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Lithological and Structural Characterization of the Gold Mineralization of the Bagoe Basin (Syama-Boundiali) in Northern Ivory Coast: Involvement in Mining Research

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Abstract: ***The Bagoe basin is located in northern Ivory Coast, on the border with Mali and accords with the Syama-Boundiali Paleoproterozoic (Birimian) basin. In the present study, we propose to make a contribution to the lithological and structural characterization of the mineralization of this basin from data collected in the two main mines located on both sides of the basin: the Syama gold mine in Mali and that of Sissingué in Ivory Coast. The results of our work indicate that the basin can be divided into two geologically distinct parts. Indeed, the basin is composed of two divisions, namely a west branch oriented N-S and an east branch oriented NNE-SSW. The two parts are separated by the Bagoeriver, which coincides with a major regional structure called the "Shear-Zone of Syama" with NNE-SSW direction. The mineralization is preferentially associated with intrusive and felsic dykes in the Sissingué zone in the western part, whereas in Syama it is not controlled by preferential lithology, even if the highest concentrations are in the aphanitic-textured basic volcanics and strongly hydrothermalized and brecciated. Hydrothermal alteration is the common feature of the basin's mineralization and could be a proximal indicator of this during exploration campaigns. It is of the propylitic type dominated by the chlorite-sericite-epidote-calcite-silica assemblage.***

Keywords: Bagoe Basin, Shear zone, Greenstone belts, Hydrothermal alteration, Propylitic alteration

1. Introduction

The study area is located in northern Ivory Coast between the towns of Boundiali and Syama (southeastern Mali) via Kouto, Sissingué and Tabakoroni (Figure 1). This area is composed of green rocks, also called Bagoe belt. In this basin, we find the mines of Sissingué in Ivory Coast and Syama in Mali [1]-[3].

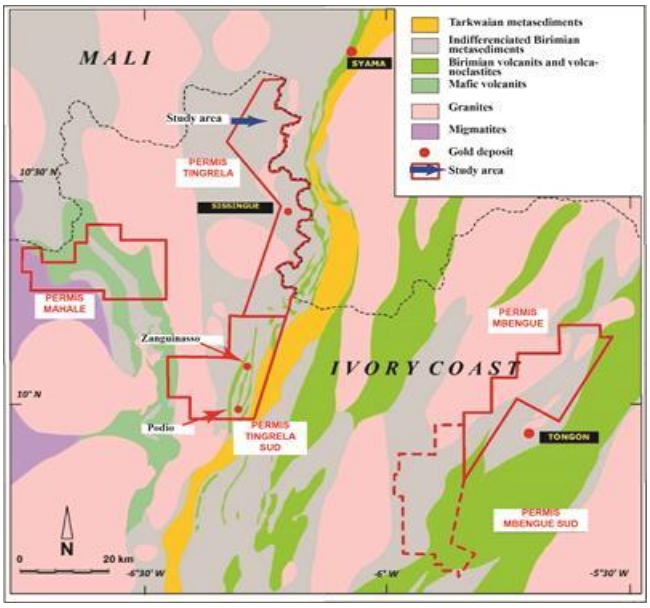

Figure 1: Geological map of the Syama-Sissingué-Boundiali study area

The basin consists of a basaltic series of tholeiitic character and a metasedimentary series. The ensemble is intersected by intrusive granites, felsic to calc-alkaline dykes and migmatites. These different formations are affected by a metamorphism of greenschist facies and strong hydrothermal alteration [1], [4].

The Bagoe basin is located in a geological and structural environment favorable to gold mineralization [5]. Several deposits including Syama and Sissingué are known in this basin. Our work aims to make a contribution to the lithological and structural characterization of gold mineralization in this basin. The results will make a significant contribution to geological knowledge and mineral exploration in this basin under-explored.

2. Material and Methods

In the absence of outcrops, almost all of our work focused on core samples. The material used consisted of conventional core material. To this, must be added computer and office equipment for the processing of results.

This work is based on the compilation of historical works done in the region that we integrate with our observations and recent studies at the Syama mine in Mali, and Sissingué in Ivory Coast. From the drill profiles, we establish the following main spatial correlations: mineralization-lithology, mineralization-structures, and mineralization-hydrothermal alteration.

3. Results and Discussion

We divided our area in two parts: a North-East zone that extends over the Malian territory dominated by the Syama mine and its satellite mines; and a southwestern area in Ivory Coast in the Sissingué mine area.

3.1. Geology and mineralization of the north-east sector of Bagoe (Syama Zone)

3.1.1. Litholologies

It should not be recalled that before the Syama mine, this area was the subject of a project called "The project MLI-79/003, Prospection of the Bagoe Gold Region" in 1979 and had as objectives geological and geochemical prospecting for gold in the Bagoe region, as well as the training of national personal in the technics of mining research and evaluation. The project, funded by the United Nations Development Program (UNDP) was carried out jointly for Mali by the Department of Technical Cooperation for Development. Our work takes into account previous surface results [6]. As well as more works in the Syama mine from the core drilling [1]. Thus, the following formations were observed:

- Shales and tuffaceous schists, grauwackes and arkoses;
- Intermediate jasper and meta-volcanoes (Figure 2);
- Intrusives dominated by basalts with aphanitic texture and often brecciated (Figure 3);
- Polygenic conglomerates, grauwackes, sandstones (Tarkwaïen facies).

All these rocks are metamorphosed in the epizone.

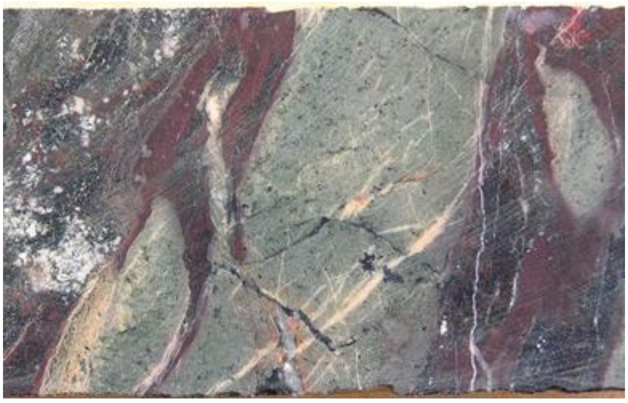

Figure 2: Veins of reddish jasper in a basaltic formation (core samples observed in Syama)

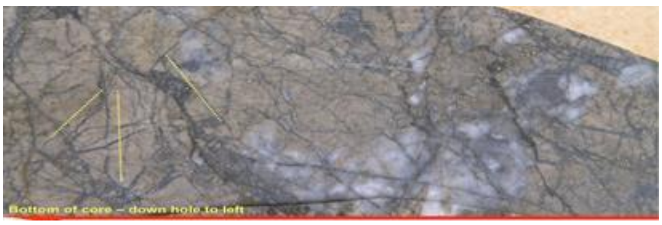

Figure 3: Hydrothermalized, brecciated and highly mineralized basalt sample

3.1.2. Study on core drilling samples

The Syama gold deposit is located in the Syama-Boundiali regional shear zone, in the Bagoe basin. This major structure called shear zone has a direction N25° and a dip of 50°W with a length of more than 100km. It is the boundary between two main lithological formations. One to the east formed of medium to coarse sediments (grauwackes and conglomerates) and the other to the west formed of basalt with intercalations of andesites, grauwackes, jaspers and graphitic argillites.

According to [1], [7], the Syama basin corresponds to a shear zone sub-stantially NS of 100 kilometers long and about ten kilometers wide. This corridor is a zone of strong deformation resulting in: i) a dipping NNE-SSW cleavage of about 70°-85° W defined by the minerals of the regional metamorphism of greenschist facies; ii) overlapping accidents parallel to this cleavage. Second-order structures are the most dominant and can be divided into four groups (Table 1):

Table 1: Classification of secondary structures

Faults	Directions	Dips	Dip directions
Reverse faults	N020 - N040°	60 - 70°	NW and SE
Overlapping faults	N040 - N230°	30 - 45°	NW
Vertical to sub-vertical faults	N000 - N020°	80 - 90°	West and East
Transversale faults	N150 - N170°	80 - 90°	SW and NE

3.1.3. Characteristics of the mineralization of the deposit

The Syama mineralization, about 800 meters long from north to south, has been confirmed by diamond drilling over a depth of 400 meters. It has been identified in a series of locally hydrolyzed tholeitic volcanic rocks with siliceous or manganese levels. The mineralizing fluid is of hydrothermal origin [5]. The deposit of the gold would be due to a desulfurization or a separation of the phases during the different tectonic events. The main mineral indicator of this mineralization is the fine pyrite disseminated in the rock. However, there is another coarse, less mineralizing pyrite. The mineralization is also associated with veins and quartz-carbonate stockworks and mineralized shears in metasediments. Shallow areas of sericitic alteration are commonly developed, with propylitic alteration all around, with disseminated fine pyrite often adjacent to the veins.

The morphology of the mineralized body is lenticular in nature with disseminated mineralization, oriented N20° with a 55° to 65° dip to the west. It has been recognized over 800m long, its power ranging from 30 to 40m. It consists of an oxidized portion about 40m deep and a sulphide portion over 300m deep [8].

The mineralization is characterized by the absence Pb, Sb, As. The main sulphides are pyrite (abun-dant) and sphalerite (frequent). Chalcopyrite is rare and is always associated with sphalerite. Some traces of accessory minerals such as pyrrhotite, bornite, galena, covellite are present. Gold comes in several forms:

- In ranges ranging from 1 to 150 microns. It can be included in gangue minerals (quartz or carbonates).
- In fine inclusions in pyrite (1 to 50 microns), exceptionally in chalcopyrite or at the edge of the pyrite grains. On the microscopic studies have shown the presence of arsenopyrite in pyrite.
- Finally, some gold ranges appear in late quartz veinlets, in association with chalcopyrite [9].

3.1.4. Geological control of the mineralization

Lithology and mineralization

Core studies indicate that the gold mineralization at the Syama mine is not related to preferential lithology;

especially since all rocks, can often contain gold. However, the percentage of mineralized volcanic rocks and the amount of ore associated with these volcanic rocks far exceed those of other formations. Dominant lithologies are basalts, andesites, grauwackes and argillites.

Alteration and mineralization

Our observations show that the relationship between weathering and mineralization is obvious. The emplacement of the mineralization is due to a hydrothermal alteration that affected the pre-existing rocks. The relationship between gold mineralization and alteration minerals (type of alteration) is often very clear. The gold content in the rocks varies greatly with the degree of weathering. However, they are not linearly dependent. Otherwise, gold is very often contained in heavily weathered areas, but there are also well-weathered areas that are not mineralized.

This finding leads us to conceive that it had two phases of hydrothermal alterations: one mineralized and the other non-mineralized that would have succeeded one after the other in the region. Our work did not allow us to know which preceded the other.

3.2. Geology and Mineralization of the Southwest Sector of Bagoe (Sissingué Zone)

3.2.1. Lithology and Mineralization

In the absence of outcrops, our work focused on core samples from the Sissingué mine and surrounding areas. On the lithological plane, the deposit consists of a sedimentary ensemble composed of sandstones, metaconglomerates, metasilts and an intrusive magmatic ensemble composed of granites and porphyritic microgranites.

Gold mineralization is a disseminated sulphides in intrusives (granites and porphyritic microgranites) and in their enclosures (metaconglomerates and sandstones), mainly in contact zones. However, grades appear to be higher in granite, and secondarily in porphyry microgranites. Disseminated mineralization appears to be related to intrusions of granite domes and felsic dykes. Sissengué gold is accompanied by fine grains of arsenopyrite and disseminated pyrite. The pyrite identified is much larger than arsenopyrite and is almost present in all formations, especially in metasilts where its automorphic form suggests that it is syngenetic. Arsenopyrite is generally identifiable in mineralized rocks and is also found in quartz veins that contain visible. As a result, arsenopyrite can be considered a key indicator of gold [10].

3.2.2. Characteristics of the mineralization

Disseminated gold

Disseminated gold is more common in granites and felsic dykes. It could be due to the destabilization of the gold complex in the magmatic fluids, following a rapid cooling.

Visible gold in veins

Gold lying mainly in the altered clasts of quartz veins is generally interpreted as the direct result of an interaction between the fluid and the host rock. The sulfurization process is a type of fluid-rock interaction considered to be very effective for gold deposition when it exhibits a strong spatial association with iron sulphide [11]-[13].

During the sulfurization, H_2S and S in the Au-S complex ($Au[HS_2]$) of the fluid, react with silicates or iron oxides, from the host rock, to transform them into iron sulphides; here arsenopyrite (FeAsS) and pyrite (FeS_2), at the walls of the hydrothermal pipe. The reduction of sulfur in the fluid thus destabilizes the Au-S complex causing the precipitation of gold: $Au(HS)_2 + FeO \longrightarrow Au + FeS_2 + H_2O$.

This destabilization takes place at a sudden drop in temperature and pressure associated with fine grains of sulphides at the walls of the veins. Gold appears free in veins of quartz when its quantity is abundant in the fluid, and when there are fewer free sites to occupy in the sulphides and cooling is rapid.

3.2.3. Mineralization and hydrothermalism

The relationship between arsenopyrite and sericitic alteration suggests concomitant placement. There is also a strong carbonation in the matrix of magmatic rocks and also in altered sediments in the contact zones.

The formation of sericite could be related to the phase of emplacement of the mineralization. Thus, the sericitization observed in the granites or metasediments near or within the mineralization could be mainly due to the hydrolysis of the plagioclase present in the granite following the fluid-rock contact. It is a metasomatism by the H^+ present in the hydrothermal fluid with silicate minerals such as sericite and quartz. Carbonates come from the decomposition of biological debris in metasediments and the alteration of plagioclase in magmatic rocks.

3.2.4. Mineralization and structural control

The mineralization is related to a microgranite intrusion in the direction of the major NNE-SSW fault and intrusions of felsic dykes. These formations are enriched in sulphide associated to gold and consist of porphyry feldspars that crystallized in NNW-SSE oriented fractures in the metasedimentary formations (sandstones and metasilts in the contact zones). The mineralization is accompanied by a hydrothermal alteration marked by a sericitization associated with calcite and an additional silicification marked by the presence of veins and veinlets of quartz associated with fine crystals of disseminated pyrite and arsenopyrite, and with the wall rock veins with some-times visible gold (Figure 4).

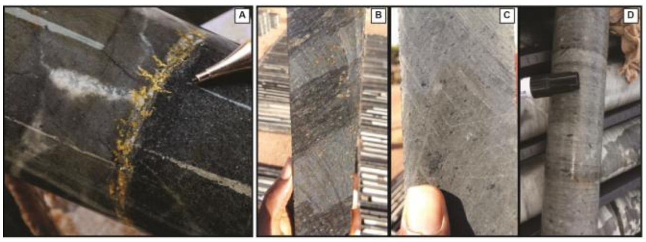

Figure 4: Samples of Visible Gold (A) and Disseminated (B) and Non-Mineralized (C), Mineralized Granitoid (D)

4. Conclusion

At the end of our work on the lithological and structural characterization of the Bagoe basin, it appears that the basin can be divided into two distinct parts: A eastern part is dominated by the Syama mine and a western part dominated by the mine of Sissingué. The first part has been the subject of many studies, while the second has been few studied. In this basin, the geological formations consist essentially of: i) metasediments (schists, grauwackes, arkoses, sandstones, jaspers, metaconglomerates, metasilts); (ii) metabasalts; and (iii) granitic intrusions.

Thus, the results of our work, can make a significant contribution to the understanding of the geology of this birimian unit especially in the Ivorian part or very few studies have already been done outside the ongoing gold prospecting work by the mining companies.

For mining exploration, it should be noted that the Bagoe basin is characterized by a major regional structure, the NNE-SSW-oriented Syama shear-zone, which is the main conduit favorable to mineralizing fluids. The deposits are located either at the heart of this structure, such as that of Syama in the northeastern part of the basin, or in its immediate vicinity, such as Sissingué in Ivory Coast in the south-eastern part of the basin. Alongside this main regional structure, there are several structures and secondary microstructures of varied direction that have played a major role in the trapping of mineralization.

The mineralization is preferentially associated with intrusives and felsic dykes in the Sissingué zone, whereas in Syama it is not controlled by preferential lithology, even if the highest contents are in the basic volcanic rocks with aphanitic texture and strongly hydrothermalized. Hydrothermal alteration is the common feature of the basin and could be a proximal indicator of the mineralization during exploration campaigns. It is of the propylitic type dominated by the assemblage: chlorite-sericite-epidote-calcite-silica.

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