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Evolution of gold content along the orebody in the Torkera gold deposit, Gaoua district: Deformation and hydrothermal alteration

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ABSTRACT: Mineralization at the Torkera gold deposit is located at the contact between volcanic rocks (basalt-andesite) and volcanosedimentary rocks (pyroclastite, blackshale) in the relay zone within the large West Batié Shear Zone (WBZ). Along strike, these formations are not only strongly sheared, but are also affected by intense hydrothermal fluid circulation. The deposit has not yet been characterized in terms of deformation and hydrothermal alteration. The present study aims to constrain the factors controlling the variation in gold content. Direct field measurements show that the mineralized body contained within the shear zone is affected by two phases of deformation. The first is a shear-type deformation known as D1T, marked by S1T schistosities. This first phase of deformation is taken up by a second phase of deformation called D2T. This second phase is marked by S2T fracture or crenulation schistosity. Two hydrothermal alteration phases affect these formations. The first phase of hydrothermal alteration is a carbonate-chlorite-quartz ± pyrite ± iron oxide paragenesis, while the paragenesis of the second phase of alteration is quartz-pyrite-white mica ± carbonate. Gold mineralization is associated with pyrite crystals from the second phase of hydrothermal alteration, whatever the nature of the host rock. The variation in gold content along the ore body is controlled by the intensity of fluid circulation in relation to deformation. The more space freed up by deformation, the more the hydrothermal fluid interacts with the host rock, resulting in a strong silicification and pyritization phase capable of trapping gold.

KEYWORDS: Gold deposit, Torkera, mineralized body, Gold grade.

1 INTRODUCTION

In the West African craton (Fig. 1), especially in Burkina Faso (Fig. 2), most economically viable deposits are located in shear zones ([1], [2], [3], [4], [5], [6], [7], [8], [9]). These shear zones are often the source of gold mineralization and are commonly referred to as orogenic gold ([10], [11]). Hydrothermal alteration is the transformation of a rock's minerals into neoformed minerals or the modification of its chemical composition by hot hydrothermal fluids. These fluids also change their chemical composition after interacting with the rocks they pass through, and this is reflected at the time of crystallization by mineralogical assemblages related to this composition ([12]). This mineralogical assemblage, also known as hydrothermal alteration, is responsible for the formation of numerous deposits, especially gold deposits in orogenic settings ([3], [13], [14], [15]). This is the origin of the concept of orogenic gold ([10], [11]). The various studies carried out on most of the different deposits ([16], [17], [18], [7], [19]) in the West African craton show that they can be grouped essentially into two types: i) disseminated sulfide-gold deposits with high tonnage and low grade, and ii) high-grade, low-tonnage quartz vein-concentrated gold deposits. The present work is carried out in the Torkéra gold deposit, which has not yet been characterized. Our aim is to follow the evolution of the gold content along the ore body in order to propose a model of emplacement. To this end, we have characterized the Torkéra orebody in terms of deformation and hydrothermal alteration. These data are then discussed and compared with other deposits in Burkina Faso and elsewhere in the world.

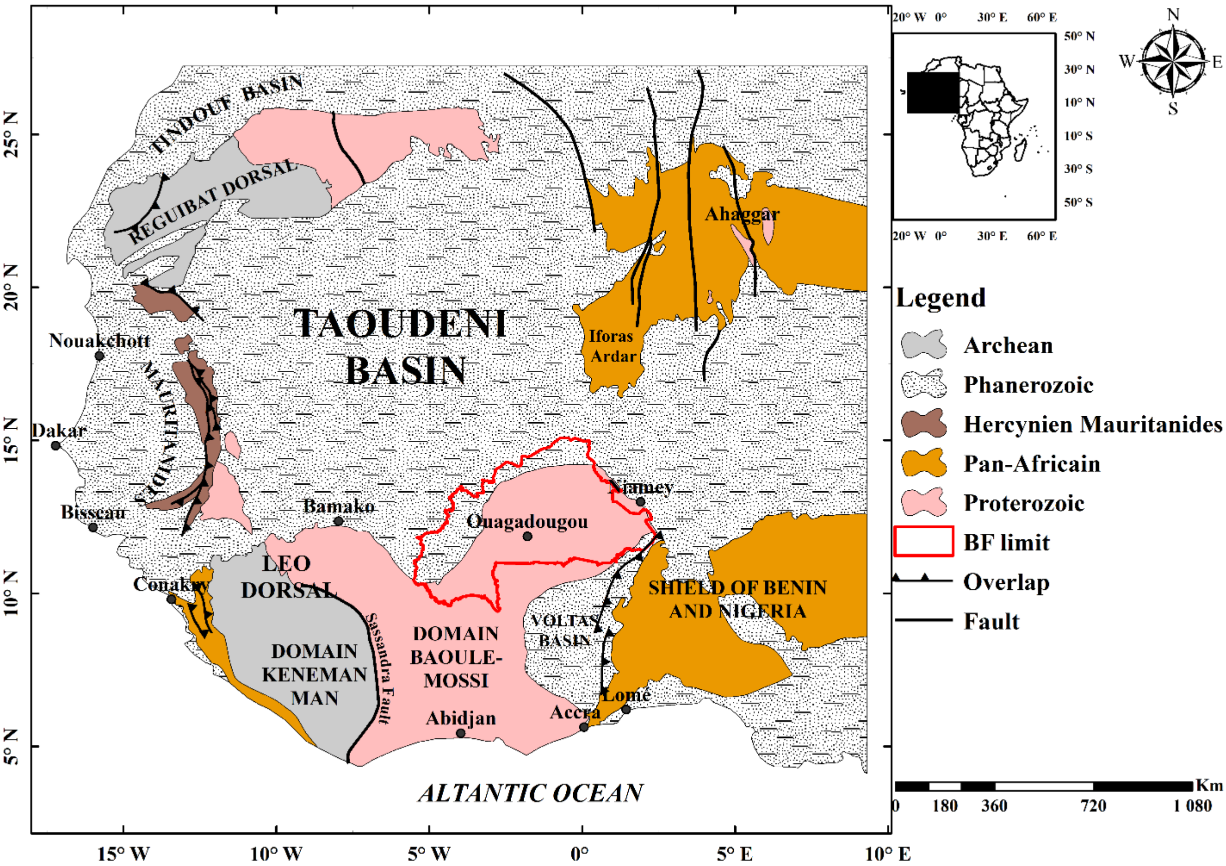

Fig. 1. West African craton ([17] modified)

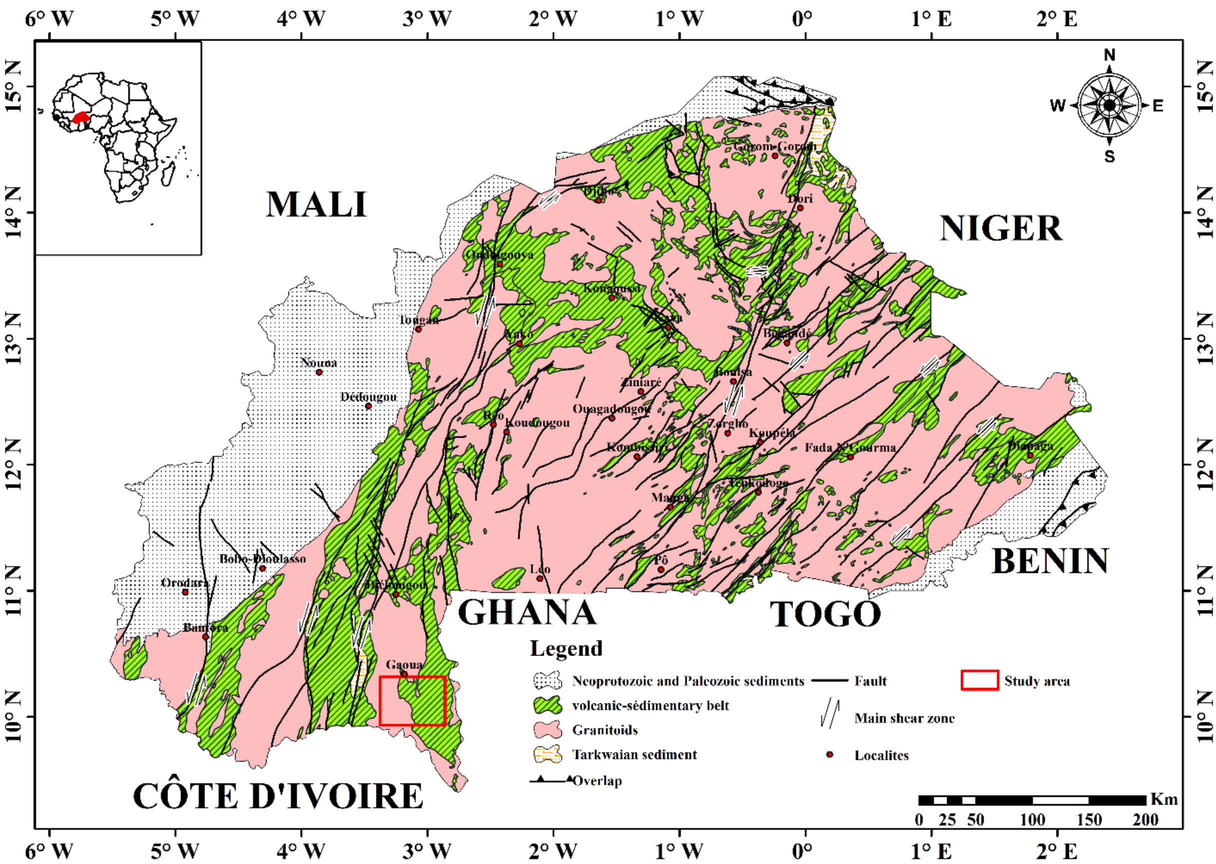

Fig. 2. Simplified geology of Burkina Faso ([20] modified)

2 GEOLOGICAL CONTEXT

The Man/Léo dorsal in the south of the West African craton (Fig.1) comprises a Kénéma-Man domain with Archean-age formations and a Baoulé/Mossi domain with Paleoproterozoic-age formations. Formations of Paleoproterozoic age are referred to as Birimian formations ([21]). These formations are organized in greenstone belts, bordered by vast batholiths of tonalite, trondhjemite and granodiorite (TTG), which are syn-tectonic granitoids ([22], [23]). The Gaoua region to the south of Gaoua shares similarities with the Man/Léo ridge. Indeed, the Gaoua district is characterized by an association of volcanic and volcanosedimentary series, birimian sediments and granitoids ([24], [25], [26], [27], [28], [9]). The volcanic and volcanosedimentary series are composed of volcanic to subvolcanic rocks of a basic nature. These rocks include aphyric basalts, plagioclase phenocrystalline basalts, porphyritic andesitic basalts and andesites in the form of flows and projections (Fig. 3). In terms of deformation, ([29], [26]) have defined first-order, second-order and third-order structures. These are regional structures trending N-S to NE-SW and locally NW-SE. The study area (Tokera) is located on the same extension as the Nassara gold deposit, in a relay zone within the large western Batié shear zone (Fig. 3).

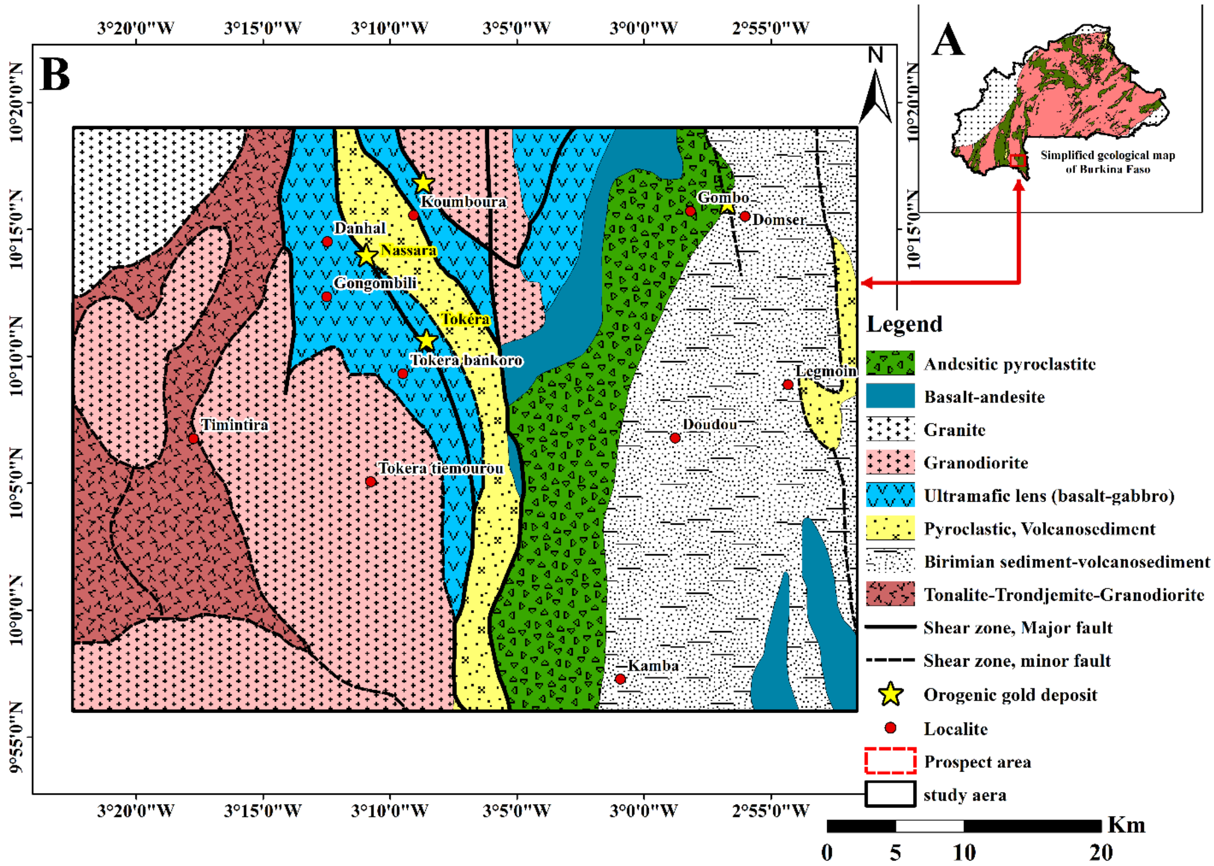

Fig. 3. Revised geological map of western Burkina Faso showing the different geological formations and structures in the study area (modified from [27])

3 SAMPLING AND ANALYSIS METHODS

Field work initially consisted in: i) making direct field measurements of obvious structures within the shear corridor, ii) taking rock samples from core drilling to monitor variations in gold content along the orebody. The equipment used included a GPS to locate the measured structures, a Brunton compass to measure the structures, and a clinometer to measure dip. We also described and collected core samples using a hammer. We took five (05) core samples and approximately twenty-six (26) samples were taken directly in the field. Laboratory work consisted in making polished thin sections (25) in the thin section workshop of the Geosciences and Environment Laboratory (LaGE) at Joseph KI ZERBO University. Observations and studies were carried out using a metallogenic microscope equipped with a camera for taking microphotographs. Reflected light observations enabled us to carry out a metallographic study to identify the position of the gold in the sulfides.

4 RESULTS

The results address the characteristics of the ore body, hydrothermal alteration and ore mineralogy.

4.1 MINERALIZED BODY CHARACTERISTICS

A more recent study [15], [9] showed that the mineralized body is affected by transpressive deformation. Magnetic lineation data ([28]) showed that mineralizing fluids in the Nassara zone flowed from NW to SE, i.e. towards the Torkera gold deposit (Fig.4). The Torkera gold deposit has the same petrographic and structural characteristics as the Nassara gold deposit ([15]).

A cross-section of a borehole section intersecting the Torkera mineralized zone shows that the main formations are volcanic rocks (basalt-andesite), pyroclastites and sedimentary formations (blasckshale) (Fig.5). This ensemble is intersected by late dykes of microdiorite and microgabbro. Apart from these late dykes, all the formations are affected by several phases of deformation. Direct field measurements (over sixty) in the shear zone show shear deformation (S1T) with a main orientation N 320°E, dipping steeply to moderately to the southwest in the shear zone ([15]). This is taken up by crenulation or fracture schistosity (S2T) whose main direction is northeast, with values ranging from N50°E to N80°E.

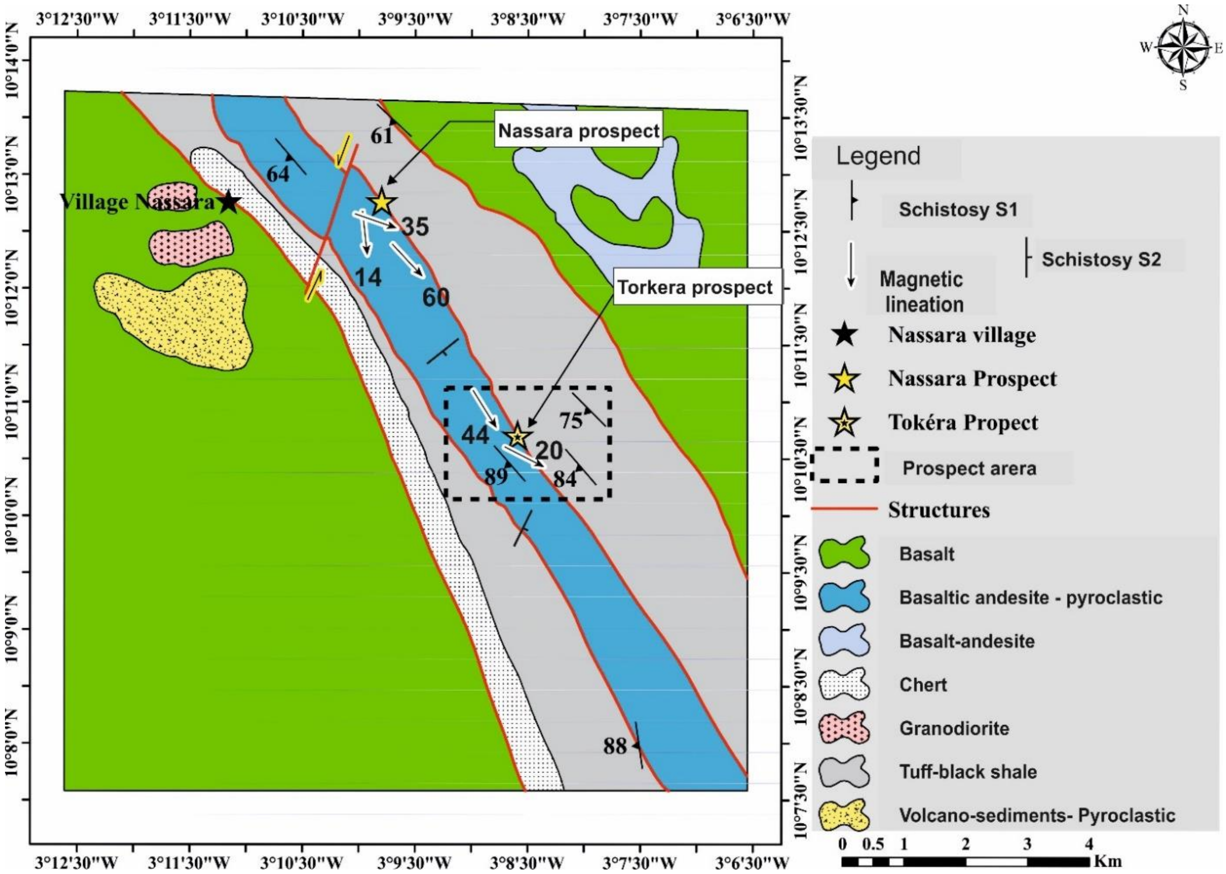

Fig. 4. Geological map of the Nassara-Torkéra shear zone, showing material flowing SE from Nassara towards Torkéra ([9])

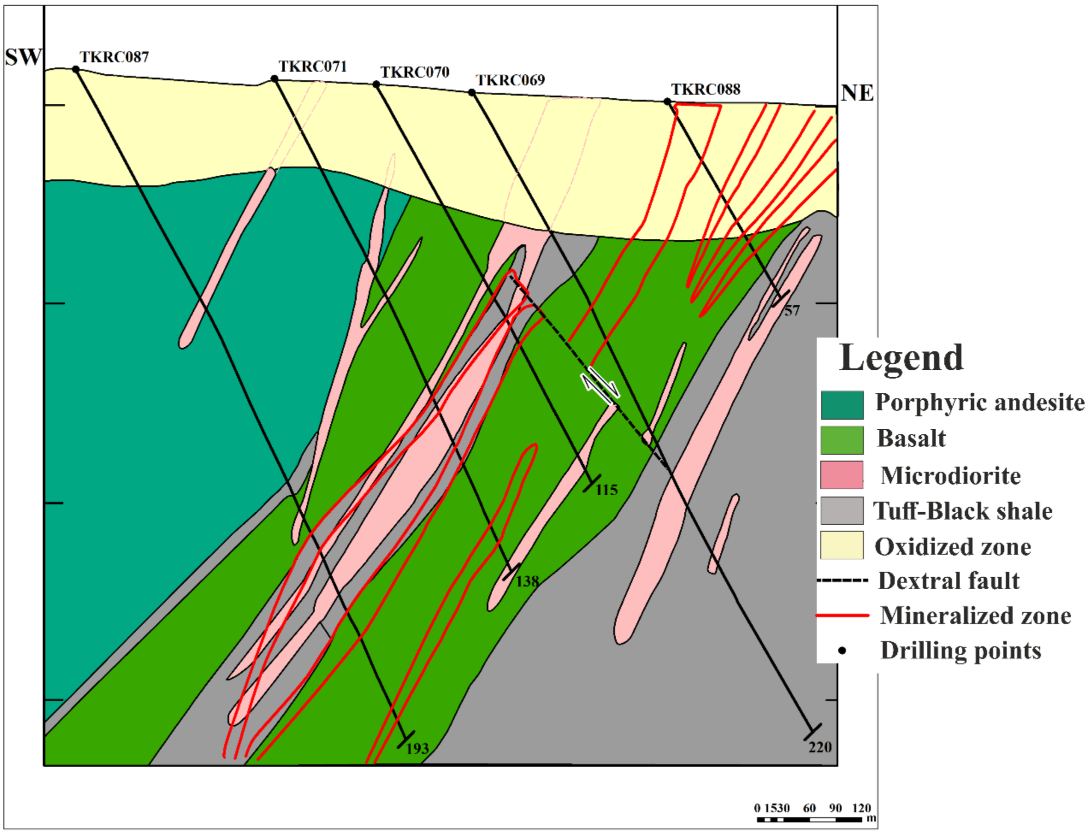

Fig. 5. Geological cross-section of a borehole section at Torkéra

On a microscopic scale, the first phase of D1T deformation is characterized by a variable-intensity S1T penetrative flow schistosity with a mean orientation of N320°E (Fig.6A). Deformation D2T is manifested by a crenulation schistosity S2T that intersects S1T, with a main orientation of N45°E (Fig.6B). The first phase of deformation is highlighted by chlorite-iron oxides in areas where the intensity of deformation is low (Fig.6C and Fig.7A). Where deformation is intense, schistosity is highlighted by white-mica-rich bands around pyrite crystals (Fig.6D). Pressure shadow zones also develop at the interfaces of pyrite crystals filled with fibrous quartz, whose direction of growth is parallel to S1T (Fig.7B). This crenulation schistosity is highlighted by the axes of the microfolds (Fig.7C). During this deformation phase, pressure shadows also develop around pyrite crystals whose growth direction is perpendicular to S1 (Fig.7D).

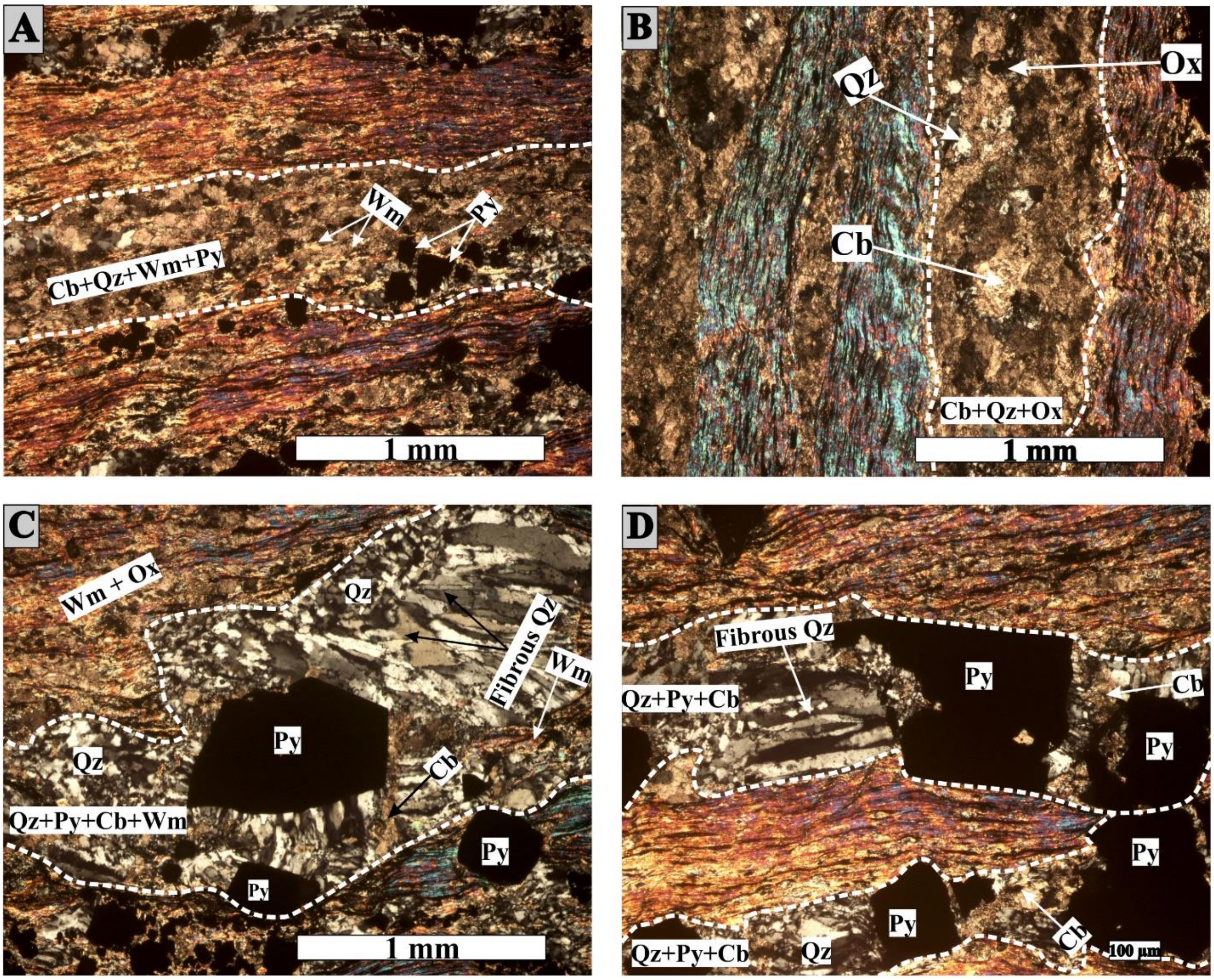

Fig. 6. Directional rosettes of schistosities and photograph showing structural relationships. A-B: showing the direction of S1T and S2T schistosities; C: a sugar section of weakly hydrothermalized metaandesite where the S1T is outlined by chlorites; D: a core section of a strongly hydrothermalized metaandesite showing the S1T outlined by white micas

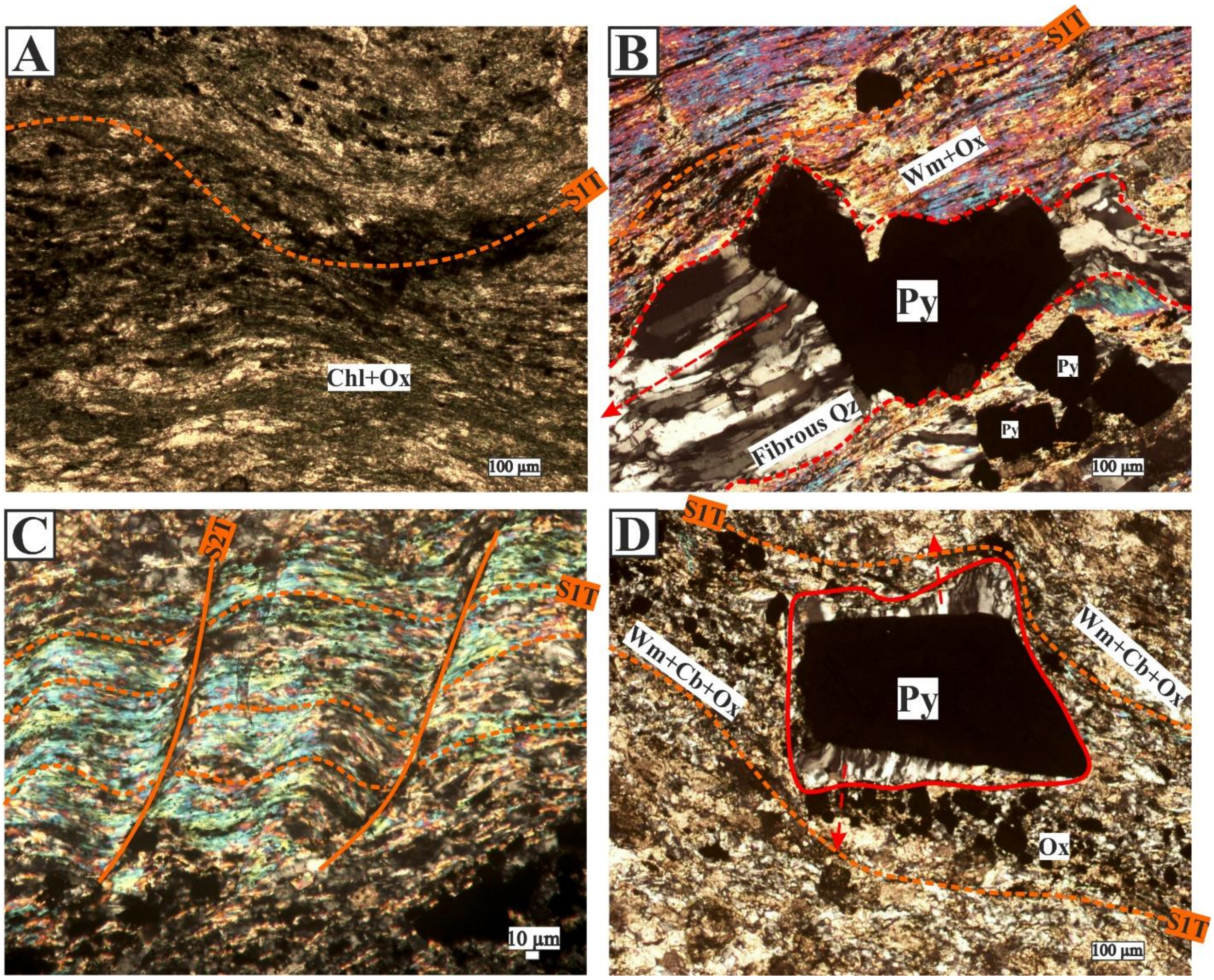

Fig. 7. Microphotographs of deformation-related microstructures. A: S1T shear schistosity (penetrative flow) highlighted by chlorites and iron oxides; B: quartz-filled pressure shadow around a pyrite whose growth direction is parallel to the shear structure (white mica); C: S1T shear schistosity marked by white micas and S2T crenulation; D: quartz pressure shadow with growth perpendicular to the shear structure

4.2 Hydrothermal Alterations In Host Rocks

The rocks hosting the mineralization in the Torkéra gold deposit have been subjected to hydrothermal fluid circulation of variable intensity, synchronous with shear deformation (Fig.8). They are generally affected by two phases of hydrothermal alteration. The first phase takes the form of fairly pervasive veins/veinlets filled with carbonate-quartz-white mica-pyrite ± iron oxide, consistent with the shear structure. Pyrite crystals are mainly found at the spandrels of the latter (Fig.8A, B). The second phase of alteration may take the form of white quartz-pyrite-mica ± carbonate ± albite veins/veinlets, or as pressure shadows around pyrite crystals with fibrous quartz infill secant to the shear structure (Fig.8C, D). Partial recrystallization of quartz crystals can also be observed. In some cases, pressure shadows develop parallel to the direction of the shear structure

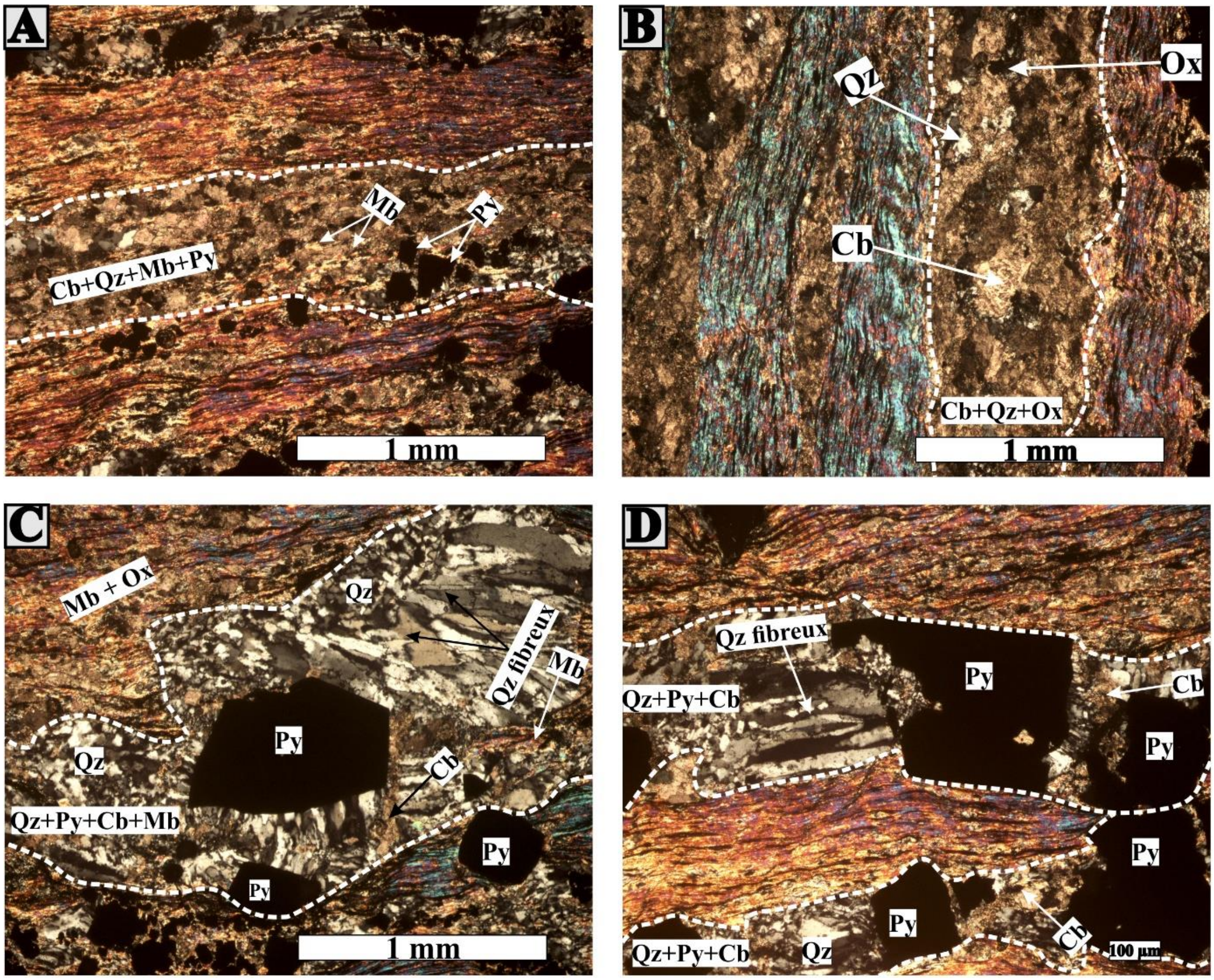

Fig. 8. ***Microphotograph of alteration paragenesis. A and B: The first weathering paragenesis with pyrite crystals in the spandrels; C and D: The second weathering paragenesis and fibrous quartz pressure shadows. Ab: Albite; Cb: Carbonate; Chl: Chlorite; Qz: Quartz; Wm: White mica; Ox: Iron oxide; Py: Pyrite***

4.3 Ore Mineralogy

In the deposit, sulfides are mainly pyrrhotite crystals and pyrite crystals. Gold mineralization is mainly associated with pyrite crystals, regardless of the nature of the host rock (fig. 9). The pyrite crystals with which gold is associated are arranged at the spandrels of the veins or are organized in white mica-rich bands along the shear structure (Fig. 9C, E). These gold pyrite crystals are related to the second phase of hydrothermal alteration with quartz-pyrite-white mica ± carbonate ± albite (Fig. 9ACE). The individual gold grains are xenomorphic in shape, with sizes not exceeding a few micrometers within the pyrite crystals. They either occupy the micro-fractures (Fig. 9B, D), or are included (Fig. 9F).

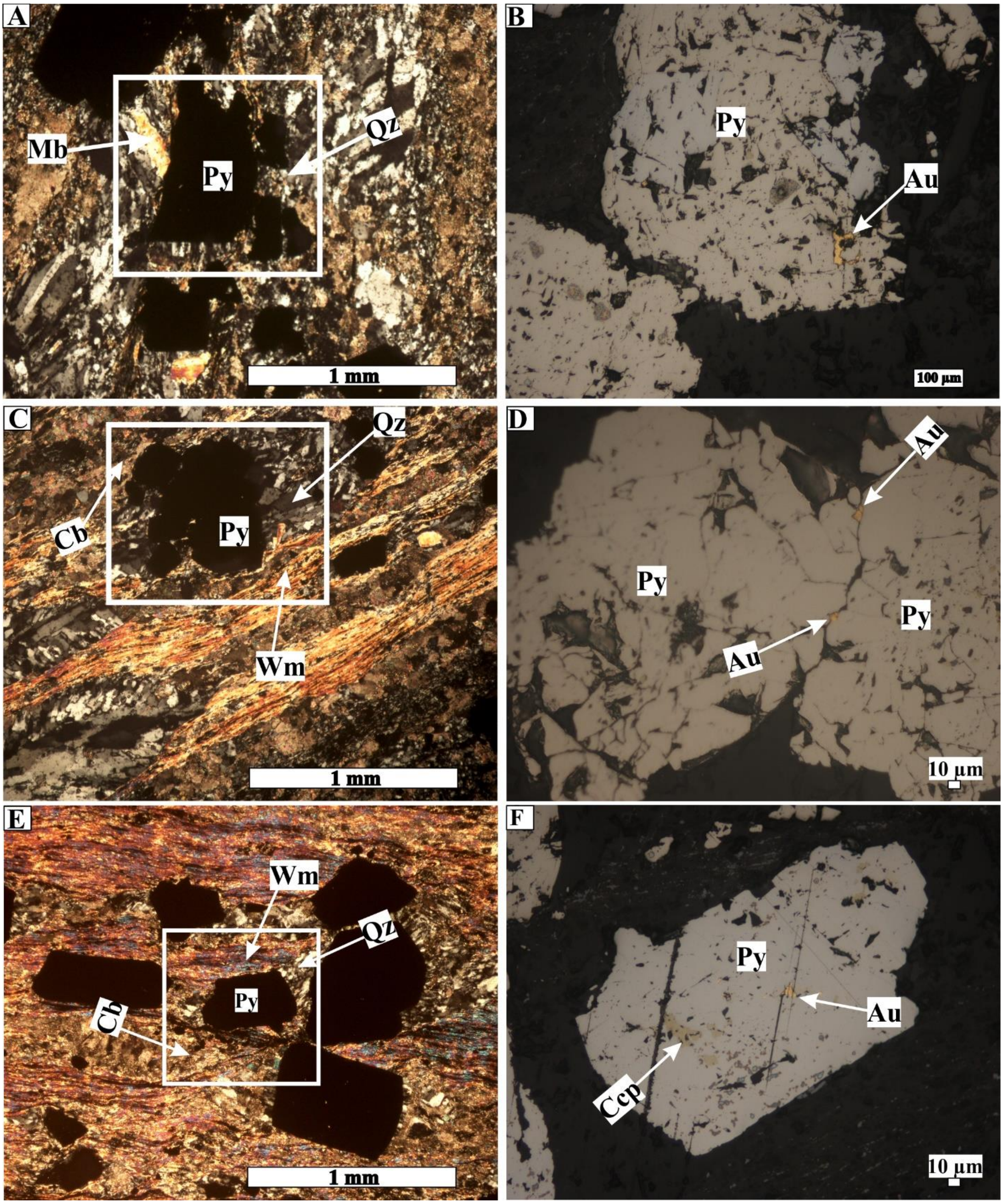

Fig. 9. Microphotograph of gold and associated paragenesis. A-C-E: Paragenesis (Qz-Py-Mb±Cb) associated with gold with fragmented pyrite crystals in AC. B-F: Xenomorphic gold grains in pyrite; D: Gold grains in a microfracture. Py: Pyrite; Cb: Carbonate; Qz: Quartz; Ccp: Chalcopyrite; Mb: White Mica; Au: Gold

5 DISCUSSION

Mineralization within the Torkera gold deposit is located at the contact between volcanic rocks (basalt-andesite, pyroclastites) and highly sheared sedimentary rocks (blackshale). The first phase of deformation, D1T, is shear deformation of variable intensity, with an average orientation of N320°E. It corresponds to the second phase of deformation at Nassara ([15], [9]) and the third phase of deformation on the Gaoua scale (Baratoux et al., 2015). It corresponds to the third deformation phase at Nassara ([9]) and to the fourth deformation phase at the Gaoua scale ([29]).

Gold mineralization is linked to fluid circulation from the ductile to the ductile-breaking to brittle stages ([11], [31], [32]). As the fluid rises, the original minerals in the rock interact with the fluid, resulting in mineralogical assemblages related to this composition during crystallization ([12]). At Torkera, the first phase of hydrothermal circulation is a mixture of metamorphic and hydrothermal fluid, which globally materializes in the surrounding rocks as pervasive carbonate-chlorite-iron oxide ± quartz ± pyrite alteration. The second fluid phase is hydrothermal circulation itself, resulting in intense silicification. This silicification phase is accompanied by sericitization and pyritization.

The alteration paragenesis is organized in the form of veins/veinlets concordant with the S1T shear mill, with pyrite crystals at the spandrels of the latter. Multi-filled pressure shadows (quartz-albite) develop around the pyrite crystals. The work of certain players ([31], [32], [33]) has demonstrated that these pressure shadows are due to a subsequent reactivation of the shear zones, causing them to develop around the pyrite crystals. This reactivation caused a localized and repeated drop in pressure, inducing a reaction between the fluid and the host rock, followed by crystallization of the minerals in the spaces left behind.

The variation in gold content along the Torkéra orebody is often marked by low, medium and high-grade zones, due to the intensity of hydrothermal fluid circulation on the one hand, and the fluid's ability to interact with the host rocks on the other (Fig. 10). With regard to the intensity of fluid circulation, we note that the weakly hydrothermalized metaandesite-metabasalts are mainly affected by the first phase of hydrothermal circulation, which is a mixture of metamorphic and hydrothermal fluid. This fluid is poorly enriched in gold because it has only weakly interacted with the host rock, resulting in grades of 2.01g/t at 154.5m depth (Table I and Fig. 10). This increase in silica and pyrite content is thought to be the catalyst for the higher gold content in these moderately hydrothermalized host rocks (5.09 g/t at 132.5m) (Table I and Fig. 10). What's more, these moderately hydrothermalized enclosing formations are closer to the strongly hydrothermalized enclosing formations, where high levels of silica, sericite and pyrite generally control the high gold content (134.7m at 18.2 g/t) (Table I and Fig. 10). We can thus say that the more hydrothermal fluid circulates, the more material is available to form the quartz and pyrite crystals that catalyze the variation in gold content (Table I). These gold-bearing pyrite crystals are associated with the strong silicification, sericitization and pyritization reflected in the white quartz-pyrite-mica ± carbonate paragenesis (see Fig. 9CE). The link between pyrite crystals and gold on the one hand, and the high gold content associated with a strong pyritization phase in the host rocks on the other, are not new facts in the West African craton ([34], [35], [18], [36], [37], [38], [39], [40], [41], [7], [15], [42], [43], [44]).

Table 1. Summary of relationships between alteration phases, sample depth, grade and alteration paragenesis.

Lithology	Moderately altered metaandesite	Highly altered metaandesite	Black shale	Microdiorite	Slightly altered metaandesite
Depth	132.5 m	134.7 m	136.6 m	147.7 m	154.5 m
Gold grade	5.09 ppm	18.2 ppm	1.74 ppm	-	2.01 ppm
Alteration minerals					
Carbonates	Medium	Weak	Abundant	None	Abundant
Quartz	Medium	Abundant	Weak	Weak	Weak
White-mica	Medium	Abundant	None	None	None
Chlorites	Medium	None	None	None	Abundant
pyrites	Medium	Abundant	None	Weak	Weak
Iron oxide	Medium	Weak	Medium	None	Abundant
Albites	Weak	Weak	None	Weak	None

Abundant — Medium — Weak — None

The capacity of the fluid to interact with the surrounding rocks depends on the rheology of the rocks and the intensity of deformation. Indeed, the intensity of hydrothermal fluid circulation is related to the intensity of deformation, and this results in the reactivation of certain zones. In these reactivated zones, the deformation is extensible with fragmented pyrite crystals, with pressure shadows developing around the pyrite crystals (Fig. 8 B D and Fig. 9 A C). It is these openings that allow the fluid to enter and interact with the pyrite crystals already formed and the host rock, remobilizing the primary gold and then re-precipitating it within the latter ([45], [32], [33]). This is explained by the work of [46], which showed that primary gold is present in the Nassara basaltic rocks. We therefore propose that the variation in gold content is related to the intensity of deformation and hydrothermal fluid circulation, since the more spaces there are due to deformation, the more fluid circulates.

However, in graphitic schists, the gold content is relatively low. This is due to the low capacity of the fluid to interact with graphite schists, which are more ductile than basalt-andesites, which are ductile-breaking to brittle. In these rocks, we find quartz veinlets with rare pyrite crystals, demonstrating that it is the high concentration of pyrite crystals in conjunction with the intensity of hydrothermal fluid circulation that controls the gold content.

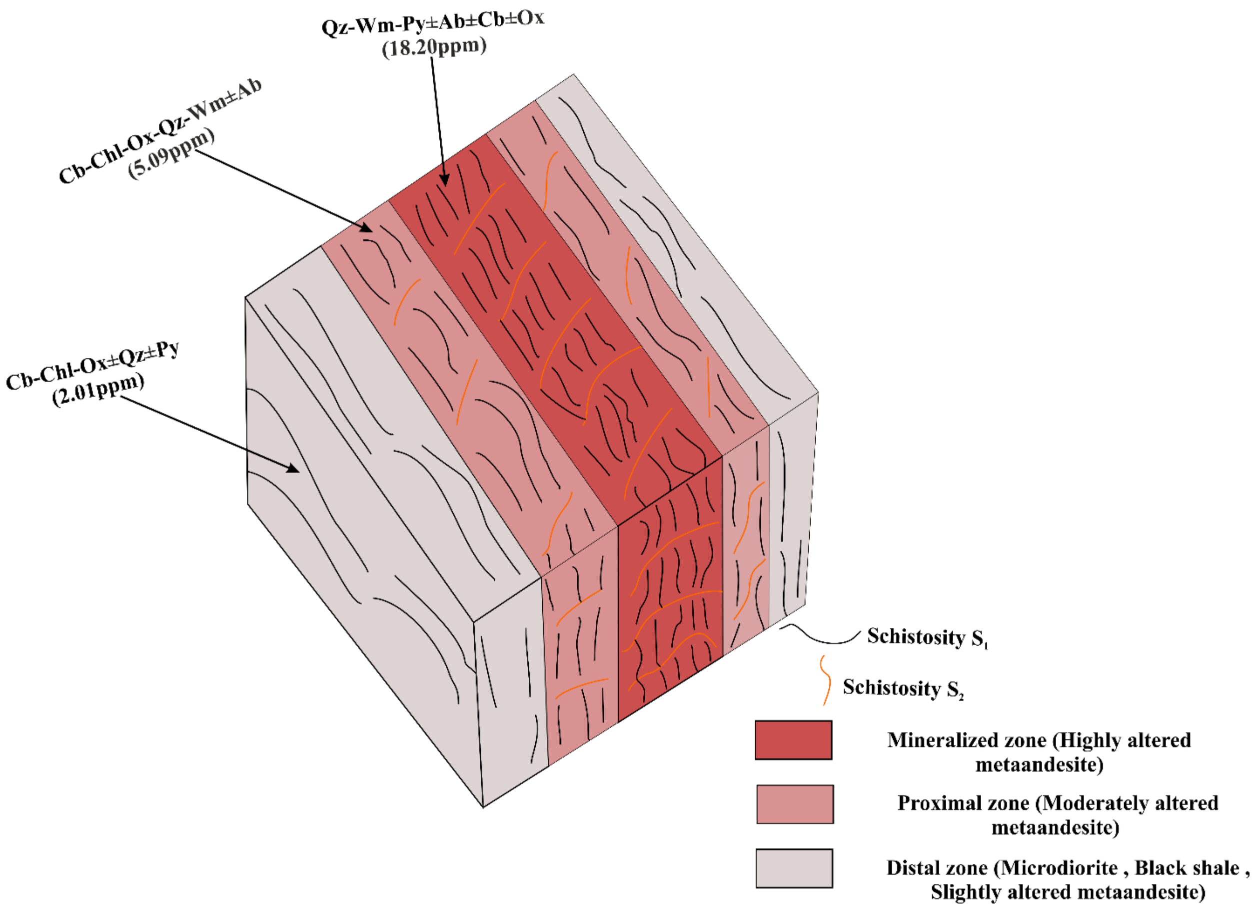

Fig. 10. Block diagram of alteration zones associated with schistosity, gold content and alteration paragenesis in the study area

6 CONCLUSION

Characterization of the Torkéra gold deposit shows that mineralization occurs at the contact between volcanic (basalt, basaltic andesite) and volcanosedimentary (pyroclastite, graphitic schist) rocks. These formations were affected by polyphase deformation along a shear corridor where, overall, two deformation phases can be identified. These are D1T, a shear-type deformation marked by S1 schistosity, and D2T, marked by S2 schistosity, which repeats the first. D2T is characterized by either crenulation schistosity or fracture schistosity.

Two phases of hydrothermal alteration have been identified in the Tokéra gold deposit. The first phase is characterized by a carbonate-chlorite-iron oxide ± quartz ± pyrite mineralogical association, while the second phase is characterized by a quartz-white-mica-pyrite ± carbonate paragenesis silicification. Intense fluid circulation, silicification, intensity of deformation and high concentration of pyrite crystals are the parameters controlling the variation in gold content. Gold mineralization is related to pyrite, regardless of the nature of the host rock, and occurs in or embedded in microfractures.

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