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Gold Mineralisation in the Intiédougou Prospect (Diébougou District) in Southwest Burkina Faso, West African Craton

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Abstract

The Intiédougou located in the Houndé Birimian greenstone belt has been the subject of several mining and geoscience studies that have led to the discovery of mineralized gold targets. One of these mineralized targets has prompted work that raises the issue of control factors for the gold mineralization of the prospect. The methodology used in this study combines a study of core drill hole data located in the area and laboratory studies. The Intiédougou sector is based on andesito-basaltic, andesitic interstratified volcanoclastite rocks and Tarkwaïen type detrital sedimentary rocks caught in a vice in the volcano-sedimentary unit. Lithostructural analysis of the sector shows that the subvolcanic rocks bearing gold mineralization are subjected to heterogeneous ductile to brittle deformations and affected by hydrothermalism evolving at stages marked by large fissure fillings. These hydrothermal phases evolve in the zones of expansion created by the brittle deformations that have contributed to the deposits of different types of gold-enriched sulphides. These different phases of hydrothermal destabilization generally of low degree accompany the tardi to post-eburnean brittle tectonics. This deformation system is favorable to the establishment of gold mineralization in the form of vein bodies. The overimposition of deformed and altered areas suggests a genetic relationship between deformation and hydrothermal activity. In conclusion, the mineralization of Intiédougou in vein styles, set up in a volcanic arc environment with a paragenesis of gold-pyrite deposit ± chalcopyrite would be controlled by the structural aspect and accompanied by hydrothermal alteration.

Keywords

Intiédougou Prospect, Shear, Hydrothermal, Tarkwaïan, Gold Mineralization

1. Introduction

Burkina-Faso is part of the south-east portion of the West African craton of the Baoule-Mossi domain, where the Precambrian rocks formed during the Eburnian orogeny (2250-2100 Ma) are organized into greenstone belts trending NE-SW and NNE-SSW. These greenstone belts are often intruded by basin-type or belt-type granitoids ([1] [2]). The surrounding formations of these granitoids have been metamorphosed under greenschist facies conditions, reaching amphibolite near certain plutons ([2]; Lompo, 2010). Several belts have been identified, one of which is the Houndé greenstone belt in southwestern Burkina-Faso, the subject of this study. Previous work has detailed lithostructural units, lithofacies and mineral resources through geological and metallogenic maps, geochemical and geophysical prospecting ([3] [4] [5] [6] [7]). Orezone Inc. holds several licenses in the Diebougou area, and has been conducting exploration campaigns since 1998, resulting in the discovery of several gold targets including the Intiedougou mineralisation. This snapshot highlights the context of mineralization through field investigations and the study of deep drill core from the Intiedougou target.

Intiédougou (**Figure 1**) is located in the Diébougou district in southwest Burkina-Faso, 100 km from the main town of Bobo-Dioulasso. It lies between 11˚ and 12˚ north latitude and 3˚ and 4˚ west longitude. The area features a relatively rugged topography, with mountain chains trending almost N-S. It extends to the western edge of the Houndé belt of Birimian rocks. This belt has been, and continues to be, the subject of several exploration campaigns. The Intiédougou target comprises a unit of Tarkwaïan-type clastic sediments sandwiched within volcanic and volcano-sedimentary rocks of andesitic flow to breccia and tuf ([7] [8] [9] and [10]). The volcanic and sedimentary units are intruded by circumscribed granitic massifs attributed to the Birimian (Koffi *et al.*, 2018), with ages between 2170 Ma and 1500 Ma. The granite-gneissic massifs outcropping on either side of the Houndé Birimian greenstone belt were individualized into a Burkinian system (2400 - 2100 Ma) by [11]. The late dolerite in the area cuts across volcanic and intrusive and Tarkwaian rocks, as do dykes of felsic to mafic composition. All the rocks are metamorphosed into greenschist facies accompanied by the effects of various hydrothermal or meteoric alterations.

Prospecting in the area has revealed several patterns of regional deformation, interpreted from airborne geophysical data collected by the SYSMIN (System for Mineral Product) project in 2003, as shear corridors. These shear corridors are ductile to brittle, linked to transpressional movements, and feature a major S1 schistosity associated with P1 isoclinal folds and an S2 phase linked to P2 crenulation

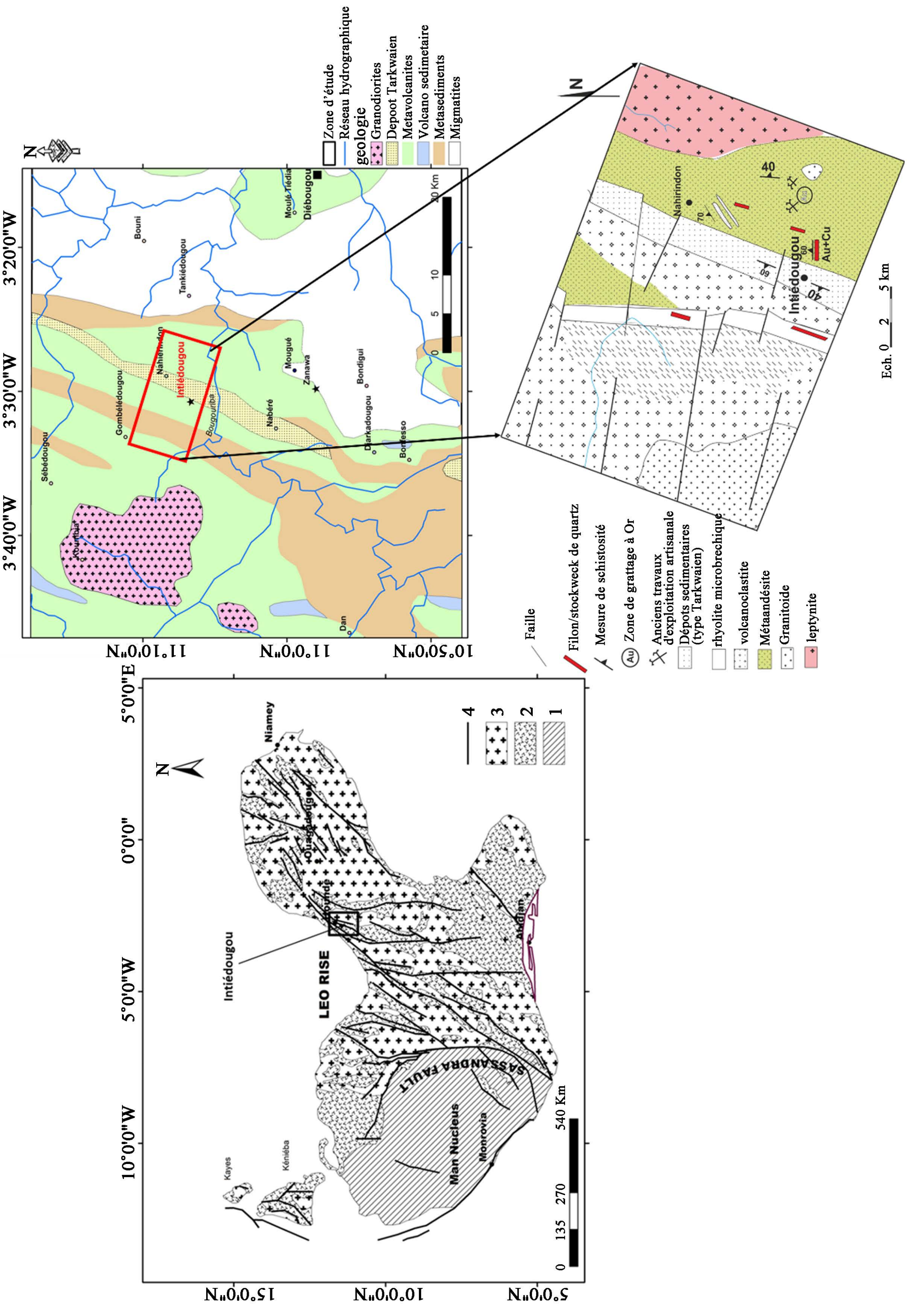

Figure 1. Geological map of Intiédougou prospect.

folds. These structural features have been described by [6] and [12]. NNE-SSW-trending faults identified in the study area have been considered as second-order structures of the Houndé fault. The Houndé greenstone belt's Intiédougou gold deposit is intersected by the Houndé-Ouahigouya fault, which exhibits a left-lateral displacement and moves in a north-south to north-northeast and south-southwest direction, according to a study by [7]. The gold deposit is accompanied by highly silicified areas containing quartz veins and veinlets, as well as carbonatitic alteration and disseminated sulfides with concentrations of up to 3%.

2. Methodology

In this study, we combine an analysis of data from diamond boreholes in the Intiédougou area, field mapping and pre-existing regional mapping data ([7] [8] [9] and [13]). Ten diamond holes were fully logged (2405 m) drilled by Orezone Mining Inc. The holes are drilled with a dip of almost 50˚ to the southeast, except for two holes drilled to the northwest (**Figure 2**). The petrographic description of the core samples (**Figure 2**) was carried out on twenty thin sections and ten polished sections at the laboratory of geology of the Joseph Ki-Zerbo University (Burkina-Faso).

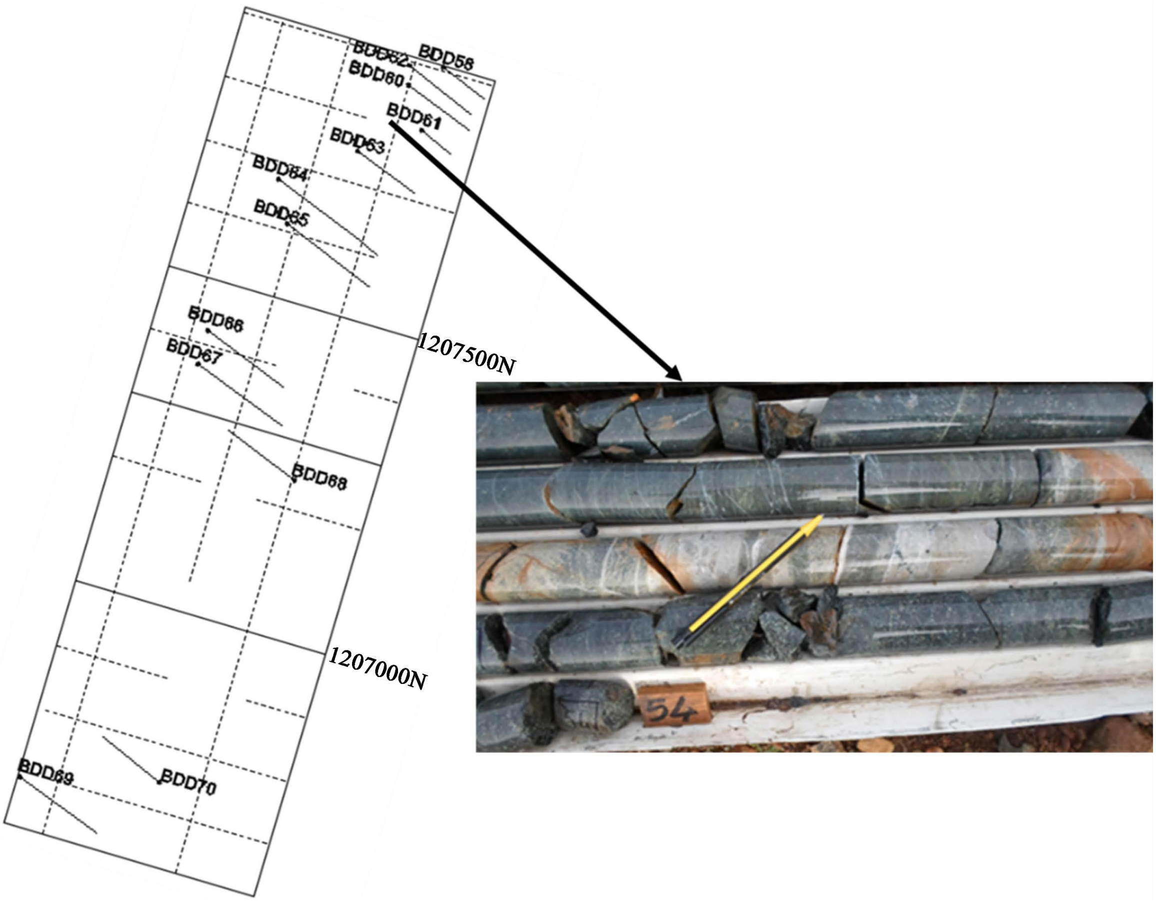

Figure 2. Location of core drilling collars in the Intiédougou target with a photograph of a core box.

3. Results and Interpretation

3.1. Petrography

Based on the petrographic analysis, it has been identified that there are three primary units present: a volcano-sedimentary unit, a detrital sedimentary unit, and a tectono-metamorphic unit.

3.1.1. Volcanic-Sedimentary Unit

The volcano-sedimentary unit comprises alternating flows of basic, andesitic, and felsic volcanic rocks. Predominantly felsic in nature, these rocks bear a striking resemblance to intercalary terrigenous sediments, composed of minerals and fragments resembling volcanic tuffs and breccias with a mixed texture. The unit is also crossed by hypovolcanic formations in vein form, predominantly characterized by diorite injections.

3.1.2. Detrital Sedimentary Unit

In the area, there is a detrital sedimentary unit made up of polygenic conglomerate and feldspathic sandstone facies. The heterogranular clastic rocks are composed mainly of angular quartz debris, ranging from fine to coarse-grained. The proximal transport character of the product is evident in the angular appearance of the lithic elements and mineral debris.

3.1.3. Tectono-Metamorphic Unit

The tectono-metamorphic unit comprises both regional and contact metamorphic rocks, including gneiss, amphibolite, and mylonite. The development of these rocks occurs in either ductile or brittle shear zones, depending on the nature of the protholith. To identify these tectonised and altered rocks, a mineralogical approach was used, with a focus on recognizing primary relict minerals. The study uncovered that all rocks in the area were impacted by greenschist facies deformation and metamorphism during the Eburnian orogeny.

3.2. Gold Mineralization Host Rocks

The target area boasts a variety of rocks, including mylonites and breccias derived from microdiorites and feldspathic sandstones. These rocks have undergone tectonic activity, resulting in their unique composition. Mineralized areas contain hydrothermal breccias, which feature large veins and veinlets filled with quartz, carbonate, albite and sulfides. These breccias are intricately linked to mineralizing fluids and contain between 3% and 5% of disseminated sulfides. Hydrothermal alteration has transformed the brecciated rocks through silicification, carbonation, and albitization, ultimately leading to sericitization. The mylonites are identifiable by their greyish-green, sheared, and foliated appearance, complete with well-defined micro-folds. Petrographic analysis reveals that the mylonitic character of microdiorites and feldspathic sandstones is marked by multiple deformation phases, including plastic deformation, fragmentation, and brecciation (Table 1). These changes are particularly pronounced in intensely deformed zones and around the contact between plutons and volcano-sedimentary rocks.

Upon close examination, it is possible to observe mylonitization occurring in multiple phases. The protomylonites consist of finely recrystallized microcrystals, which appear ghostly and coarse under microscopic observation (as depicted in Figure 3). These crystals are connected to a network of intense fissures and crushing zones, which isolate small rock fragments. In areas where ultramylonitization has taken place, the rocks are unrecognizable and exhibit hydrothermal alteration along with the presence of sulfides. This process results in a mineralogical transformation where plagioclase and green hornblende crystals are replaced by static recrystallization, maintaining their long rod shapes. The presence of chloritization in important amphibole microblasts, accompanied by opaques, epidote, damourite, and carbonate clusters, are significant indicators of mylonitic deformation. Additionally, the existence of relics of rod-shaped minerals

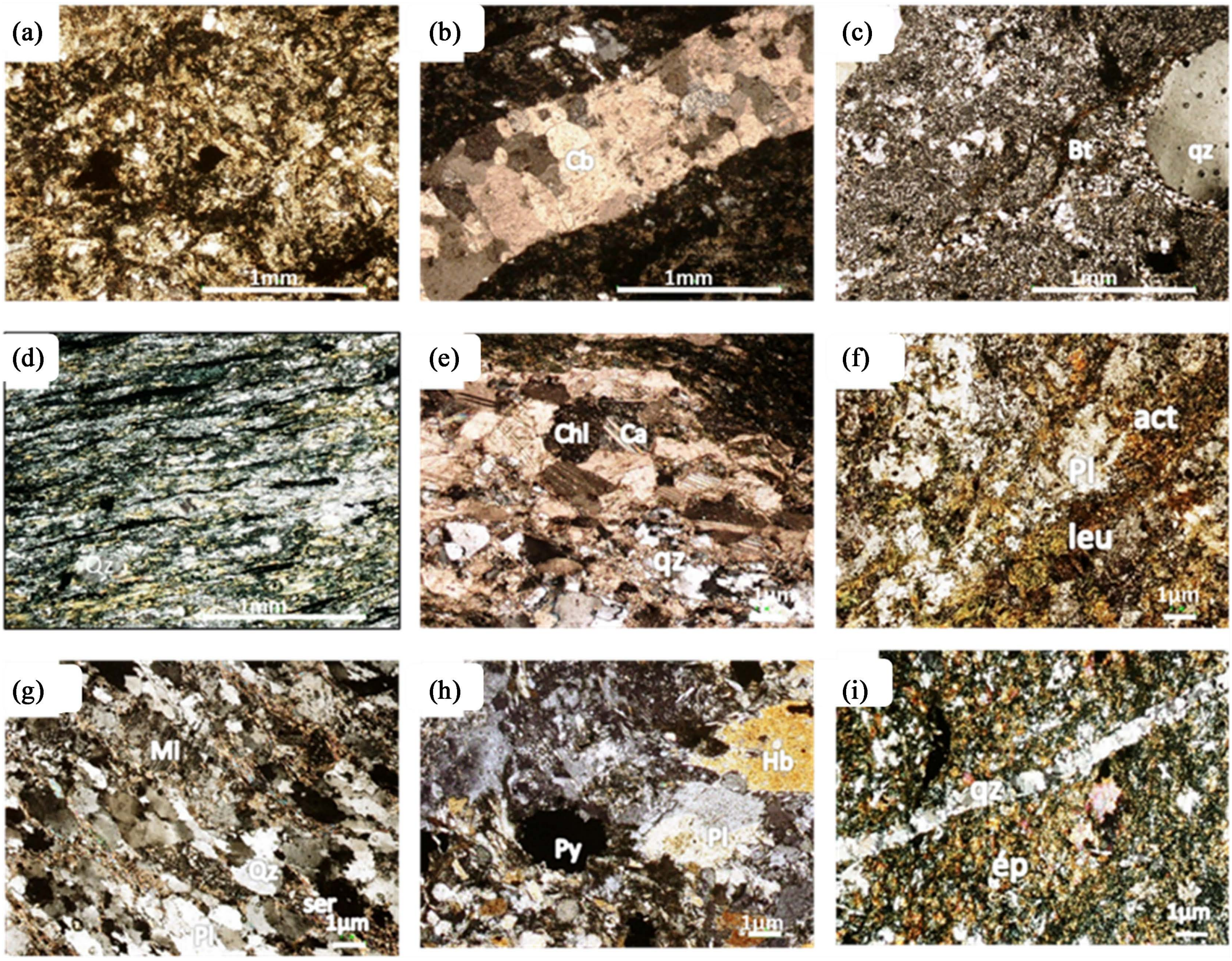

Figure 3. Under microscope: ((a); (b)) metabasalt that had been fully hydrothermalized in carbonate and chlorite, with a veinlet filled with carbonate cutting through it; (c) photograph of a metarhyolite displaying a frustrated deformation character with quartz phenocrysts; ((d), (e)) microscopic observation of a metaandesite that was dominated by calcite and carbonate; (f) texture of a microdiorite that showed plagioclase undergoing saussuritization; (g) mylonitic sandstone; (h) porphyritic microdiorite with plagioclase and green hornblende phenocrysts; and (i) fully epidotized metaandesite crossed by quartz veinlet.

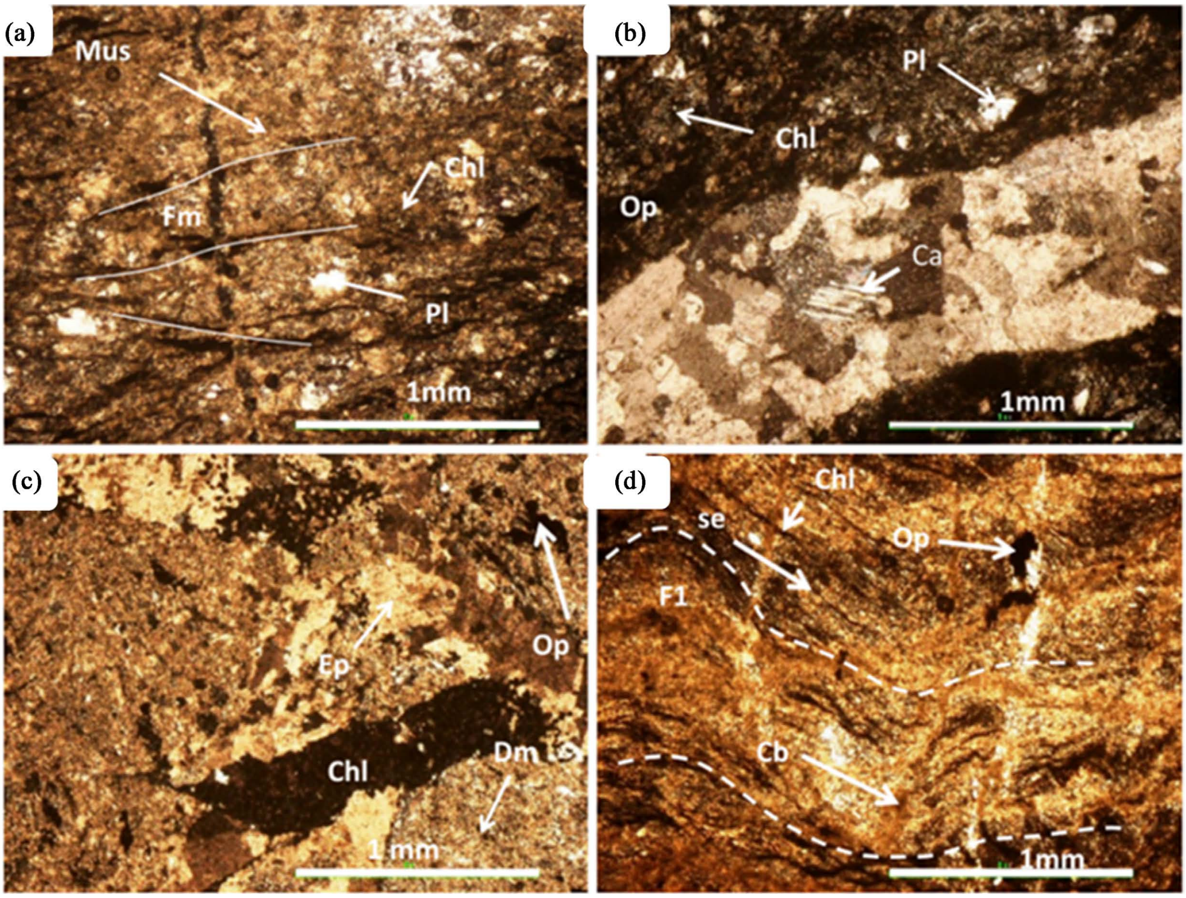

Figure 4. Microphotographs of the Intiédougou mineralization. (a) Spherulitic andesite deformed and hydrothermalized at a depth of 79.30 meters; (b) late carbonate and calcite-filled veinlet; (c) hydrothermalite with a network of chlorite- and epidote-filled fissures accompanied by iron oxides; (d) mylonitic gneiss with P2 micro-crenulation foliation and carbonate-filled veinlets observed at a depth of 66 meters.

provides evidence of the subvolcanic origin of the protolith, likely microdiorites (Figure 4).

3.3. Tectonic

3.3.1. Brittle Deformation

When rocks experience brittle deformation, they go through various stages of tectonic and hydraulic brecciation, which can happen concurrently. The initial stage involves rock fragmentation from fracture networks, along with crushing. Other stages are caused by hydraulic fragmentation of fluids due to magmatic injections of microdiorites. Hydrothermal products join the fragments together. Hydraulic fragmentation resulting from fluid pressure may occur with the development of gold-bearing quartz veins and veinlets. Upon microscopic examination, there is a fissural polyphase with several Fn phases, with the last phase, Fn + 1, leading to the overall decroaching of the polydeformed rocks. This brittle deformation follows mylonitic ductile-shear deformation.

Crushed zones display intense carbonate- and chlorite-dominated alteration. The fluids that exploit brittle deformation lead to metasomatic transformations

Table 1. Main lithofacies in the diamond boreholes at Intiédougou.

Diamond borehole	Thin section	Rock type	Structure et texture	Mineralogical assemblages	Comments
BDD060	D60P4	Biotite bearing quartz microdiorite	Heterogranular microcrystalline sheared	Plagioclases, chlorite, carbonates, muscovite, sericite and opaque	Carbonate, chlorite and micaceous hydrothermal alteration. Quartz veins associated with silicification, Two generations of opaques: (i) Synkinetic shearing, (ii) Postkinetic
BDD062	DP62 P1	Amphibole diorite	Sheared	Amphibole and opaque plagioclase, chlorite and epidote	Opaque to coarse crystals destabilizing to leucoxene
BDD060	D60P3	Amphiboloschist	schistosed micro-eyed nematoblastic	Actinote, chlorite, carbonate, and epidote	Late quartz-carbonate veinlets, several phases of brittle deformation, filled with hydrothermal fluids.
BDD060	D60P9	Amphibolo schist/Actinotite	Sheared, schistosed nematoblastic	Actinote, quartz, plagioclase, carbonate, epidote and opaques	
BDD064	D64P5	Hydrothermalite,	Breccia	Carbonate (70%), Chlorite (15%), Damourite and séricite (5%)	Breccia infilled with carbonate and accessory chlorite, microcracks filled with chlorite Likely protolith of quartz microdiorite.
BDD070	D70P12	Feldspathic sandstone	Mylonite	Angular quartz, damouritized plagioclase, perthite, orthoclase, incidental biotite, chlorite, muscovite and opaques	Abundant chlorite and epidote fracture-filled

of the protholith. Hydrothermal alteration also affects contact and regional metamorphic rocks and is believed to be an ongoing, late-stage process.

3.3.2. Brittle-Ductile Deformation

In the target scale, there exist ductile deformation varied degrees of deformation (Figure 5). A flow schistosity, trend from N010 to N035˚, telescoped the primary stratification (S0) and is observed dipping towards the southeast in microdiorites and feldspathic sandstones. These areas display S1/S2 schistosity, fracture schistosites, and dissymmetrical microfolds. Additionally, Chlorite and amphibole exhibit a preference for orientation within this plane-like structure. The S2 crenulation schistosity, is characterized by microfolds. The central axis of the shear corridor contains the latter, where P2 folds occasionally occupy the S1 schistosity. Asymmetrical folds with quartz-carbonate veinlets present sigmoid geometry and "S" hooks, which are an indication of sinister shearing. These structures primarily impact spherulitic microdiorite rocks and feldspathic sandstones. Isoclinal folds are common when their axial plane is sub-parallel to the S1 schistosity.

3.3.3. Veining

Textural styles of veins can provide a valuable insight into the tectonic and hydraulic conditions present in the vein zones. The study has identified three types

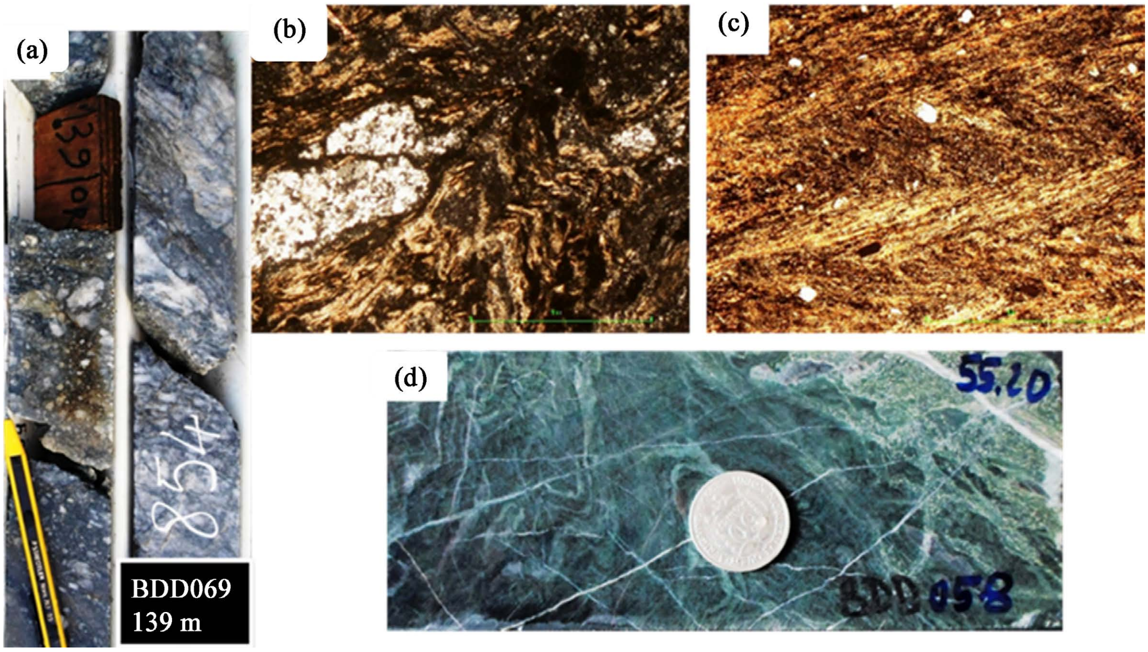

Figure 5. Photographs of structure recorded in drill core. (a). Brecciated microdiorite core, (b). Mylonite (microdiorite) with microfolds, (c). Orthoschist showing frustrated schistosity, and (d). Late calcite and epidote fill fracture coss early foliated and andesite basalt.

of veins: banded, laminated, and massive veins. Veins and veinlets are typically found running parallel to spandrels and schistosity (S1) and may be curled, following small asymmetrical folds. These veins are usually filled with chlorite-carbonate or quartz-carbonate and are observed in the upper levels of the core hole, resulting in textures of bonded fragments. The contact between each fragment may indicate a change in fluid composition or a shift in depositional conditions. Laminated veins, also known as shear veins, are often discovered in intensely sheared zones and may be locally curled. These veins are filled with quartz-sulfide-carbonate and are situated at the center of the shear zone. These veins form under conditions of local compression and high differential stress, caused by alternating deposition and tectonic movement. In Figure 6, you can see that the massive veins that intersect the regional schistosity at an oblique angle. Although these veins have varying inclinations, they share a consistent composition of sphalerite, pyrite, calcite, and quartz. Late in their development, these veins formed through a combination of tectonic and hydraulic processes. The intricate shape and structure of the quartz veins and veinlets are the result of complex geological activity, which is influenced by the mechanical behavior of the rock and the hydraulic domains that exist beneath the surface.

3.4. Metalliferous Paragenesis

After careful observation, it has been discovered that significant sulfide mineralization is primarily associated with mylonitized microdiorites and sheared veins and veinlets. In-depth metallographic and scanning electron microscopy analysis revealed that the metalliferous paragenesis consists mainly of pyrite, chalcopyrite,

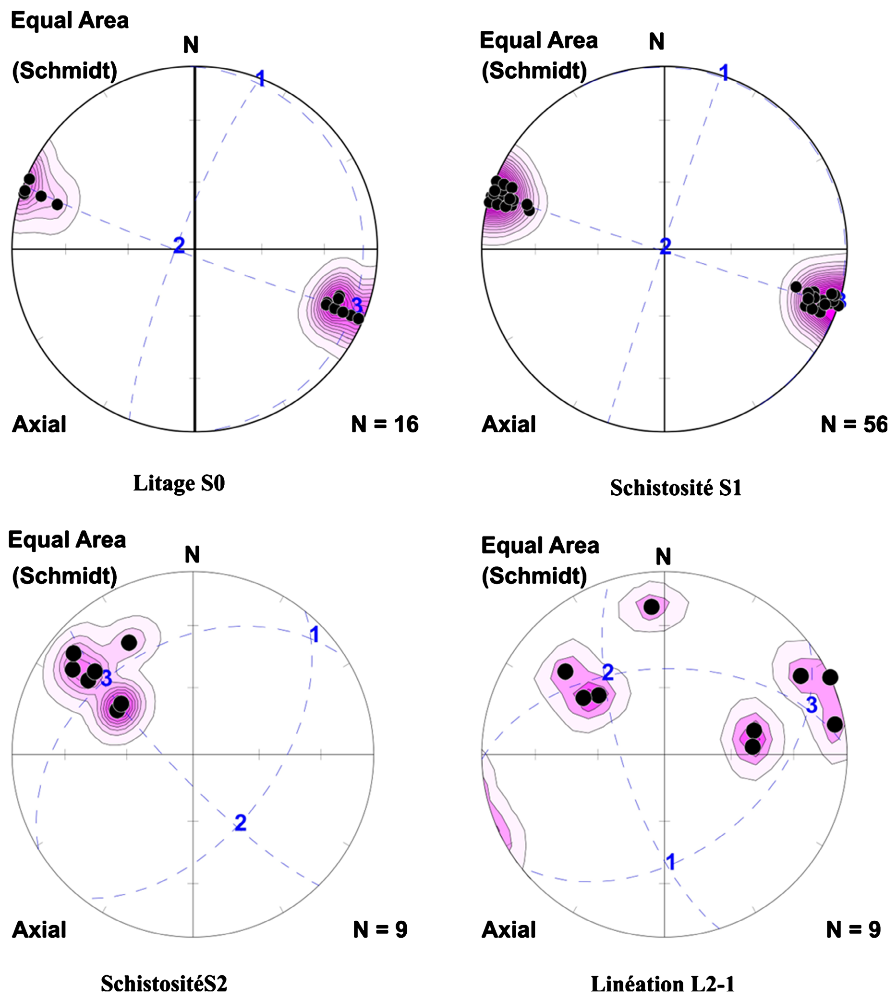

Figure 6. Stereographic projections of tectonic structures in the Intiédougou target.

marcasite, gold, sphalerite, galena, ilmenite, and (as shown in **Figure 7**). Pyrite typically appears in large, fractured patches ranging in diameter from 2 to 5 mm. Chalcopyrite often replaces pyrite, especially in zones with fractures. It is also occasionally found in automorphic grains in fractures and sometimes laminated in the S2 schistosity planes where it coexists with quartz and iron oxides (hematite and magnetite). Chalcopyrite appears as disseminated xenomorphic patches that alter to covellite and as small sub-automorphic crystals in microfractures that affect pyrite. Marcasite forms small xenomorphic patches that replace pyrite and chalcopyrite. Sphalerite always appears embedded in pyrite and exhibits a clear substitution of Zn for Fe (7.5 wt%). Observations have indicated that pyrite may contain galena inclusions or be in contact with it, whereas Ilmenite is commonly associated with carbonates and pyrite. The orientation of the sulfides and gangue is distinct, suggesting that the ore has undergone metamorphic recrystallization. In addition, gold is present in a very fine particle, with assay analyses revealing interesting grades in sections where no visible gold grains were observed under the optical microscope. Electron-microprobe analysis of the gold grains has also shown trace amounts of silver (up to 10.3 wt%), bismuth, and

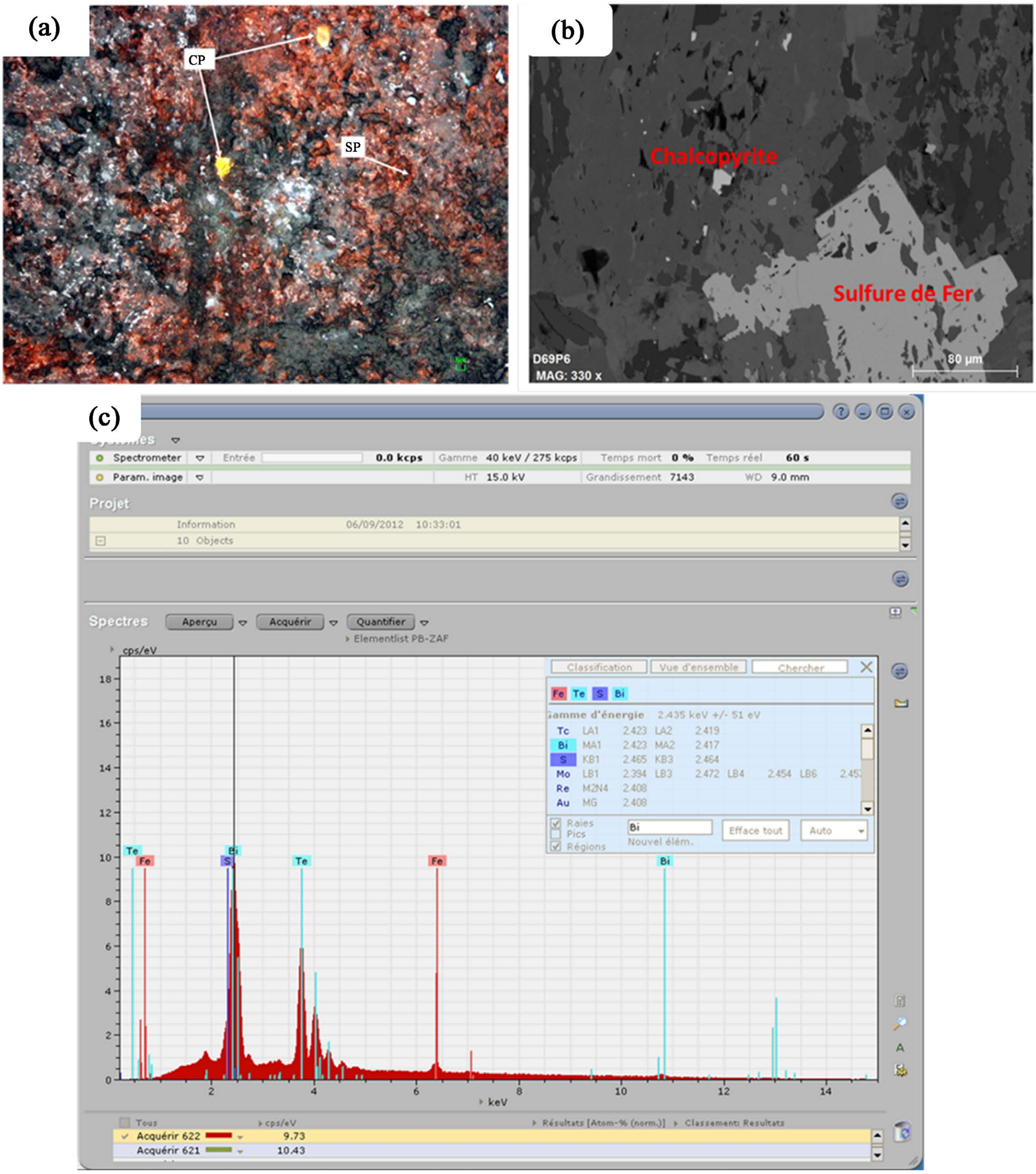

Figure 7. Mineralization Paragenesis of Metals. (a). Microscopic photo of chalcopyrite (CP) and sphalerite (SP). (b). SEM image of chalcopyrite at 80 μm magnification. (c). Spectrum analysis of a 5μm chalcopyrite grain with Bi2Te3 Ag and Te inclusions.

tellurium (as depicted in Figure 7). Throughout the studied sections, magnetite and hematite, two types of iron oxides, are widely distributed and have replaced various sulfides through alteration.

4. Discussion

The gold mineralization in the target is highly developed within hydrothermalized and sheared microdiorites. The structural characteristics in the study zone are comparable to those identified in other regions of Burkina-Faso and West Africa ([9] [14]-[22]). The tectonic structuring of the Intiédougou zone was initiated by a phase of NW to NWN compression, which resulted in the formation of ductile shear zones. This is believed to be the outcome of the ductile-brittle deformation phase, which occurred due to the E-W compression-transgression mechanism, leading to transcurrent shearing.

During this stage, small folds, minor fractures, and veins and veinlets start to form. Mineral-rich fluids flow through most of these structures and create networks of veins with twisted veinlets. These likely developed during a process called brecciated hydrothermal activity, which occurred when felsic and basic dykes were being inserted. This stage also impacts secondary shear zones, which are pathways for fluid circulation that can remobilize, concentrate, and deposit gold. A comparison of the findings from the Intiédougou zone with those of [23] indicates that the abundance of gold-bearing quartz veinlets is a result of transcurrent shear phase events. These authors link gold mineralization in Burkina-Faso with shear zones accompanied by fracturing and gold mineralization episodes.

The Intiédougou area's gold analyses carried out by OREZONE support the authors' idea. The analyses revealed high gold grades concentrated in sheared, crushed, and silicified zones of microdiorite. This rock is dominated by numerous quartz veins and veinlets associated with calcite and sulfides, indicating hydrothermal fluid activity. This suggests mineralization of vein and hydrothermal origin. The hydrothermal fluid would have deposited the gold mineralization through fracturing. This type of mineralization has already been observed in most of Burkina Faso's Poura [24], Taparko [25], and Côte d'Ivoire's Aféma deposits [26] [27], as well as Ghana Ashanti, Mali Sanoukou [28] in West Africa.

5. Conclusion

The geological study conducted on the Intiédougou prospect revealed a diversity of lithologies affected by intense deformation and hydrothermal alteration process. These formations include volcanic and volcanoclastic units with different lithofacies, such as andesites, andesito-basalt, basic to acidic tuffs, breccias, volcano-sediments, terrigenous sediments, mylonites, ultramylonites, hydrothermalites, and metasomatites. There is also a plutonic unit consisting mainly of gabbro, tonalites, diorite, and leucocratic granites. All of these formations have experienced strong ductile-breaking deformation due to the E-W compression-transpression mechanism, which has resulted in transcurrent shear zones that are conducive to mineralization deposition. The most recent event led to the creation of secondary shear zones and fracturing of the competent rocks. The study also found that the sheared and hydrothermalized microdiorite veins and clastic units of the Tarkwaian form a positive metallotect for gold mineralization. This knowledge of the stratigraphy that supports sulphide and gold alteration provides excellent opportunities for prospecting in the Intiédougou region on and hydrothermal alteration.

Acknowledgements

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Conflicts of Interest

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

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