Open Journal of Geology, 2025, 15(9), 568-585
https://www.scirp.org/journal/ojg
ISSN Online: 2161-7589
ISSN Print: 2161-7570

Petro-Structural and Metallogenic Study of the Kimoukro and Kokumbo Geological Formations (Côte d'Ivoire, WAC)

Kouadio David Koffi[1*], Brice Roland Kouassi[2], Gnagnon Raymond Stephane Koffi[1], Marc Ephrem Allialy[1]

[1]Laboratory of Geology, Mineral and Energy Resources/Training and Research Unit in Earth Sciences and Mineral Resources, Félix Houphouët-Boigny University, Abidjan, Côte d'Ivoire
[2]UFR-Biological Sciences, Geosciences Department, Peleforo Gon Coulibaly University, Korhogo, Côte d'Ivoire
Email: *dakoff007@yahoo.fr

How to cite this paper: Koffi, K.D., Kouassi, B.R., Koffi, G.R.S. and Allialy, M.E. (2025) Petro-Structural and Metallogenic Study of the Kimoukro and Kokumbo Geological Formations (Côte d'Ivoire, WAC). *Open Journal of Geology*, **15**, 568-585.
https://doi.org/10.4236/ojg.2025.159028

Received: August 25, 2025
Accepted: September 19, 2025
Published: September 22, 2025

Abstract

The Kimoukro and Kokumbo areas are marked by gold mining dating back to the colonial era. The objective of this work is to characterize the mineralization associated with the geological formations in this area. To achieve this, we conducted a petrostructural study and chemical analyses using portable XRF on the collected samples. Metaandesites, schists, metadolerites, metagabbro-doleritic granodiorites, quartz or calcite veins and veins represent the majority of the geological formations. They are affected by low- to medium-grade metamorphism of the greenschist facies and rarely amphibolite. Two deformation mechanisms are evident in the study area: flattening and shearing. The main fracture directions in the study area are SSE and ENE. Furthermore, the presence of C/S structures confirms the existence of a left-trending shear zone oriented N18˚, or NNE. The primary mineralization in the study area is gold, accompanied by pyrite, chalcopyrite, gray copper, and zinc. Mineralization is disseminated both in quartz or calcite veins and in their host rocks (greenstones and sericite schist). Gold is also found in laterites, alluvium, and colluvium.

Keywords

Gold Mineralization, Geological Formations, Kimoukro, Kokumbo, Toumodi

1. Introduction

The West African Craton (WAC) is composed of several Birimian greenstone belts

[1]. These rocks generally host gold mineralization, making them of paramount importance for mining research. Thus, Birimian formations have become key targets for mining and academic research to better understand them and discover new mineral resources.

This is why Côte d'Ivoire, which aims to make the mining sector an important pillar of its economy, is paying particular attention to Birimian formations. Faced with such potential, we are witnessing a proliferation of mining companies in West Africa and numerous geological studies, in collaboration with mining companies, with the aim of understanding the origin of this geological wealth. Gold mineralization in the Paleoproterozoic domain is mostly associated with shear zones or contact zones between metasediments and greenstones intruded by granitoids [1] [2] and 1992 [3]-[6].

However, it should be noted that studies concerning mining exploration have had purely economic aims and have paid little attention to the processes of emplacement (genesis) of mineralization in the Ivorian Birimian. Some authors, such as [7] and [1], have proposed genetic hypotheses on mineralization in Côte d'Ivoire. However, these must be reviewed and updated to establish more detailed metallogenic maps and models for specific regions that will serve as a guide for the search for mineralization.

The main objective of this work is to characterize the mineralization associated with the geological formations in the Kimoukro and Kokoumbo areas. This will then contribute to improving the geological knowledge of this part of the Toumodi region.

2. Geological Setting

The West African Craton (**Figure 1**) stabilized at ca. 1900 Ma and comprises the northern Reguibat Rise, the southern Leo-Man Rise, as well as the Kédougou-Kéniéba and Kayes Inliers [8]-[12]. These three provinces border the Taoudenni Basin, a Late Proterozoic to Phanerozoic cratonic platform of sediments. The Reguibat and Leo-Man Rise are composed of Archean nuclei in their western segments and Paleoproterozoic portions in their eastern regions, whereas the Kédougou-Kéniéba and Kayes Inliers are composed of Paleoproterozoic units [8]-[10] [13].

The southern Leo-Man Rise comprises the western Archean Kénéma Man and the eastern Paleoproterozoic Baoulé-Mossi domain. The Baoulé-Mossi domain includes the Birimian linear to arcuate volcanic belts and corresponding volcano-sedimentary basins [8] [10] [12] [14]. The Birimian units are commonly intruded by large granitic terranes [8] [10] [15]. Birimian volcanic belts are characterized by tholeiitic and calc-alkaline rocks, whereas the basins are dominated by shales, greywackes and carbonates [16]-[19].

The Paleoproterozoic Baoulé-Mossi domain hosts a number of world-class gold deposits initially described as: 1) pre-orogenic deposits, characterized by stratiform mineralization associated with extensional zones, 2) syn-orogenic deposits, in extensional zones with disseminated Au sulfide mineralization in metavolcanite or metadiorite and auriferous paleoplacers in Tarkwaian conglomerates, and 3) late-orogenic deposits, represented by discordant mesothermal gold mineralizations, which represent the economically most important deposit type [3] [20] and references therein. In the western subprovince of the Baoulé-Mossi (comprising our study area), several types of gold deposits have been described: 1) orogenic type Siguiri district in Guinea [21], 2) intrusion-related type (Morila mine in Mali [22]), and 3) carbonate-hosted type (*i.e.*, Ity mine in Côte d'Ivoire [23] [24]; Sadiola Hill in Mali [25]). Geochronological data bracket the timing of the gold mineralization between ca. 2.10 and 2.07 Ga [4] [22] [25], indicating that they were formed syn- to late-Eburnean.

The study area belongs to the southern part of the Oumé-Fettèkro belt, where several gold deposits, such as Agbahou and Bonikro, have emerged.

According to [5], the Agbahou gold deposit, located in the southwestern part of the Oumé-Fettèkro range, contains three major lithological units:

1) A volcano-plutonic unit, consisting of basaltic to andesitic lavas, amphibolites, chlorite schists, and microdiorite and microgabbro sills;

2) A volcano-sedimentary unit containing pyroclastics (basaltic and dacitic in composition) and sediments (shale and graywacke);

3) Late felsic veins (rhyolite and rhyodacite), probably contemporaneous with the granitoids, form the third unit.

The basalts correspond to volcanic arc tholeiites close to the N-MORB and are associated with oceanic plateau-type magmatogenesis. The andesites have a calc-alkaline composition and their geodynamic context is that of an area where transcurrent faults of lithospheric frictional extension generate thermal corridors capable of generating calc-alkaline andesitic magma through melting. This geotectonic context is undoubtedly the one that prevailed during the emplacement of the Agbahou gold mineralization. For him, the Agbahou gold deposit is controlled by structural and hydrothermal factors. It is linked to a major northeast-trending shear zone straddling the mafic volcanic and volcanosediment contact. The shear is reverse sinistral transcurrent. The main faults are NE and NW-oriented. The brittle, ductile nature of the shearing favored the rise of hydrothermal fluids and the formation of gold-bearing quartz veins: smoky quartz veins or shear veins and speckled quartz veins or extension veins. The hanging walls and tectonoclasts of the quartz veins are altered with carbonates (calcite, ankerite ± dolomite), chlorites, sericites, and sulfides.

The work of [6] showed that the Bonikro deposit is hosted by felsic Birimian formations, namely a porphyritic granodiorite and aplopegmatitic dykes that intruded mafic volcanics and volcano-sedimentary rocks, all metamorphosed. The volcanic arc within which these formations were emplaced was subject to occasional eruptive volcanism. The granodiorite, aplites, pegmatite, rhyodacite, and dacite are calc-alkaline, highly enriched in K and light rare earth elements. The basalts, on the other hand, are enriched in heavy rare earth elements, unlike the enclave.

According to him, the structural context is dominated by the Bonikro Shear Zone (BSZ), which contains brittle and fragile components. The East-West directed compressions are among the last events recorded at Bonikro, which caused an intense phase of North-South to North-East extension, creating schistosity, foliations and boudins of similar directions. In the direction of compression, the East-West oriented shortening resulted in yet another fold, and this latter one was found to the west of the quarry. The structural history of Bonikro is also under the imprint of two dextral faults, which upset the orientation and the dip of the primary structures and/or those mentioned above and subdivided the granodiorite into three entities-oriented NNE.

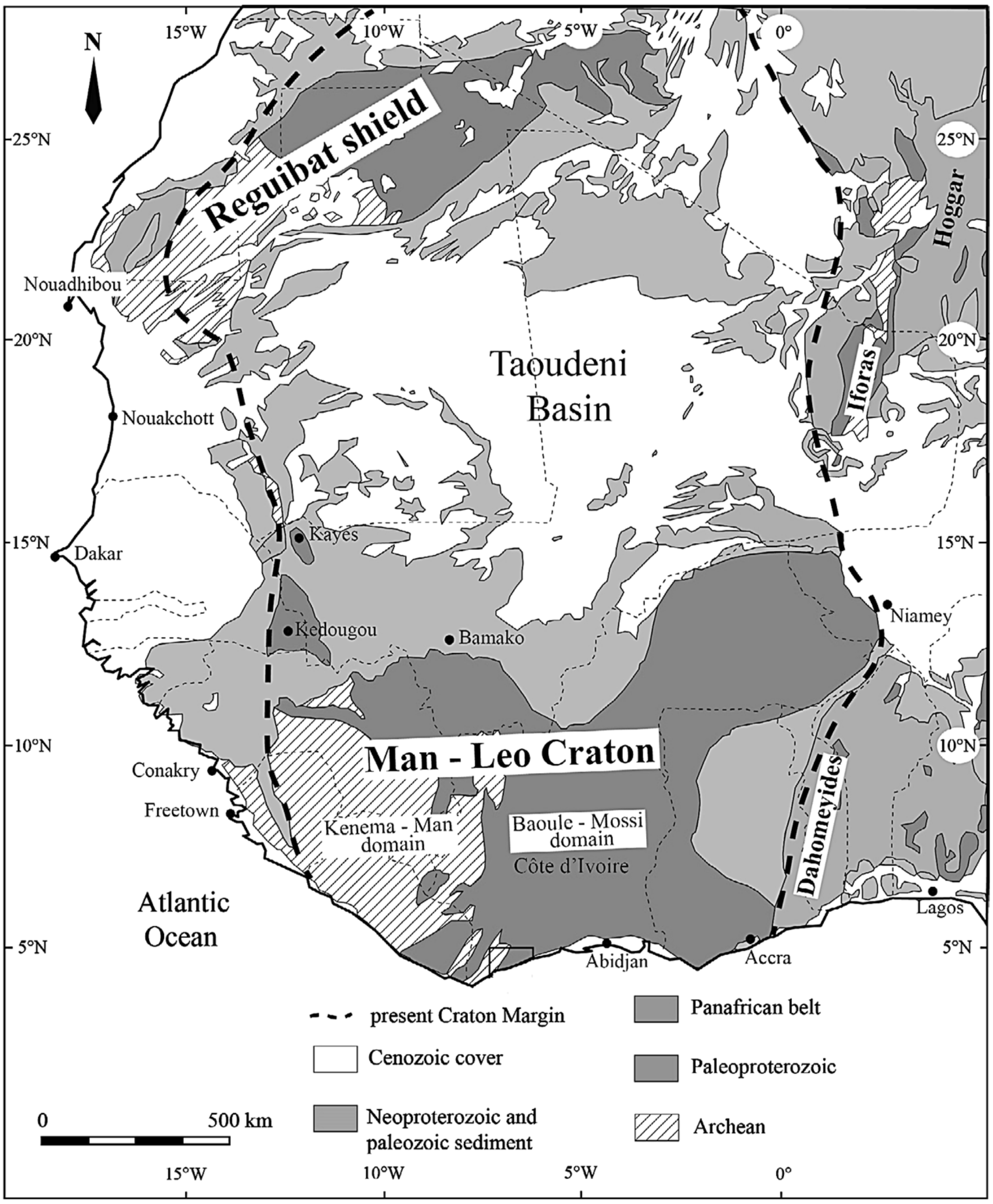


Figure 1. Simplified tectonic map of the West African Craton [26].

3. Methodology

3.1. Petrography

Macroscopic analysis covers all architectural features visible to the naked eye, observed at varying orders of magnitude, from mineralogical composition and more or less oriented crystals in a rock to the large units (facies) of a continuous outcrop. Each outcrop is described according to a diagram that includes the outcrop's shape, structure, texture, mineralogical composition, color, family, and altered state. This allows us to find or, if possible, propose a name for the rock.

The thin sections were prepared at the Geology, Mineral Resources and Energy Laboratory and were subsequently observed using a polarizing microscope at Felix Houphouët Boigny University. The minerals were observed in natural light and then in polarized light, and the mineralogical assemblages allowed us to corroborate the petrographic study carried out in the field. It also allowed us to characterize the different facies encountered in the study area.

3.2. Structural

The structural analysis consisted of making observations on the rocks, their deformation, the structural elements (stratifications, schistosity, fractures, folds and fold axes, etc.) and taking measurements for the study of deformation. The structural data thus constituted are exported in text form to the GEOrient stereography software, which allowed us to represent and visualize the directional rosette of the collected measurements.

3.3. Geochemistry

It consisted of identifying the mineralizations associated with the geological formations of the study area from the chemical compositions of the samples taken in the field. We used X-ray fluorescence spectrometry (XRF method) to determine the chemical composition of the different samples. We first proceeded with the selection of the samples presenting visible sulfides (macroscopic and microscopic study). The equipment used to determine the chemical composition of the selected samples is the Niton XL3t. This gun-type device allows rapid transport and use on-site in order to quickly determine the elemental content of a soil or rock sample. X-ray fluorescence spectrometry (portable XRF) allowed us to perform a multi-element analysis of 35 elements of the periodic table (Ba, Sb, Sn, Cd, Pd, Ag, Mo, Nb, Zr, Sr, Rb, Bi, As, Se, Au, Pb, W, Zn, Cu, Ni, Co, Fe, Mn, Cr, V, Ti, Ca, K, Al, P, Si, Cl, S, Mg). Note that each selected sample underwent two types of analyses. An analysis in "mining" mode gives the content of the elements in percentage (%) and an analysis in "soil" mode gives the content of the elements in parts per million (ppm). For the various analyses, samples were taken with a hammer. The soil analyzed by portable XRF was taken at a depth of at least 50 centimeters to avoid removing topsoil.

The coordinates of the different sites studied are compiled in **Table 1**.

Table 1. Location of the sites visited in the study area.

	Easting	Northing	Long	Lat
SITE 1 KIMOUKRO CAMP	246,055	713,212	5˚17'45" W	6˚26'49" N
KIMOUKRO CAMP	245,331	713,289	5˚18'5" W	6˚26'52" N
SITE 2 KIMOUKRO CAMP	244,379	712,965	5˚18'39" W	6˚26'41" N
KIMOUKRO VILLAGE	245,702	720,576	5˚17'58" W	6˚30'49" N
KOKUMBO VILLAGE	251,023	723,566	5˚15'5" W	6˚32'27" N
GOLD PANNING SITE 1 STAND KOKUMBO	250,654	724,675	5˚15'17" W	6˚33'3" N
MINERALIZED SAMPLE 1 KOKUMBO	250,309	724,520	5˚15'28" W	6˚32'58" N
MINERALIZED SAMPLE 2 KOKUMBO	250,466	724,703	5˚15'23" W	6˚33'4" N
GOLD PANNING SITE 2 KOKUMBO	250,189	724,455	5˚15'32" W	6˚32'56" N
GOLD PANNING SITE 3 KOKUMBO	250,384	725,025	5˚15'26" W	6˚33'14" N
NIANKE-KONANKRO VILLAGE	253,527	723,081	5˚13'43" W	6˚32'12" N
SITE 1 NIANKE-KONANKRO	252,371	722,649	5˚14'21" W	6˚31'57" N
KPLESSOU SLAB 1	259,989	725,998	5˚10'13" W	6˚33'48" N
KPLESSOU SITE 3	259,669	726,215	5˚10'24" W	6˚33'55" N
KPLESSOU SLAB 2	259,389	726,030	5˚10'33" W	6˚33'48" N
KPLESSOU VILLAGE	259,403	726,142	5˚10'33" W	6˚33'52" N
SITE 1 SEREME	256,440	723,733	5˚12'9″ W	6˚32'33" N
SITE 2 SEREME	254,502	726,045	5˚13'12" W	6˚33'48" N
SITE 3 SEREME	254,503	726,069	5˚13'12" W	6˚33'49" N
SITE 4 SEREME	254,357	726,282	5˚13'17" W	6˚33'56" N
SEREME VILLAGE	254,356	726,321	5˚13'17" W	6˚33'57" N
SITE 5 SEREME	255,298	727,313	5˚12'46" W	6˚34'30" N
SAMPLE 1 SERE	254,343	726,383	5˚13'17" W	6˚33'59" N
SITE 1 GBONTI	254,360	726,879	5˚13'17" W	6˚34'15" N
SITE 2 GBONTI	257,122	732,855	5˚11'48" W	6˚37'30" N
SITE 1 KIMOUKRO CAMP	256,487	732,250	5˚12'8" W	6˚37'10" N

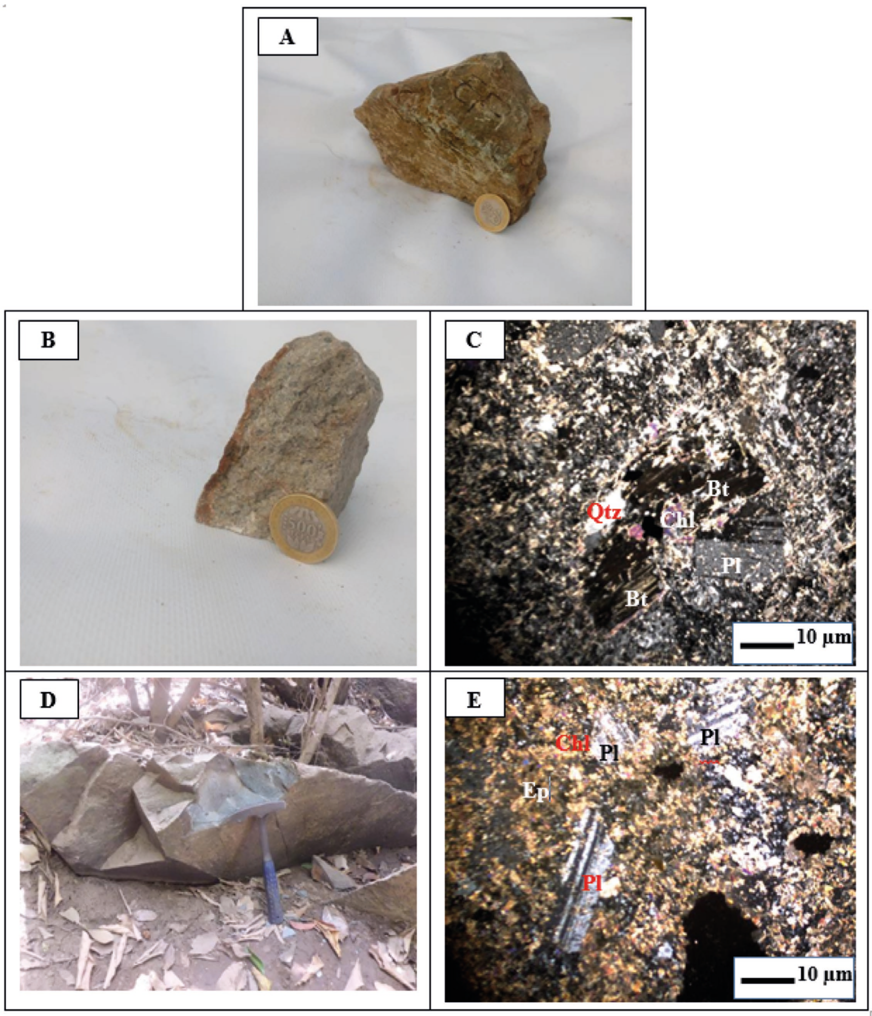
4. Results

4.1. Petrography

Kimoukro

Three main sites were visited in this locality. The first contains blocks of brown schist (Figure 2(A)) containing sulfides with a N0˚ schistosity. The second contains decimeter to meter-scale quartz veins that cannot be measured, as most of them have been displaced by gold mining, and the others do not offer good, clear planes. For the third site, we have two lithologies.

The first lithology is a granodiorite. It is massive, mesocratic, and altered with a grainy texture. Quartz, feldspar, and amphibole crystals are visible to the naked eye (Figure 2(B)). This rock has undergone intense hydrothermal alteration, which is illustrated under the microscope by chloritization and sericitization of amphibole and plagioclase, respectively (Figure 2(C)). The second is a green metaandesite with a fine structure (Figure 2(D)). The mineralogy is mainly composed of plagioclase and amphibole. As accessory minerals, we have chlorite and epidote resulting from the progressive alteration of plagioclase and amphibole (Figure 2(E)).



(A) Kimoukro schist; (B) Kimoukro granodiorite; (C) Kimoukro granodiorite (polarized light); (D) Metaandesite block at Kimoukro; (E) Kimoukro metaandesite (polarized light); Qtz: quartz; Bt: biotite; Chl: chlorite; Ep: epidote; Pl: plagioclase

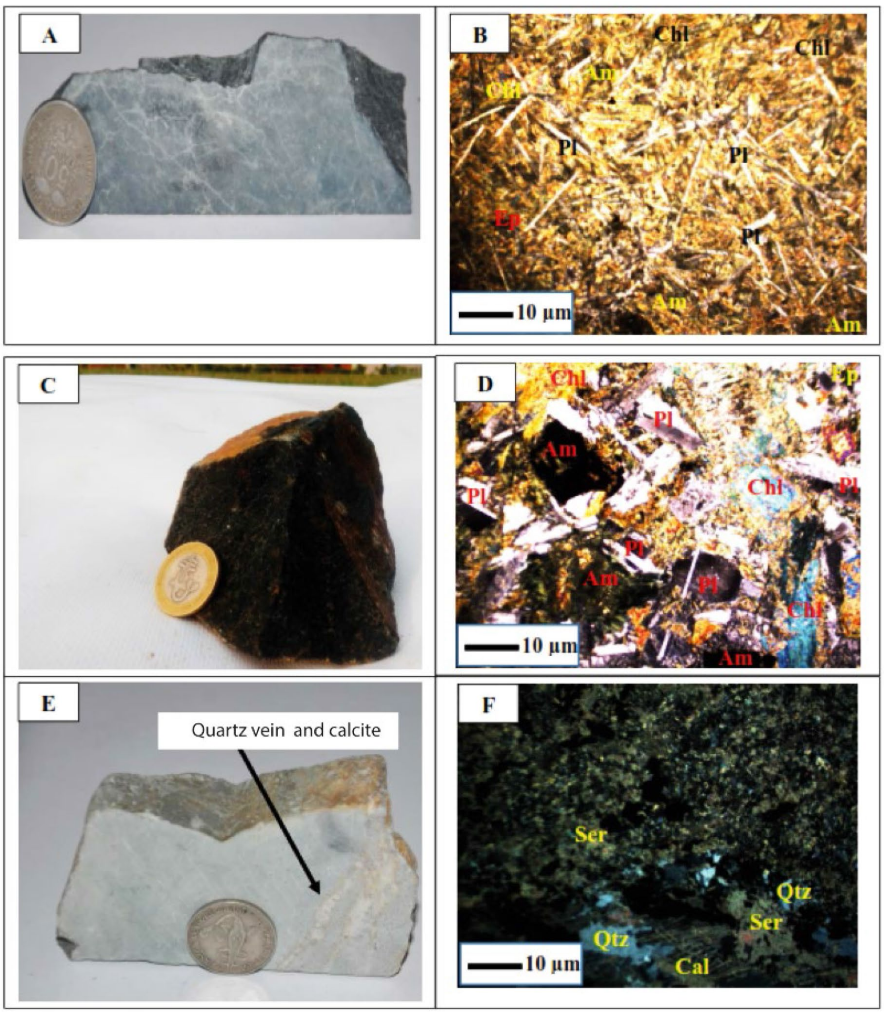
Figure 2. Macroscopic and microscopic photographs of rocks found at Kimoukro.

4.2. Kokumbo

The sites visited are located respectively on the slope of Mount Kokum, approximately 2 km from the village of Kokumbo. The formations are not visible at the surface due to the significant lateritic cover. For our study, we used formations from old mining operations and gold panning sites. Three lithologies were identified.

The first lithology is a massive, dark green rock. It has a relatively fine-grained structure, and the presence of disseminated sulfides and quartz-feldspathic veins is noted (Figure 3(A)). A residual doleritic texture is observed under the microscope, and the minerals present are plagioclase, in thin, tangled rods, and amphibole, in subautomorphic green crystals with intense direct pleochroism, sometimes chloritized. Accessory minerals are chlorite and epidote (Figure 3(B)). The two types of alteration observed are chloritization and saussuritization. This is a metadolerite.

The second lithology is a massive, dark green rock. It has a coarser or less fine-grained structure than metadolerite. Plagioclase crystals are observed embedded in a ferromagnesian groundmass (Figure 3(C)).



(A) Kokumbo metadolerite; (B) Kokumbo metadolerite (polarized light); (C) Kokumbo metagabbro-doleritic; (D) Kokumbo metagabbro-doleritic (polarized light); (E) Kokumbo metaandesite; (F) Kokumbo metaandesite (polarized light); Qtz: quartz; Pl: plagioclase; Ser: sericite; Am: amphibole; Chl: chlorite; Cal: calcite; Ep: epidote.

Figure 3. Macroscopic and microscopic photographs of the rocks at Kokumbo.

Microscopic observation reveals a grainy texture in which the residual doleritic texture is still visible. The predominant minerals are plagioclase, in tangled rods; some crystals are sericitized; and amphibole, in subautomorphic green crystals with intense direct pleochroism; some crystals are chloritized. Accessory minerals are chlorite and epidote (crystals present within amphibole crystals) (**Figure 3(D)**). The three types of alteration observed are chloritization, sericitization, and saussuritization. It is a metagabbro-doleritic rock.

The third lithology is a metaandesite, a massive rock of light to dark green color. It has a very fine structure and is crossed by quartz and calcite veins (**Figure 3(E)**). It should also be noted that disseminated sulfides are visible in the rock. A residual porphyritic texture is observed under the microscope. The predominant minerals are plagioclase, which is highly sericitized and randomly arranged, and amphibole, in chloritized crystals. Accessory minerals are chlorite, epidote, quartz, and calcite (**Figure 3(F)**). Opaque xenomorphic to subautomorphic minerals are present. The two types of alteration observed are sericitization and chloritization. It is a metaandesite.

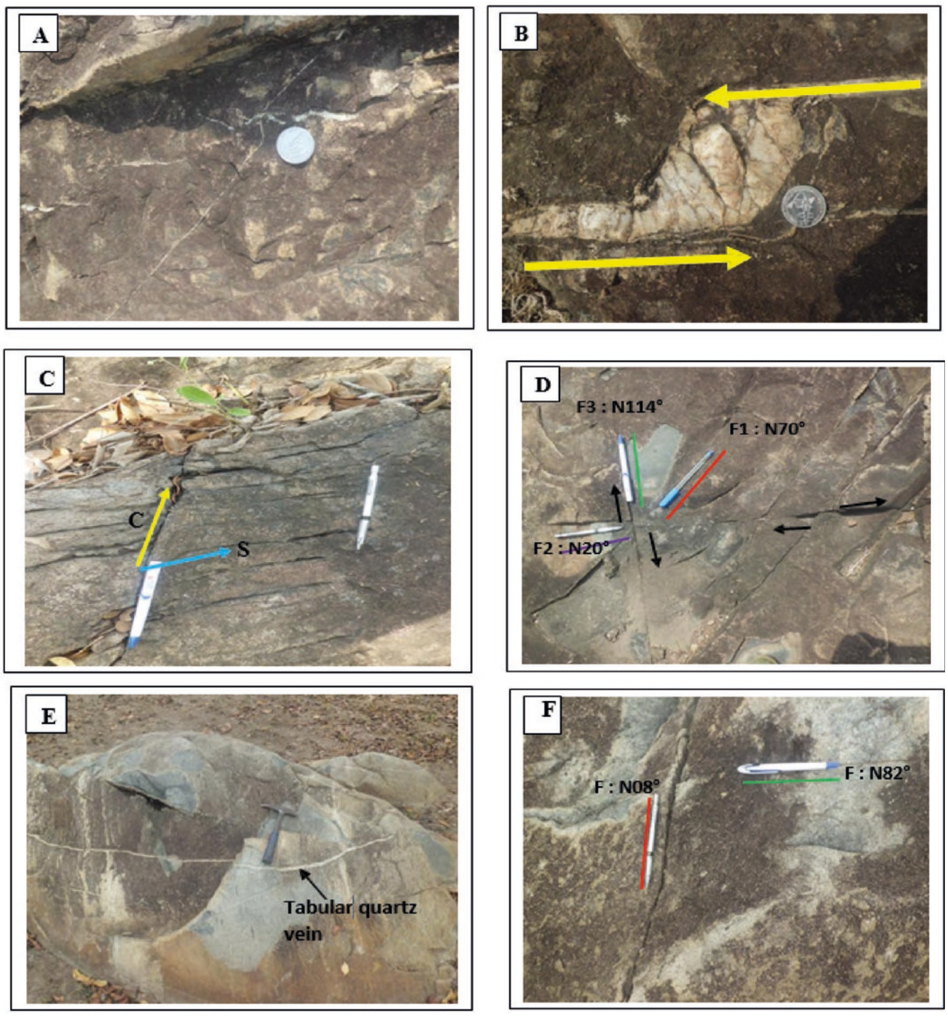
4.3. Structural

These are brittle and ductile geological structures. Ductile structures are folds and C/S structures.

The fold is observed at the Kplessou site. It is a wavy quartz vein within a metadacite (**Figure 4(A)**). The vein direction is N150˚. This asymmetric folding characterizes ductile movement, and the deformation mechanism behind it is flattening. A sigmoid pattern is also visible. It is a quartz vein oriented N150 within which there is a large crystal indicating sinistral shear (**Figure 4(B)**). C/S structures are penetrative and affect a given volume of igneous rock whose emplacement is synchronous with the activity of a shear zone. At Kplessou, we observed a shear band schistosity or C/S structure within the metadacite. The C/S structure includes an "S" schistosity plane with a N80 - 70˚N direction and a "C" shear, sinistral with a N18 direction (**Figure 4(C)**). These C/S planes highlight the existence of a NNE-directed shear corridor in the Kplessou area.

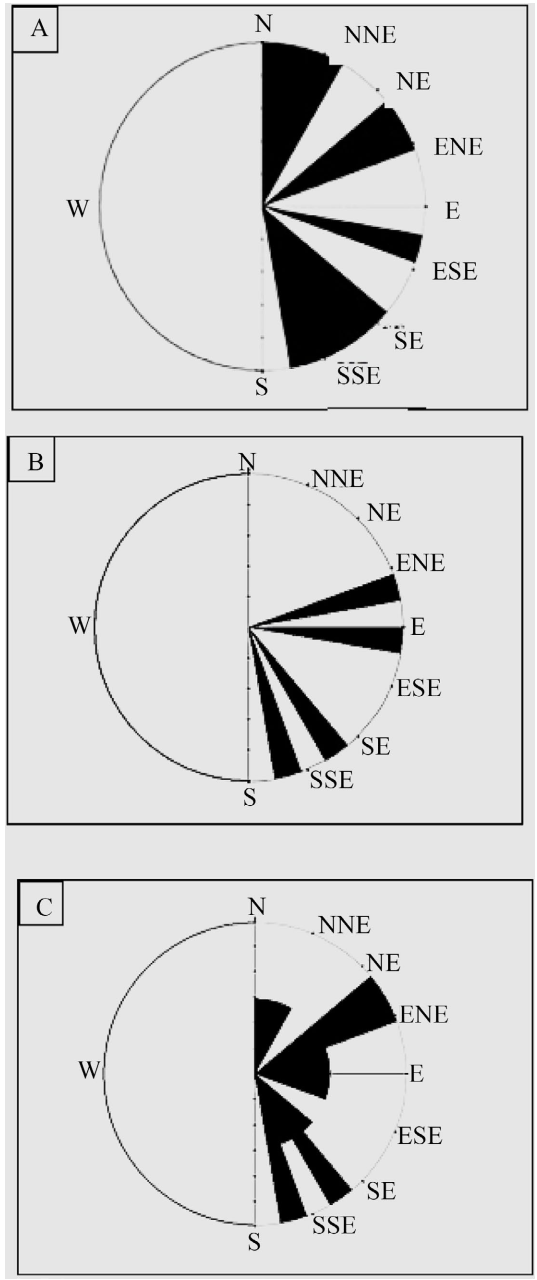
Brittle deformations are mainly fracture schistosity, strike-slip faults and fractures. Fracture schistosity affects schist formations with directions varying from N0˚ to N156˚. Two fracture schistosity planes (N96˚ - 36˚SE and N155˚ - 73˚SW) were also measured on metadacite blocks. The first fracture schistosity episode allowed the emplacement of N150-trending veins and the second episode, which intersects the first is N50-trending and the markers are visible within the previously emplaced veins. These fracture schistosities characterize brittle shear. Several dextral strike-slip fractures with directions F1 (N70), F2 (N20), and F3 (N114) respectively intersect each other. These strike-slip faults characterize a brittle movement and the deformation mechanism at the origin of these is shearing (**Figure 4(D)**). It should also be noted that we encountered tabular veins crossing the geological formations at the Gbonti site (**Figure 4(E)**).

In order to better understand the variations in fracture directions in the study area, directional rosettes of the fractures in the localities of Kplessou and Gbonti were examined. A global rosette of the structures encountered was also produced in order to highlight the overall direction of the fractures in the area. Thus, in the locality of Kplessou, the main directions of the fractures are SSE and NNE (**Figure 5(A)**), corresponding to the fractures oriented N135˚ to N160˚. In addition to this direction, the ESE and ENE directions are added. In Gbonti, the directions of the fractures observed are E and SSE (**Figure 5(B)**). They respectively include fractures oriented N66˚ to N114˚ and N135˚ to N170˚ (**Figure 4(F)**). The overall rosette of the structures encountered highlights two main directions. The ENE direction is formed by the N40˚ to N85˚ structures and the SSE direction is formed by the N66˚ to N114˚ structures (**Figure 5(C)**). In addition to these directions, there are the secondary NNE and ESE directions.



(A) Crenulation in metadacite at Kplessou; (B) Winding pattern in metadacite at Kplessou; (C) C/S structures in metadacite at Kplessou; (D) Fractures and strike-slip faults in metadacite at Kplessou; (E) Tabular vein in quartzite at Gbonti; (F) Conjugate fractures in quartzite at Gbonti.

Figure 4. Aspects of ductile and brittle deformation markers at Kplessou and Gbonti.

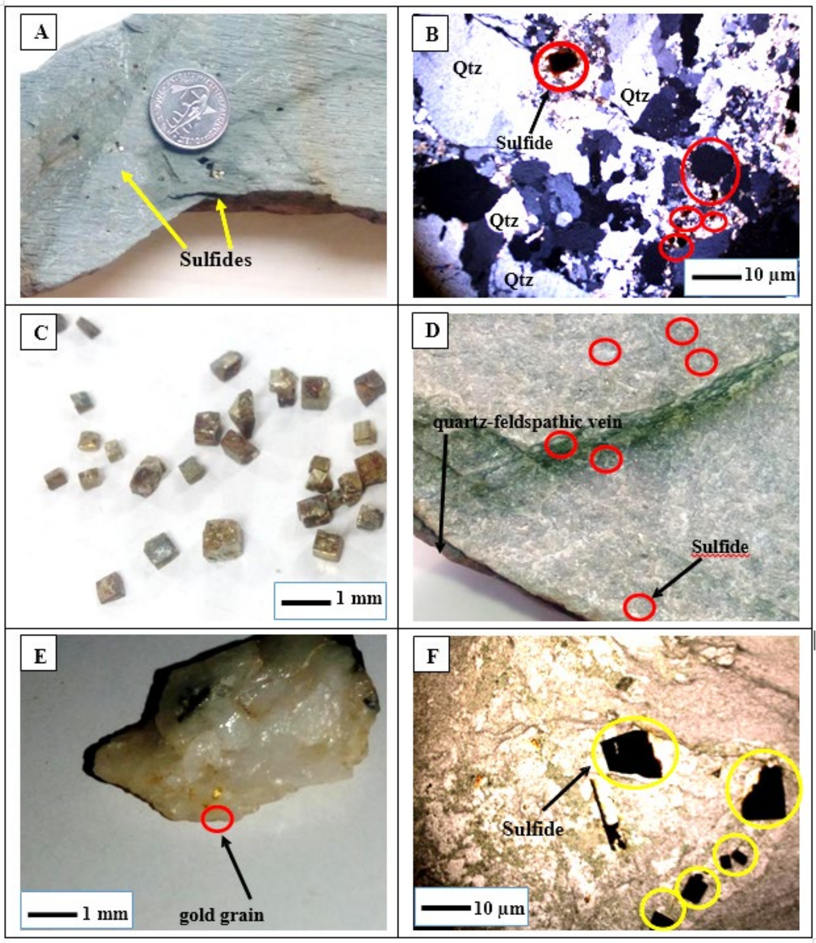


(A) Rosettes of fracture directions in the Kplessou area; (B) Rosettes of fracture directions in the Gbonti area; (C) Overall rosette of structures in the study area.

Figure 5. Rosettes of fracture and vein directions.

4.4. Associated Mineralization

Petrographic analysis of the rocks in the study area allowed us to observe and identify mineralization in certain lithologies of the study area. The observed mineralization includes sulfides and gold. These minerals are found, on the one hand, in the form of millimeter-sized grains, disseminated either in quartz or calcite veins, or in schists. On the other hand, it is in the form of small points within the greenstones. We very rarely observed gold grains with the naked eye in the veins and in the rocks. However, the presence of gold panning sites indicates the presence of gold in the formations of the study area. The most frequently observed sulfides are pyrite and chalcopyrite (**Figure 6**). XRF (X-ray fluorescence) analysis of the samples allowed the detection of several interesting trace elements associated with the mineralization present in certain lithologies of the study area. We have, among others, Au, Cu, Pb, Zn and As. **Table 2** presents the different contents (in ppm) of these elements in the various petrographic facies. The sulfides observed in the mineralized rocks of the study area are pyrite, chalcopyrite, and gray copper because of the proportion of copper detected by portable XRF. Note that at this stage of the analysis, it is difficult to highlight the sulfide paragenesis closely linked to gold. We believe that there are two phases of sulfide mineralization based on our description (macroscopy and microscopy) of the sulfides present in the mineralized rocks of the study area.



(A) Disseminated sulfides in a sericite schist at Kplessou; (B) Chalcopyrite and pyrite crystals in a quartz vein (polarized light); (C) Millimeter-sized grains of pyrite and chalcopyrite (macroscopic view); (D) Disseminated sulfides present in a metaandesite at Kokumbo; (E) Raw gold grain in a piece of quartz; (F) Disseminated sulfides in a sericite schist at Kplessou (natural light); Qtz: quartz.

Figure 6. Sulfides in the mineralized rocks of the study area.

Table 2. Au, Cu, Pb, Zn, and As content (in ppm) in mineralized samples from the study area.

Samples	Au	Cu	Pb	Zn	As
F 6	<LOD	<LOD	6.5	57.04	4052
KC 1	<LOD	23.84	9.3	42.93	<LOD
F 1	<LOD	<LOD	10.23	23.53	<LOD
KP	7.66	58.55	<LOD	153.34	22.9
KOK 5	12.5	116	<LOD	87.45	5.65
KOK 3	<LOD	56.23	<LOD	69.77	10.18
BONT 1	<LOD	<LOD	1.9	50.9	<LOD
KOK 6	10.77	49.98	<LOD	55.53	15.43
KP	<LOD	<LOD	<LOD	75.71	13.21
SER	7.81	<LOD	<LOD	88.57	8.43
SER 1	<LOD	33.82	<LOD	88.47	4.57
QTZ	<LOD	64.8	<LOD	8.03	4.75

5. Discussion

5.1. Petro-Structural

The study area contains several lithologies. It is mainly composed of metavolcanic rocks (basic and acidic) and greenstones, with associated granitoids (granodiorite). It is noted that the greenstones have retained their original texture (porphyritic microlithic and doleritic), thus indicating low to medium metamorphism. The association of minerals such as chlorite, calcite, epidote, amphibole and neoformed quartz confirms the degree of metamorphism. The volcanic and volcanosedimentary formations of the Kokumbo region are affected by hydrothermal alteration phenomena and general metamorphism with mineral paragenesis that reflects a metamorphism essentially of greenschist facies and rarely amphibolite facies [5] [6] [27]. The different structural objects observed in the studied area are schistosity, detachments, quartz and/or calcite veins, sigmoid figures, fractures, folds and C/S structures. These structures could indicate the presence of a shear zone [28].

The work of [29] in the Toumodi-Fettèkro trench highlights a range of ductile mylonitic structures in a strike-slip regime. Indeed, these ductile structures appear along large linear shear zones and are generally oriented NS. The strike-slip shear zone is oriented mainly NS with left-hand play, the S/C structures, the major folds, the very penetrative S2 schistosity with a fairly steep dip and the microfoldings highlighted in the south of the trench, allow confirmation of the existence of the first and second phases of major deformations recognized in the Birimian domain. Indeed, according to [1], the D2 phase is associated with the major folds and the NS strike-slip zone. It is also responsible for the structuring of the Birimian series, oriented NNE-SSW to ENE-WSW. It is marked by a very penetrative S2 schistosity with a fairly steep dip and is finally accompanied by a shear corridor with (C/S)

NS structures with left-hand play. The N-S oriented fractures and microfoldings would correspond to the D1 and D2 deformation phases [30]. These two deformation phases observed in the south of the Toumodi-Fettèkro trench corroborate the observations made by [11] and by [31] in Burkina Faso, and by [6] in the Bonikro deposit.

5.2. Implementation of Mineralization

Ore formation processes involve the concurrent development of several critical elements, including favorable lithospheric architecture, a transient geodynamic setting, metal fertility, and preservation of the primary depositional zone [32] [33].

Observations of the rocks in the study area indicate that the primary mineralization is gold and sulfides, primarily pyrite and chalcopyrite. However, gray copper and zinc are also present. Mineralization is disseminated in quartz or calcite veins and in their host rocks (greenstones and sericite schist). It should be noted that gold is also present in laterites, alluvium, and colluvium due to the presence of numerous gold mining sites in the study area. We cannot provide an exact estimate of the gold content of the geological formations in the study area, as our data are insufficient to do so.

From a genetic point of view, we cannot determine the origin of the mineralization due to the rarity of outcrops and the lack of data. However, [34] concludes after his work on the gold mineralization of the Kokumbo sector that the vein mineralization, certainly linked to the Birimian calc-alkaline volcanism, seems to be controlled by Eburnean tectonics (NS to NE-SW) and by granitization. Three hypotheses are put forward for the emplacement of the mineralization:

1) A relationship between gold and basic magma.
2) A tectonic control of gold mineralization.
3) A control of mineralization by granitization.

5.3. Proposal of a Geological Map of the Study Area

The petrographic and structural data available to us are insufficient to propose a typical geodynamic model of the formations in the study area. Nevertheless, they allow us to list the various geological phenomena that contributed to the formation of the geological formations in the study area. First, volcanism followed by greenschist to amphibolite facies metamorphism is noted, as the study area is essentially composed of lavas (basic and acid) and some weakly metamorphosed volcanic products (tuffs). This complex would have subsequently undergone a granitoid intrusion accompanied by multiple fractures that allowed the formation of veins and dikes (quartz and calcite).

Furthermore, [34] concluded after his work that the Kokumbo sector is composed essentially of basic eruptive rocks (basic breccias) associated with some sporadic occurrences of rhyodacitic acid lavas. It indicates that granitoids affected by brittle deformations are intruding into the basic rocks and that these deformations are at the origin of the quartz and/or calcite veins included in the host rocks. The results obtained at the petrographic and structural levels allowed us to propose a geological map of the study area at a scale of 1/100,000 (**Figure 7**).

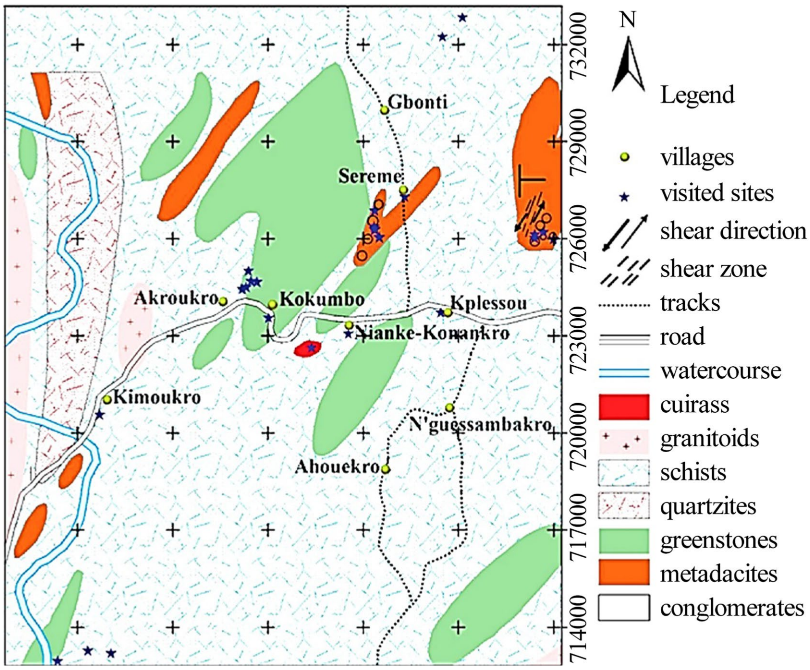


Figure 7. Simplified geological map of the study area at a scale of 1/100,000, [35] modified).

6. Conclusions

The work carried out highlighted the petrographic, structural, and metamorphic characteristics, as well as the mineralization associated with the Kimoukro and Koumbo geological formations. Fieldwork and thin-section analyses revealed that the study area contains metaandesites, metadacites, metaconglomerates, quartzites, schists, metadolerites, metagabbro-doleritic rocks, granodiorite, and quartz and calcite veins. These formations belong to the northern part of the Toumodi-Fettèkro trench and are in the greenschist facies. It should be noted that they have been affected by general metamorphism and weathering phenomena.

Two deformation mechanisms are observed: flattening and shearing. The structural features were observed at Kplessou and Gbonti. At Kplessou, there are two fracture directions: SSE and NNE, while at Gbonti, there are E and SSE directions. Furthermore, the presence of C/S structures confirms the existence of a left-sided shear corridor oriented N18˚, or NNE.

The primary mineralization in the Kimoukro and Kokumbo areas is gold and sulfide, mainly pyrite and chalcopyrite. However, gray copper and zinc are also present, the grades of which were detected by XRF. We believe there are two phases of sulfide mineralization due to the disseminated mineralization both in the quartz or calcite veins and in their host rocks (greenstones and sericite schist). Gold is also present in laterites, alluvium, and colluvium due to the presence of numerous gold mining sites in the study area.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Milési, J.P., Feybesse, J.L., Ledru, P., Dommanget, A., Ouedraogo, F., Marcoux, E., Prost, A., Vinchon, C. and Sylvain, J.P. (1989) Minéralisations aurifères de l'Afrique de l'Ouest, leurs relations avec l'évolution lithostructurale au Protérozoïque inférieur. Carte géologique au 1:2000000. *Chronique de la Recherche Minière*, **497**, 3-98.

[2] Fabre, R. And Morel, B. (1993) Stratigraphie des unités birimiennes dans le centre de la Côte d'Ivoire (Afrique de l'Ouest). *Bulletin de la Société Géologique de France*, **164**, 609-621.

[3] Milési, J., Ledru, P., Feybesse, J., Dommanget, A. and Marcoux, E. (1992) Early Proterozoic Ore Deposits and Tectonics of the Birimian Orogenic Belt, West Africa. *Precambrian Research*, **58**, 305-344. https://doi.org/10.1016/0301-9268(92)90123-6

[4] Feybesse, J.L., Billa, M., Milési, J.P., Lerouge, C. and Le Goff, E. (2000) Relationships between Metamorphism-Deformation-Plutonism in the Archean-Paleoproterozoic Contact Zone of West Africa. 31*st International Geological Congress*, Rio de Janeiro, 6-17 August 2000, 285-291.

[5] Houssou, N.N. (2013) Etude pétrologique, structurale et métallogénique du gisement aurifère d'Agbahou, Divo, Côte d'Ivoire. Master's Thesis, Universite Felix Houphouet-Boigny.

[6] Ouattara, Z. (2015) Caractères lithostratigraphiques, structuraux, géochimiques et métallogéniques du gisement d'or de Bonikro, sillon birimien de Fettekro, centresud de la Côte d'Ivoire. Master's Thesis, Universite Felix Houphouet-Boigny.

[7] Sonndrucker, P. (1969) Étude de synthèse sur l'or en Côte d'Ivoire Rapport de fin de mission. Rapport SODEMI n° 222, 127 p.

[8] Abouchami, W., Boher, M., Michard, A. and Albarede, F. (1990) A Major 2.1 Ga Event of Mafic Magmatism in West Africa: An Early Stage of Crustal Accretion. *Journal of Geophysical Research*: *Solid Earth*, **95**, 17605-17629. https://doi.org/10.1029/jb095ib11p17605

[9] Baratoux, L., Metelka, V., Naba, S., Jessell, M.W., Grégoire, M. and Ganne, J. (2011) Juvenile Paleoproterozoic Crust Evolution during the Eburnean Orogeny (~2.2 - 2.0 Ga), Western Burkina Faso. *Precambrian Research*, **191**, 18-45. https://doi.org/10.1016/j.precamres.2011.08.010

[10] Boher, M., Abouchami, W., Michard, A., Albarede, F. and Arndt, N.T. (1992) Crustal Growth in West Africa at 2.1 Ga. *Journal of Geophysical Research*: *Solid Earth*, **97**, 345-369. https://doi.org/10.1029/91jb01640

[11] Jessell, M., Santoul, J., Baratoux, L., Youbi, N., Ernst, R.E., Metelka, V., *et al.* (2015) An Updated Map of West African Mafic Dykes. *Journal of African Earth Sciences*, **112**, 440-450. https://doi.org/10.1016/j.jafrearsci.2015.01.007

[12] Taylor, P.N., Moorbath, S., Leube, A. and Hirdes, W. (1992) Early Proterozoic Crustal Evolution in the Birimian of Ghana: Constraints from Geochronology and Isotope Geochemistry. *Precambrian Research*, **56**, 97-111. https://doi.org/10.1016/0301-9268(92)90086-4

[13] Parra-Avila, L.A., Belousova, E., Fiorentini, M.L., Baratoux, L., Davis, J., Miller, J., *et al.* (2016) Crustal Evolution of the Paleoproterozoic Birimian Terranes of the Baoulé-Mossi Domain, Southern West African Craton: U-Pb and Hf-Isotope Studies of Detrital Zircons. *Precambrian Research*, **274**, 25-60.

https://doi.org/10.1016/j.precamres.2015.09.005

[14] Vidal, M. and Alric, G. (1994) The Palaeoproterozoic (Birimian) of Haute-Comoé in the West African Craton, Ivory Coast: A Transtensional Back-Arc Basin. *Precambrian Research*, **65**, 207-229. https://doi.org/10.1016/0301-9268(94)90106-6

[15] Parra-Avila, L.A., Kemp, A.I.S., Fiorentini, M.L., Belousova, E., Baratoux, L., Block, S., *et al.* (2017) The Geochronological Evolution of the Paleoproterozoic Baoulé-Mossi Domain of the Southern West African Craton. *Precambrian Research*, **300**, 1-27. https://doi.org/10.1016/j.precamres.2017.07.036

[16] Béziat, D., Bourges, F., Debat, P., Lompo, M., Martin, F. and Tollon, F. (2000) A Paleoproterozoic Ultramafic-Mafic Assemblage and Associated Volcanic Rocks of the Boromo Greenstone Belt: Fractionates Originating from Island-Arc Volcanic Activity in the West African Craton. *Precambrian Research*, **101**, 25-47. https://doi.org/10.1016/s0301-9268(99)00085-6

[17] Béziat, D., Dubois, M., Debat, P., Nikiéma, S., Salvi, S. and Tollon, F. (2008) Gold Metallogeny in the Birimian Craton of Burkina Faso (West Africa). *Journal of African Earth Sciences*, **50**, 215-233. https://doi.org/10.1016/j.jafrearsci.2007.09.017

[18] Block, S., Jessell, M., Aillères, L., Baratoux, L., Bruguier, O., Zeh, A., *et al.* (2016) Lower Crust Exhumation during Paleoproterozoic (Eburnean) Orogeny, NW Ghana, West African Craton: Interplay of Coeval Contractional Deformation and Extensional Gravitational Collapse. *Precambrian Research*, **274**, 82-109. https://doi.org/10.1016/j.precamres.2015.10.014

[19] Leube, A., Hirdes, W., Mauer, R. and Kesse, G.O. (1990) The Early Proterozoic Birimian Supergroup of Ghana and Some Aspects of Its Associated Gold Mineralization. *Precambrian Research*, **46**, 139-165. https://doi.org/10.1016/0301-9268(90)90070-7

[20] Markwitz, V., Hein, K.A.A. and Miller, J. (2016) Compilation of West African Mineral Deposits: Spatial Distribution and Mineral Endowment. *Precambrian Research*, **274**, 61-81. https://doi.org/10.1016/j.precamres.2015.05.028

[21] Lebrun, E., Thébaud, N., Miller, J., Ulrich, S. and Mccuaig, T.C. (2015) WITHDRAWN: The World-Class Orogenic Gold Siguiri District, Siguiri Basin (Guinea, West Africa). *Ore Geology Reviews*. https://doi.org/10.1016/j.oregeorev.2015.08.013

[22] McFarlane, C.R.M., Mavrogenes, J., Lentz, D., King, K., Allibone, A. and Holcombe, R. (2011) Geology and Intrusion-Related Affinity of the Morila Gold Mine, Southeast Mali. *Economic Geology*, **106**, 727-750. https://doi.org/10.2113/econgeo.106.5.727

[23] Tabaud, A.S., Trap, P., Durand, C., Marquer, D., Lescuyer, J.L. and Furic, R. (2015) New Insight on the Magmatic and Tectono-Metamorphic Evolution of the Paleoproterozoic Gold-Bearing Toulépleuity District (SW Ivory Coast). 13*th SGA Biennial Meeting*, Nancy, 17-20 May 2015, 85-115.

[24] Vic, G. and Billa, M. (2015) Geological Setting and Types of Carbonate-Hosted Gold Deposits in the Birrimian of West Africa. 13*th SGA Biennial Meeting*, Nancy, 17-20 May 2015, 145-175.

[25] Masurel, Q., Thébaud, N., Miller, J., Ulrich, S. and Hein, K.A.A. (2015) WITHDRAWN: The Sadiola Hill Carbonate-Hosted Gold Deposit, Kédougou-Kénieba Inlier, West Africa. *Ore Geology Reviews*. https://doi.org/10.1016/j.oregeorev.2015.11.005

[26] Grenholm, M., Jessell, M. and Thébaud, N. (2019) A Geodynamic Model for the Paleoproterozoic (ca. 2.27 - 1.96 Ga) Birimian Orogen of the Southern West African Craton—Insights into an Evolving Accretionary-Collisional Orogenic System. *Earth-Science Reviews*, **192**, 138-193. https://doi.org/10.1016/j.earscirev.2019.02.006

[27] Gnanzou, A. (2014). Etude des séries volcano-sédimentaires de la région de Dabakala (Nord-Est de la Côte d'Ivoire): Genèse et évolution magmatique. Contribution à la

connaissance de la minéralisation aurifère de Bobosso dans la série de la Haute Comoé. Master's Thesis, Université Félix Houphouët-Boigny.

[28] Passchier, W. and Trouw, R.A.J. (1998) Microtectonic. Springer, 289 p.

[29] Daouda Yao, B. (1998) Lithostratigraphie et Pétrologie des formations birimiennes de Toumodi-Fettekro: Implication pour l'évolution crustale du Paléoprotérozoïque du Craton ouest-Africain. Master's Thesis, Orleans University.

[30] Papon, A. (1973) Géologie et minéralisations du Sud-Ouest de la Côte d'Ivoire. *Mémoire du BRGM*, **80**, 284 p.

[31] Metelka, V. (2011) Geophysical and Remote Sensing Methodologies Applied to the Analysis of Regolith and Geology in Burkina Faso, West Africa. Ph.D. Thesis, Université de Toulouse.

[32] Groves, D.I., Condie, K.C., Goldfarb, R.J., Hronsky, J.M.A. and Vielreicher, R.M. (2005) 100th Anniversary Special Paper: Secular Changes in Global Tectonic Processes and Their Influence on the Temporal Distribution of Gold-Bearing Mineral Deposits. *Economic Geology*, **100**, 203-224. https://doi.org/10.2113/gsecongeo.100.2.203

[33] McCuaig, T.C. and Hronsky, J.M.A. (2014) The Mineral System Concept: The Key to Exploration Targeting. *Society Economic Geology Special Publication*, **18**, 153-175.

[34] Beba, F.A. (1995) La minéralisation aurifère dans les formations volcano-sédimentaires du Birimien cas de Kokumbo. Mémoire, Diplôme d'Etudes Approfondies, Université de Cocody, 45 p.

[35] Yace, I. (1976) Le volcanisme Eburnéen dans les parties centrale et méridionale de la chaîne Précambrienne de Fettekro en Côte d'Ivoire. Master's Thesis, The University of Abidjan.