"N / 5°13'17.10"W, the artisanal gold miners have dug about 200 m of successive gold panning wells of 90 meters deep striking between N136° to N150° (Figure 3). Eight samples were taken then classified according to their distal, intermediate and proximal location to the gold mineralization.

### *4.1. Characteristics of the Distal Zone*

This zone is distant five to two meters from to the mineralization. The rocks found in this distal zone are not mineralized and three samples (KLT1, KLT2 and KLT0) are helping to describe the zone. The petrography of ths distal zone is made of a volcanic rock. It is the main lithology observed with its color varies from light blue to pale green (Figure 4). In the sample KLT1, this extrusive mafic rock with a microlitic texture is clearly a basalt showing a metamorphism on its onset. In the sample KLT2, the rock is greener than KLT1 and KLT0 showing by that the impact of the metamorphism. It appears as the metamorphized volcanic rock of KLT1, metabasalt. The hydrothermal activity is shown by the presence of discontinued, elongated vein of white quartz and calcite (Figure 4C) thus the silicification and carbonatation are expressed.

### *4.2. Characters of the Intermediate Zone*

Four samples belong to the intermediate zone which is one meter to some centimeters distant from the mineralization. These samples are named KPLT3, KPLT4, KPLT5 and KPLT6.

The petrography is identical to the basalt of the distal zone. The sample KPLT3 shows a green and massive metamorphic rock with a magmatic texture. On polarizing microscope, the rock is moderately to strongly altered. As a consequent, the matrix shows in some parts the relics of the parental rock close to the elongated alteration minerals of sericite and chlorite (Figure 5). The observation of these metamorphic minerals imply that our rocks is clearly a metabasalt. We encounter this same petrographic details in the sample KLT4 (Figure 6A). In addition, muscovite is more present associated with chlorite, sericite, quartz and sulphides. The rocks appears as weakly schistosed. On the thin section (Figure 6B), the rock has a lepidogranoblastic texture. The petrography of the sample KLT5 also presents the basalt with a weak schistosity (Figure 6C and 6D). In the sample KLT6, we notice that the green color of our basalt is becoming brown due to the facts that the sample has lost its minerals and consists of sulphides and veins of white quartz and calcite (Figure 6E and 6F).

The hydrothermal alteration activity is recorded in the sample KLT3 by the appearance of the minerals of sericite and chlorite replacing respectively the minerals of feldspar and pyroxene or amphibole. Also, the metabasalt is crossed by a 2.3cm thick quartz vein that surrounds the rock and sulphides scattered within it (Figure 5B and C). The mineralogy of the vein is made of quartz, calcite and sulphides (pyrite, chalcopyrite and pyrrhotite). The silicification, carbonatation and sulphidation are then observed. The thin sections of the sample KLT4 have been

performed on the quartz + chlorite + sericite vein cutting the rock (Figure 6A and 6B). They show two types of veins: (i) the first generation of vein consists mainly of medium size minerals of calcites with multiple shape (rounded, rectangular, elongated and xenomorphic), of quartz with two cracked phenocrystals and sulphides and (ii) the second generation consists of small size crystals of calcite (98%), quartz and sulphides.


A: Aligned artisanal wells B: Artisanal prospective well

***Figure 3.*** *Differents artisanal wells at the top of the Kokumbo Bocca hill in Kpléssou.*

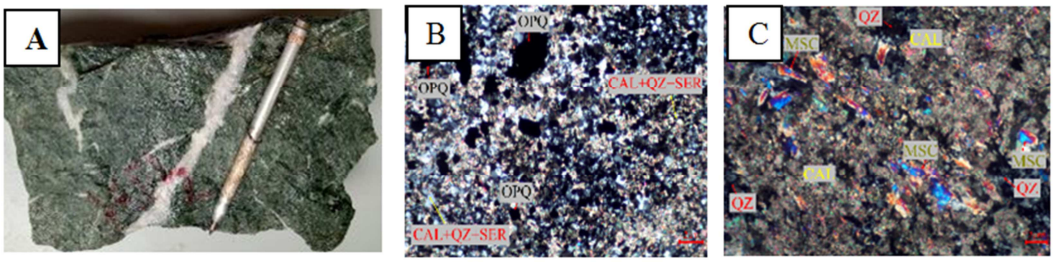

A: Sample KLT1 B: Sample KLT2 C: Sample KLT0

***Figure 4.*** *Macroscopic views of the samples related to the distal zone.*

KLT4 shows that the hydrothermal fluids were abundant because they camouflage the rock primary minerals. The ratio fluid/rock was higher and provide the calcite, quartz and sulphided that have invaded the rock. The silicification is abundant in the KLT4 and KLT5, in this one 60% of the basalt is replaced by the quartz as seen on polarized light (Figure 6A to 6C).

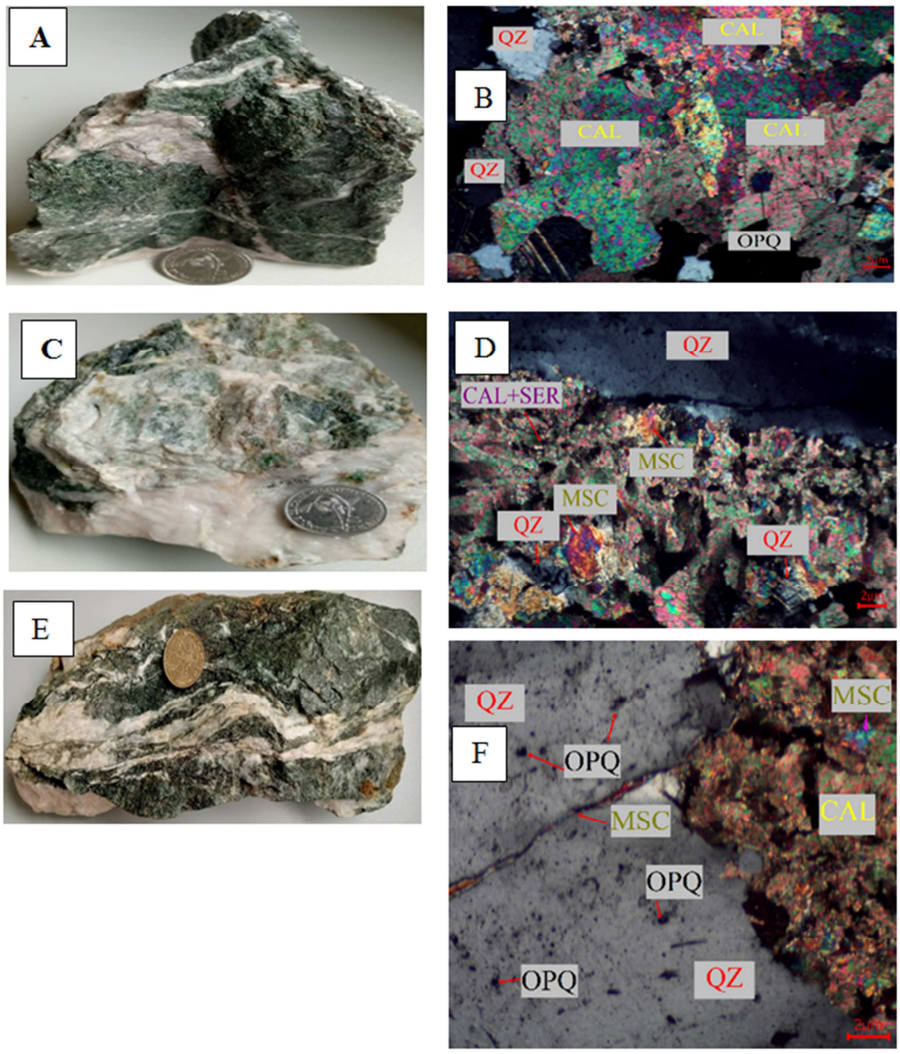
The deformation observed in the sample KLT3 contains elongated minerals of sericite and chlorite (Figure 5A to 5C). This first deformation due to the extension stress is weak in the sense that it is localized around. In the sample KLT4 to KLT6, the schistosity evolves from weak to moderate and strong at the end (Figure 6). This second deformation is associated with the compression stress. Likely to the deformation, the metamorphism of greenschist facies also evolves consequently. Then, the fracturation has taken place resulting to the fractures that have been later filled by the fluids. The third deformation is the folding of the veins as we notice particularly in KLT6 (Figure 5A), a pronounced folds as well as schistosity that are witnesses of a metamorphism. This folding comes from the extensional stress. One brittle deformation (fracturing then veining) and two ductile deformations (schistosity and fold) are noticed from the intermediate zone samples. It is indeed a folded quartz vein within the sericitoschist (Figure 6A and 6E). This folding characterizes a ductile movement and the deformation mechanism at the origin of the latter is flattening.

The metallic paragenesis of the intermediate zone is made of quartz+sericite+chlorite+pyrite.




MSC: muscovite; QZ: quartz; CHL: chorite; SER: sericite; CAL: calcite; OPQ: Opaque minerals (sulphides).

***Figure 5.*** *Macroscopic (A) and microscopic (B and C) views of the sample KLT3.*




MSC: muscovite; QZ: quartz; CHL: chorite; SER: sericite; CAL: calcite; OPQ: Opaque minerals

***Figure 6.*** *Macroscopic and microscopic observations of the samples KLT4 (A and B), KLT5 (C and D) and KLT6 (E and F).*

### *4.3. Characteristics of the Proximal Zone*

The sample KLT7 has been taken at the heart of the gold zone and three thin sections have been performed on it in order to enlight its characteristics (Figure 7).

On naked eyes, the sample KLT7 is a milky quartz vein with visible gold associated to lenses of brown to reddish mafic rock. On polarized light, we are in the presence of coarser quartz crystals surrounding the nailed sericitoschist probably the relics of the schistose basalt.

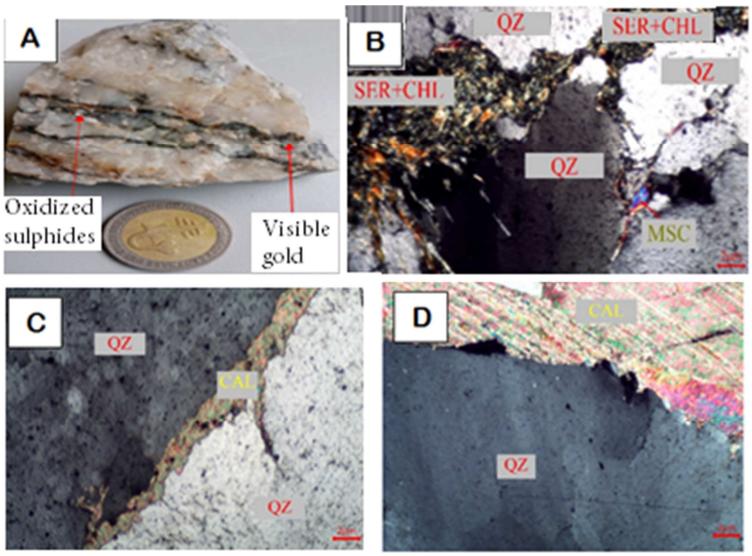
The hydrothermal activity is observed by the development of sericite, ankerite, chlorite and sulphides (non-oxidized and oxidized referring to pyrite and pyrrhotite) minerals in abundance (Figure 7). Mostly the veins consist of cracked coarse quartz crystals with carbonate (calcite and ankerite) in fractures. These crystals are divided into four by veins containing sericite, muscovite, chlorite and sulphides. These veins help to dive deeper into the the potential types and diversity of hydrothermal fluids that circulated in the area of Kpléssou. The three thin sections helped to understand details of this mineralization. The first thin section (Figure 7B) shows crystals of quartz and sulphides. Three types of quartz are noticed: Coarse crystal composed of primary quartz with fractures filled by calcite and opaque minerals; a medium size quartz crystals veins; and, a mixed veins of the two aforementionned observations. As a consequence, at least two phases of silicification are noticeable and the second is associated with carbonatation and sulphidation. The second thin section (KP3') (Figure 7C) presents primary coarse quartz fractured then filled by carbonate, sulphides and medium size quartz. The third thin section presents (KP5) (Figure 7D) crystal of quartz fractured into two parts and filled separately by chlorite + sericite in one hand and muscovite and sulphides in other hand. Overall, we encounter that the host rock is crosscut by veins of quartz, carbonate, sulphides and gold. Two main veins have been noticed: the first is unmineralized milky vein of quartz and calcite. The second is mineralized composed of quartz, ankerite, sericite, pyrite, pyrrhotite and gold. The mineralization shows that it has undergone a structural control associated with the fractures setting. The hydrothermal fluids have then used these paths and in the zone

where the ratio fluid /rock (fluids/sericitoschist) is higher, the rock has been totally hydrothermalized so that it appears as lenses of sericite, chlorite, ankerite.

The deformation in the proximal zone is shown by the fractures and lenses of the sericitoschist. The minerals in these lenses are elongated in response to the extension stresses.

The metallic paragenesis is considered by the ores found in the form of millimeter-sized grains or scattered either in quartz or calcite veins, hosted by the sericitoschist but also in the surrounding laterites.

The presence of the metamorphic rock, the influence of the greenschist facies minerals, the intensity of the hydrothermal activity from distal to proximal zones show that the Kpléssou gold mieralization is part of an orogenic lode-gold mineralization within the Fettèkro-Toumodi greenstone belt.




MSC: muscovite; QZ: quartz; CHL: chorite; SER: sericite; CAL: calcite; OPQ: Opaque minerals (sulphides)

***Figure 7.*** *Macroscopic and microscopic views of the sample KLT7.*

# 5. Discussion

## *5.1. On the Settlement of Geologic Formations*

Petrographically, the study area consists largely of mafic rocks of volcanic texture that have undergone a metamorphism; they are therefore ortho-metamorphic rocks, sericitoschists. These results are similar to those of [14], who claims to have encountered this type of rock through Kplessou. At Kplessou, observations are shown the metadacites crossed by veins of quartz and calcite [19]. A prompt observations of the relics of our rocks, those camouflaged by the minerals of alteration and the hydrothermal fluid which are calcite and quartz, through the thin section, we notice a parental rock of an acidic lavas approaching the metadacites and these assertions are confirmed by the observations of [14]. In addition, it is noted that these paleo-rock relics have retained their original texture, thus indicating a weak metamorphism. These results are in line with those of the work of [19, 1, 5]. In term of sequential settlement, all starts with the protolith rock which is a mafic. It is a mafic volcanite that has undergone a metamorphism of greenschist facies. Then, an intrusion accompanied by multiple fractures controlles the arrival of hydrothermal fluids and therefore the establishment of quartz and calcite veins. In addition, [18] concludes that Kokoumbo (to which Kpléssou belongs) is composed essentially of basic eruptive rocks (basic breccias) associated with some sporadic arrivals of rhyodacitic acid lavas. He concluded that granitoids in intrusion into basic rocks have been affected by brittle deformations and that these deformations are at the origin of quartz and/or calcite veins and veins that are crosscutting the host rocks.

## *5.2. Structural Understanding*

The different structures observed in our study area are schistosity, quartz and/or calcite veins, fractures and fold (folded quartz vein). Indeed, these structures could indicate the presence of a shear corridor in the study area, because according to [21], the elements proving the existence of a shear corridor are sigmoid structures, shear joints or veins, schistosities and folds. The Kpléssou shear corridor has been evoked by [12] and all indicates that artisanal miners are working on part of its 200 width and E-W direction.

## *5.3. Mineralization History*

The rocks concerned by this study have a mineralization (gold and sulphides) scattered in the veins of quartz or / and calcite and in their host rock i.e the sericitoschist. In addition, gold is also found in laterites because gold panning sites due to the alluvial gold. This study has observed visible gold (Figure 7) however geological survey estimated the metal content to range from 1 to 7g/t [18]. This author concludes on the Kokoumbo sector that gold mineralization is filonian and

certainly related to calco-alkaline birimian volcanism, he puts forward three hypotheses that are: (i) a filiation of gold with basic magma, (ii) a tectonic control of gold mineralization and (iii) a control of mineralization by granitization. However, comparing this origin with other mineralization we notice that a kind of balance exists between the different birimian mineralizations. It has been stated that Agbahou's gold mineralization is related to structural and hydrothermal factors [5]. As a consequence, there is a mineralization of the filonian type and a mineralization associated with the sulphides disseminated in the host rocks. This is similar to the type of mineralization of Kpléssou. He then describes the metalliferous paragenesis at Agbahou as being dominated by pyrite followed by pyrotthite, arsenopyrite, chalcopyrite, sphalerite and gold. Concerning the Bobosso mineralization, it has been described that as being hosted in a birimian complex characterized by volcanic and volcanoclastic rocks all intruded by a series of ribboned or foliated granodiorites [15]. Seeing that the mineralization of our zone is localized in quartz and calcite veins passing through sulphides scattered in the rock, it is a mineralization localized in quartz veins that are in zones of fractures, faults and shears. It is of hydrothermal affiliation controlled by tectonics and of two types: disseminated and filonian. For [1], the gold mineralization of Bonikro is mainly driven by all felsic lithologies and especially by granodiorite. This appears to be affected by sericitization, albitization, potassic alteration, silicification and hematization due in part to fluids following its implementation but also to metamorphic fluids. As far as Kplessou is concerned, lithology is affected by sericitization and chloritization. Also, just like in our study area, two gold controls are observed in Bonikro; the lithological control exercised by granodiorite and the structural control which is pervasive and affects other lithologies. The Bonikro gold depsit has shown that the Fettèkro greenstone belt is affected by an orogenic gold mineralization with an intrusion-related component [1]. In light of that, the Kpléssou gold may be influenced by the orogenic gold however the importance of the metamorphism, the intensity of the hydrothermal alteration which is showing a zoning pattern from the distal to the proximal, and associated veins link this mineralization link Kpléssou to the model of lode-gold type as defined by [22]. In the Aboisso greentone belt, the influence of the orogenic lode-gold has been pointed out within the Aféma gold district [23].

# 6. Conclusion

Field work and laboratory analyses reveal that the artisanal miners on the Kokum Hill in Kpléssou are characterized by a volcanic mafic rock as the main host lithology. The rock has undergone a progressive metamorphism of greenschist facies from schistose basalt to sericitoschist. It is crosscut by several generations of quartz and calcite veins. The hydrothermal activity shows different phases and are recognized as silicification, chloritization, sericitization, carbonatation and sulphidation. Silicification and sericitization are encountered from the distal to the proximal zone. This zone is different by the intensity of the hydrothermal alteration: silicification, carbonatation (ankerite) and sulphidation. As we approach to the mineralization, the rock is metamorphosed to schistose basalt and then sericitoschist and affected by veins of quartz and carbonate (calcite, ankerite). The abundance of the veins within the rock and the intensity of the silicification show that the fluid/rock ration was higher. The deformation is well understood by the folds, faults indicating the presence of a shear corridor. The mineralization of Kpléssou is gold and sulphide and happens to be of two types: a syngenetic type marked by the sulphides disseminated in the host rock (the sericitoschist) and an epigenetic type found in the veins characterizing the importance of the hydrothermalism in the zone. The Kpléssou gold mineralization shows a genetic link with the orogenic lode-gold type.

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