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Petro-structural Evaluation of the Toulepleu-Guéya Section on the Toulepleu-Ity Gold District, West Côte d'Ivoire

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Abstract The Birimian furrow of Toulépleu-Ity located in the Archaen domain of Côte d'Ivoire is at the heart of various mining projects. Thus, this study is initiated in three localities namely Toulepleu, Zogouiné and Guéya in order to elucidate the petrography and deformations. The data analysis and interpretations undertaken at the University of Man allow to learn deeply this Birimian furrow. Petrographically, two main groups of rocks are identified: (i) magmatic comprising granodiorite, microgranodiorite, tonalite and dolerite, (ii) metamorphic composed of gneissisified granodiorite, metatonalite, metaargilite, metadolerite and various schists (chloritoschists). Argillite is the main sedimentary rock. The metamorphism evolves from greenschist to amphibolite facies overprinted by the chlorite - green hornblende association. Eburnean magmatic event has been ended with the settlement of dolerite which appears metamorphosed and fractured suggesting the reactivation of the Eburnean event. Pervasive hydrothermal alteration is marked by mylonitized quartz veins. Structurally, three main orientations are expressed : N-S, NE-SW and NW-SE. Ductile deformations are observed in schists, metatotalites and metasediments. The schistosity planes have a dip of 44°S. Brittle deformations have a preferential NE-SW orientation and are associated with quartz plus tourmaline veins showing by that their auriferous potentiality. These structures are part of a shearzone of N080° that can serve as a target for gold exploration in the area.

Keywords: *Toulepleu-Ity birimian furrow, Archaen, petrography, deformation, Côte d'Ivoire*

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1. Introduction

The Archaen and Proterozoic epochs are recognized as geological times during which the incrustation of gold in cratons was favorable [1,2]. The most westerly Birimian furrow of Côte d'Ivoire, the Toulepleu-Ity, located into the Archaen formations as a klippe [3], is a major gold district. It hosts the oldest deposit in the country: the Ity gold. This mineralization is therefore described to have been influenced by the supergene alteration [4,5]. Today, new data and evidence are rising up from the investigations at Ity, Floleu and Dahapleu giving more confidence on the influence of the magmatism [6,7]. This Birimian furrow by bringing Precambrian terranes into contact presents a juxtaposition of lithologies as well as structural contexts and orogenies that would have played in favor of gold enrichment. It becomes crucial to extend the petrographic and structural assessment in others areas of this gold district in the objective to dive deeply into its geological knowledge. The development of artisanal and small scale gold miners [8] in this department has brought to light new gold sites and associated rocks samples that can help to their exclusive geological assessment. This assessment will be based on the investigation of artisanal and industrial gold site and bring by that keys informations in the prospective activity and the understanding of the Precambrian gold in the country. The specific objectives that flow from this are: (i) describe the petrography and (ii) characterize the deformations.

2. Geological Context

The study area comprises the localities of Toulepleu, Zogouiné and Guéya in the department of Toulépleu (Figure 1). This department is part of the Toulepleu-Ity Birimian furrow which belongs to the Man shield precisely the Archaen domain of Côte d'Ivoire (Figure 2)

where the Leonian (3500-2900 Ma) and Liberian (2900-2500 Ma) orogenies are expressed. The Toulépleu-Ity Birimian furrow, located between parallels N 6°30' and N 7°20, is oriented NNE-SSW, its length is 100km in Côte d'Ivoire and width 8 to 30 km and extends to Liberia where it would be limited to the west by the Cestos shear zone [4,10]. It would have been set up in a syntectonic context in a weakened Archaen crust [11,12]. The study area lies in the south of the Man-Danané fault which strikes NNE-SSW. The Toulépleu-Ity unit is characterized by the presence of an intrusive massif called the Guiamapleu massif. According to [13], the epi-liberian basement is the foundation of the Eburnean geosyncline and the lower structural element of the Eburnean semi-platform. He admits that the dolerites of Toulepleu belong to the epi-eburnean platform and that they are located in the meridian band following a main elongation of 120 to 150°. From [14], it appears that the Guiamapleu formations mark the eastern limit of the Paleoproterozoic Toulepleu-Ity unit included in the Archaen. Also, he observed a brutal and rapid contact marked by numerous fractures within the Archaen and Proterozoic formations. Thus, they appear orthogonal to the Eburnean directions. It is indeed a Birimian province (Paleoproterozoic) that gives a particularity to this southern domain and it has been the subject of scientific work evoking its genesis. A collision between an Archaen continent and a Paleoproterozoic province formed at 2100 Ma was suggested by [5]. According to the work of [15] who proposes a model of convergence between a cold Archaen continental crust and a warm and soft Birimian lithosphere that does not generate overlaps. The compression of warm and soft lithospheres accommodates a combination of shear transpressive zones and homogeneous lateral spread [16,17]. The study area hosts the ivorian oldest gold deposit at Ity. Therefore, it belongs to the Toulépleu-Ity unit composed of metasediments, metavolcanites and granitoids [18]. In the southern domain, Archaen formations were strongly remobilized during the Paleoproterozoic by the Eburnean orogeny [11]. Based on the Sm-Nd system on garnet, this metamorphism is dated at 2031±13 Ma [15]. A transition zone, known as called SASCA is identified between the Sassandra fault and longitude 6°W and characterized by the contamination of juvenile Birimian formations by the Archaen crust. And to this could be added the existence of Archaen relics within the Paleoproterozoic domain [19]. Structurally, three phases of major tectonic deformation are recognized in Côte d'Ivoire [14]. The deformation (D1) followed by a flexible deformation (D2) probably contemporary with the Eburnean metamorphism. It is responsible on the one hand, for the folded structure of the Eburnean metamorphic units and on the other hand, for the second folding that affected the Liberian formations. Finally, there would have been a late-eburnean deformation (D3) which played a particular role in the establishment of the crushing "channels".

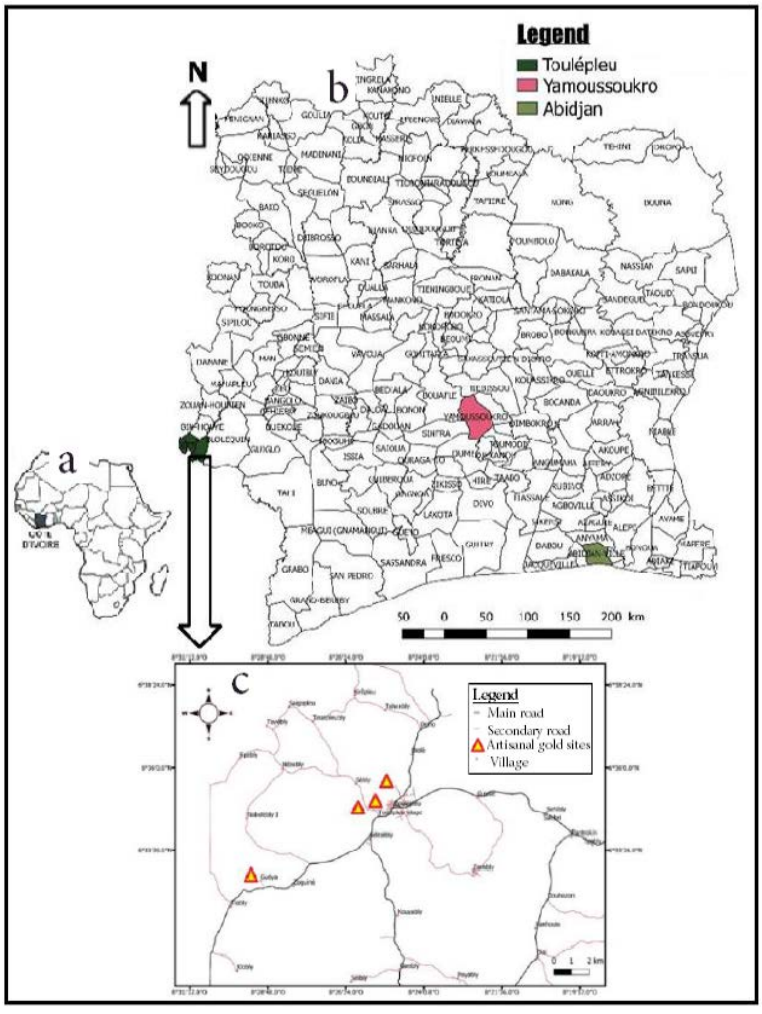

Figure 1. Localisation of the study area in Africa (a), in Cote d'Ivoire (b) and in the Toulepleu region (c)

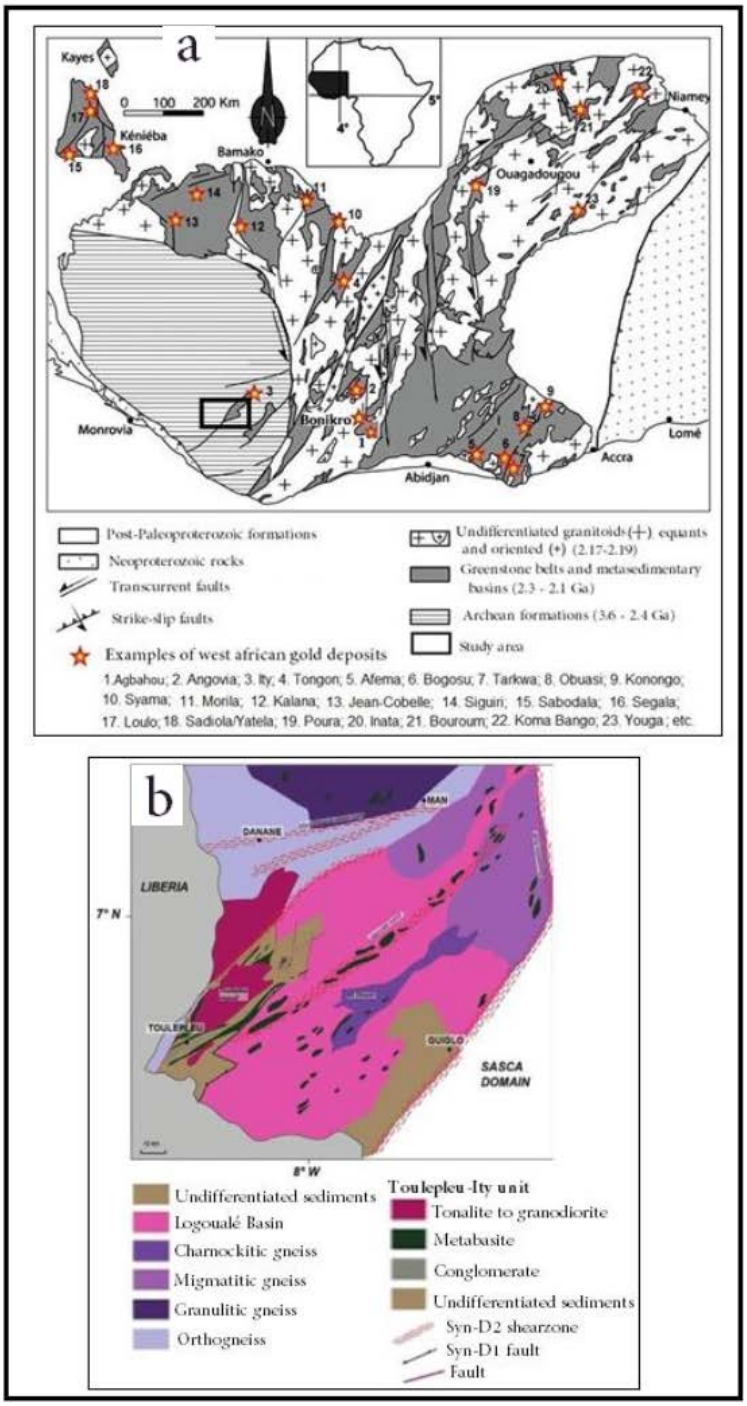

Figure 2. Geological maps of the study area, modified after [6,9]

3. Material and Methods

Petrographic and structural investigations were initiated in the field and then continued during laboratory and interpretation sessions. In the field, the study began with the macroscopic description of the outcrops and associated deformations first in the city of Toulepleu and then continued successively in the localities of Zoguiné and Guéya. This phase ended with the collection of 07 rock samples. 05 thin sections were made at the Laboratory of Geology, Mineral Resources and Energy (GRME) of the Félix HOUPHOUET-BOIGNY University in Abidjan. The microscopic observations initiated to clarify the petrography and the deformations were realized in the School of Geological and Mining Sciences at the University of Man, by a petro-microscopy and microstructural studies on a Jeulin-type polarizing microscope combined with an Amscope camera. These studies made it possible to complete the field observations. Then, we drew up the structural syntheses and stereographic projections using the GeOrient.

4. Results

4.1. Petro structural Aspect of Toulepleu

- **Light gray Gneiss**

Two outcrops have been described. At the naked eye, the rock's aspect is massive and the alternative dark and

light bands shows the foliation (Figure 3a). The dark band consists of pyroxene, amphibole and biotite while the mineralogy of the light band indicates quartz and plagioclase. It is a light gray gneiss containing in places xenoliths that were staked by ultramafic enclaves and by felsic intrusions. The ultramafic enclaves appear strongly magnetized, thus assimilating to fine-grained pyroxenites. The felsic intrusion is pegmatitic with quartz and muscovite phenocrysts. On polarized light, the rock indicates of grano-lepidoblastic texture (Figure 3b) confirming thus, the mineralogy observed on naked eye. Quartz is very abundant, present in the form of phenocystal but also of the average size of the grains of the rock. Amphibole is expressed in two minerals: first in stubby grains, with a brown coloration concordant with the brown amphibole; then fibrous mineral, with an oblique extinction and polarizing tints at the end of first order: it is glaucophane. Pyroxene crystals are mostly corroded. The microcline is euhedral to anhedral crystals, medium-grained rock size. Biotite, muscovite, plagioclase and orthoclases are present. Garnet is weakly represented. Chlorite, resulting from the destabilization of biotite and amphiboles, is observable. Quartz and opaque minerals admit a poecilitic character. The protolith of this light gray gneiss would be a tonalite having undergone metamorphism.

- **Tonalite**

On day light, this outcrop reveals an oriented rock of dark grey color, massive and foliated aspect. It is composed of amphibole, quartz, biotite, K-feldspar and plagioclase (Figure 3c). Microscopically, the thin section shows a plutonic porphyritic texture (Figure 3d). Its mineralogy included also pyroxene, microcline, orthoclase and opaque minerals. Quartz, very abundant, is issued from two generations. The first generation is indicated by phenocrysts while the second generation is with medium-sized crystals. Orthoclase, less abundant than microcline, is automorphic, altered to sericite and has a rolling extinction due to the inclusion of quartz crystals. These minerals support that our sample is an oriented tonalite or a metatonalite.

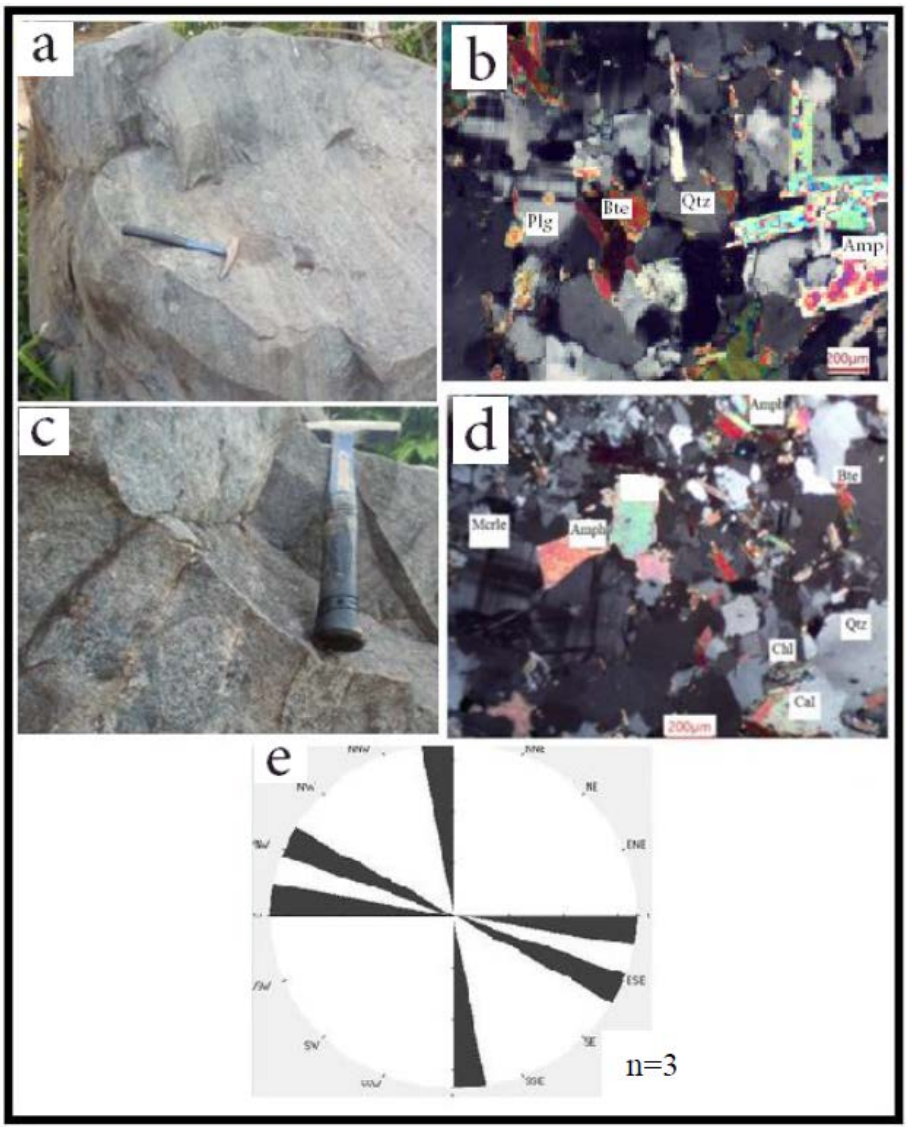

Figure 3. Petro-structural observations of the Toulepleu rocks with their structural. a) and (b): macroscopic and microscopic views of the light gray gneiss; c) and (d) : macroscopic and microscopic views of the tonalite; e) Stererographic plots of structures observed at Toulepleu (Plg : Plagioclase, Bte : Biotite ; Qtz : quartz ; Amph : amphibole ; chl : chlorite ; Mcrle : microcline ; Cal : calcite)

On their deformation history (Figure 3e), these two rocks reveal the presence of quartz veins crosscutting them. They are thus posterior to the magmatism and the metamorphism. The deformations encountered in the town of Toulépleu are of ductile and brittle types. Three generations of fracture and fault are noticeable in the directions of N030°, N080° and N090°. Associated with the light gray gneiss, the first generation of fractures hosts the felsic intrusives. The second order fractures are subperpendicular to the foliation and are characterized by dextral normal faults striking N090° with diaclase of N030° and associated quartz veins. The third fractures generation is staked by dextral normal faults oriented N30°, intersect the second generation of fractures and also highlight the sigmoidal figures. In the oriented tonalite, these three structural phases are as follows: (i) the first fractures filled by the veins of felsic rocks and quartz minerals having a N-S orientation ; (ii) the second generation of fractures is subparallel to the orientation of the minerals (E-W) and (iii) the third fracturing phase is sub-perpendicular to the orientation of the minerals and is contemporaneous with the N10° shear. Ductile deformation is represented by foliation and shearing. This foliation has an E-W orientation (N080° and N090°) and is affected by a N-S shear. At the Toulépleu site, three structural trends are present with a 33% appearence each. The first trend follows a preferential N-S direction, the second trend regroups E-W structures and the third trend the WNW-ESE structures (Figure 3e). The observation of foliation, shear and sigmoidal figures testify that ductile deformation is present in the study area.

4.2. Petro-structural Evaluation of Zogouiné

- **Argillite**

The rocks are red to greenish-brown to yellow-orange colors organized into two altered bands (Figure 4a to Figure 4c). The color variation into the bands indicates respectively the presence of hematite, chlorite, limonite and goethite. It is moreover this alteration which makes it possible to show that the red band would result from the alteration of pyroxenes and amphiboles to give hematites. A deeper look on the yellow-orange band suggests it would come from the alteration of feldspars and finally the greenish-brown band would be the product of the chloritization of biotites. As a consequence, it appears that the argillite comes from the intense alteration of the gneissified granodiorites.

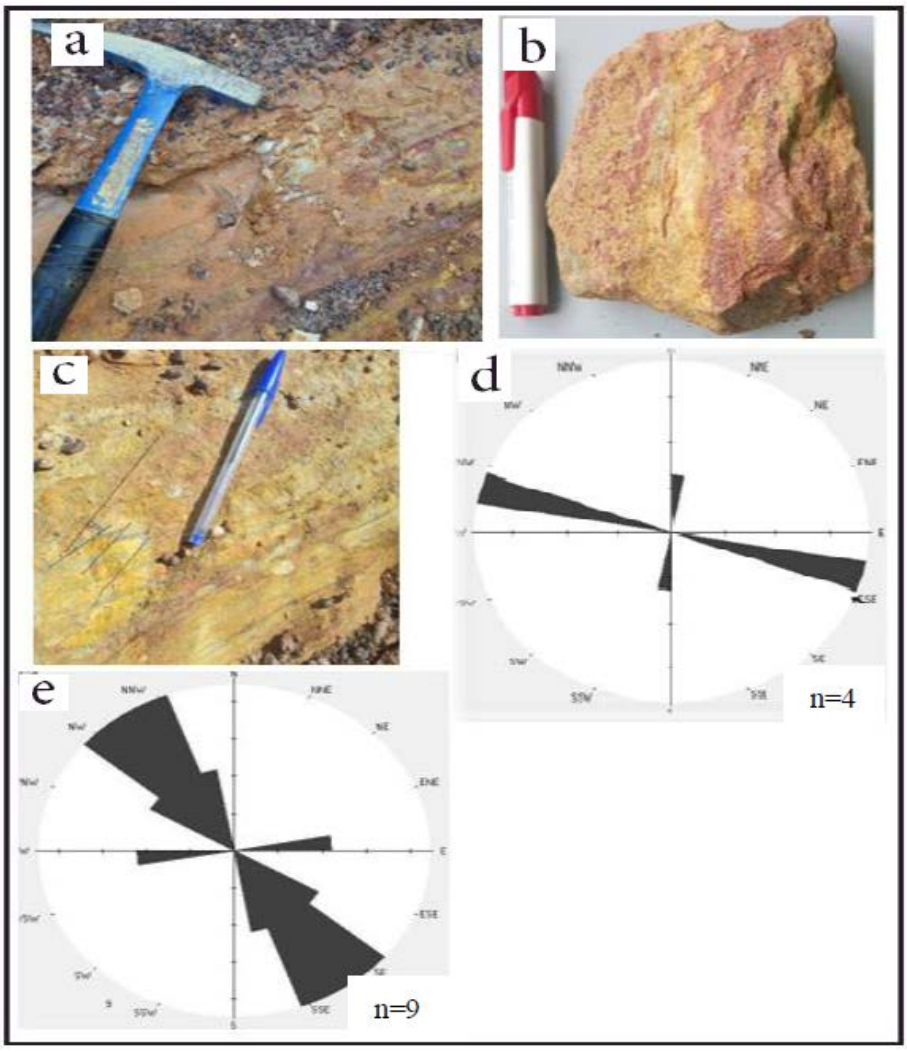

Figure 4. views of the petro-structural aspects of Zogouiné **:** a and b : macroscopic observations of the argilite **;** c, d and e : aspects of the structures and their stereographic projections

The deformation puts in light two families of faults (Figure 4c to Figure 4e). The secondary faults are abundant, representing 75% of faults, are of WNW-ESE direction then the primary faults of NNE-SSW orientation around 25%. This is consistent with the associated fractures on these faults. The proportion of fractures of secondary direction (WSW - ENE) is higher than that of the primary orientation (NW, NNW-SE, SSE; 22%) (Figure 6). This is reliable to the facts that, the first faults have been reactivated by the second generation faults so that the fractures from this second deformation overprinted the elders one.

At Zoguiné, the ductile structures are represented by folds and foliation in the argillites. The fold is isopaque with an axis of N073°. The foliation has an orientation of N082° with a dip of 34°N. The brittle deformation is a set of dextral and sinistral faults. The dextral faults affect the fold. There is also the presence of veins and fractures of N160°directions with a dip of 58°W. In addition, there are conjugate normal meso-faults in the enclaves. The quartz veins describe sigmoidal figures (Figure 4).

The presence of foliations, sigmoidal figures and folds attest the existence of ductile shearing at Zoguiné.

4.3. Petro-structural Aspect of Guéya

The formations of Guéya can be grouped into two units: magmatic and metamorphic rocks.

4.3.1. Magmatic Rocks

- **dolerite**

The dolerite appears at the entrance of the primary forest observed at the foot of Mount Djrihè-ploù (or white loincloth). It is melanocratic color and outcrops in the form of slabs, its mineralogy is composed of: flaky amphibole, resulting to their mixture; pyroxene in the form of subautomorphic to automorphic crystals; plagioclase, dominating the rock matrix (Figure 5a). The rock has an intersertal texture and is characterized by the presence of large crystals of pyroxene enclosing small laths of plagioclase. This texture is also known as ophitic or doleritic. The abundance of amphiboles is due to the ouralitization of some pyroxenes. Under polarized light, the thin section Dht confirms the mineralogy described on naked eye by completing it with orthoclase, strongly altered and quartz (Figure 5b). The crystals of quartz, plagioclase and orthoclase minerals carry those of pyroxene and amphiboles.

- **Microgranodiorite**

The sample is observed in the interface of the dolerite and the Djrihè-ploù mount. The rock has a filonian texture and a gray color with clear minerals that are identifiable on day light (Figure 5c). Thus we have quartz, feldspars, muscovites and a range of disseminated sulfides. Microscopic observation of the rock shows (Figure 5d) it is crossed by veinlets of mafic rock and quartz. The rock veinlet is composed of abundant amphibole, pyroxene, muscovite and automorphic opaque minerals. The quartz veinlets are crossed by lenses of opaque and micaceous minerals. The description of the zones that have the original nature of the rock gives to minerals an order of abundance: quartz, orthoclase, sericite, altered amphibole, biotite and chlorite. The chloritization is particularly important around the opaque minerals. The veins are observed on the flank of the outcropping hills. They are strongly deformed, appearing as intrusions in the laterite, they are thus micaceous and contain tourmaline and feldspars.

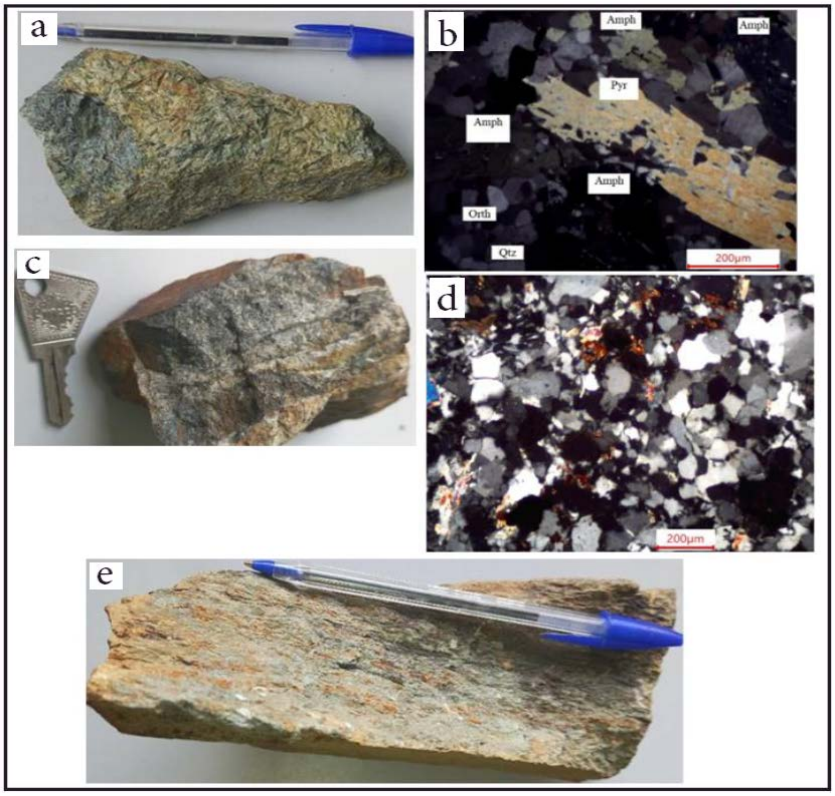

Figure 5. Petrographic observations of Guéya. a and b: macroscopic and microscopic views of the dolerite; c and d: macroscopic and microscopic views of the microgranodiorite; e: macroscopic aspects of the chloritoschist (Qtz : quartz ; Pyr : pyroxène ; Amph : amphibole ; Orth : orthoclase)

4.3.2. Metamorphic Rocks

- **Chloritoschist**

It outcrops abundantly at the top of Djrihè-ploù Mount and has a fractured appearance as a result of mechanical alteration due to the roots of primary forest trees (Figure 5e).

- **Metadolerite**

Two samples were described: the first, schistose with late metamorphism and the second with pronounced metamorphism. Some rock blocks encountered in the area show that the metadolerite has undergone a prograde and then retrograde metamorphism.

- **Oriented microgranodiorite**

Oriented microgranodiorites appear as blocks on the tailings of gold panning sites, which are sulphide-bearing. At the naked eye, this filonian rock presents a concordant texture, however, the felsic minerals are phenocrysts: quartz, plagioclase and muscovite. In addition to these characteristics, there is the presence of sulphides concentrated preferentially in the darker areas.

4.3.4. Gueya Structural

At the structural level, ductile and brittle deformations are observed (Figure 6).

- A variety of schistosities are expressed at the mount Djrihè-Ploù. From the bottom to the top of the hill, the schistosity increases. At the top, schistose fractures are widespread (Figure 6a). The flux schistosity and the fracture schistosity are striking towards N090° with a dip of 44° to the south. The S1 and sinistral faults N16° to N18° are crossed by subperpendicular fractures. The observed strike slip faults and schistosity are the results of the shearing ductility at Guéya.
- a micaceous quartzo-feldspathic vein with tourmaline of N100° orientation. The vein is affected by a series of fractures, the major ones following a N140° direction. The strong intensification of the fracturing gives to the veins a mylonitized appearance (Figure 6a and Figure 6c).

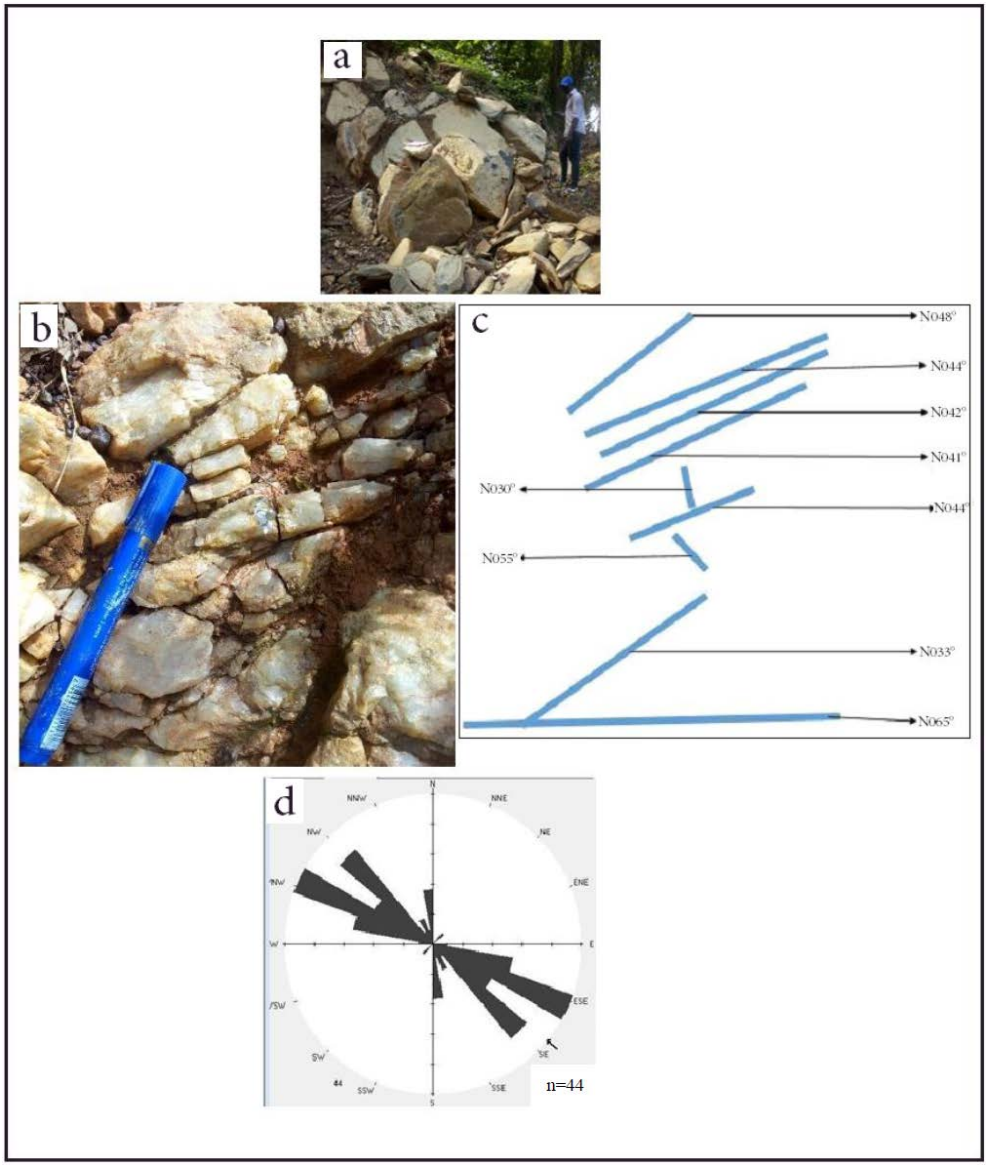

Figure 6. A view of the structures of Guéya. a : fractures in chloritoschist; b and c: Mylonitized quartz vein and the modeling; d : stereographic plots of the structures observed at Guéya

5. Discussion

5.1. A Diversity of Lithologies

The petrography of the Toulépleu-Ity Birimian furrow is similar to that of the others furrows belonging in the Paleoproterozoic area as described by the authors [20,21]. We encountered sets of magmatic and metamorphic rocks and associated sediments. The magmatic rocks are represented by tonalites, microgranodiorites and dolerites. The metamorphic rocks are constituted by metatonalites, chloritoschists and metasediments. Gneiss observed at Toulepleu is the main difference, this basement lithology is not always observed around the furrows into the paleoproterozoic area. The microgranodiorite appears as included in the chloritoschists, which means that it is posterior to them. The chloritoschists would result from the metamorphism of the amphibolites mapped by Papon in the period 1965 to 1967. This associated metamorphism could have been favored by the setting of microgranodiorites. The dolerite crosses through the subvolcanites and constitutes by that the last magmatic phase of the study area. It is therefore the youngest formations in the Toulépleu department. In Côte d'Ivoire, dolerites have been described by several authors [13,14,22] as post-Eburnean phenomena. Their presence in the study area means that the Eburnean orogeny influences locally with its tectonic and magmatic events.

The Guéya metasediments in contact with the hypovolcanites are thought to have resulted from the alteration of the metatonalites that outcrop in the town of Toulépleu. The metatonalites therefore predate the microgranodiorite. The existence of tonalites in the study area is essential in the sense that it supports the work of Tabaud et al., 2015 in opposition to previous authors such as [10,12,14,23] who observed rather metagrauwackes. The existence of probable mineralization would be related to the emplacement of sulfide-bearing microgranodiorites. Indeed, studies carried out by [6] at Ity show that the formation of Birimian granitoids intruded into the Archaen are favorable to mineralization. All of the host rocks at Gueya are affected by regional greenschist facies metamorphism. These metamorphic conditions are similar to those of several West African gold prospects and deposits [9,23,25]. In addition to the greenschist facies [6] highlighted an amphibolite facies at Ity.

5.2. At the Structural Level

The deformations observed in the study area are faults, schistosity, foliation, lineations, dextral and sinister strike-slip faults, quartz veins and veinlets, sigmoidal figures and shears, fractures and isopaque folds. Because of their settlement in rocks generated from different orogenies, the structures are also showing the orientation of these orogenies. They indicate the presence in the study area of shear corridors. According to [26], these mentioned structures can be seen as the proof of the existence of a shear corridor. We can therefore confirm the presence of a NE-trending shear-zone in the study area that occupies the contact between the chloritoschists and the microgranodiorite. This shear-zone is characterized by a development of schistosity, foliation and shear of directions N080° enclosing the sulphide hypovolcanites. In the Bonikro gold deposit, the N-S shear zone in the south is subdivided into three end-members striking N-S, NNE and NW [27], this is similar to the shear zone from this study. In terms of tectonic phases, [22] identified in the western Côte d'Ivoire, four phases D1-D4. This study shows similarities with the Koffi's phases. The first phase D1 is observed in the quartz veins. This phase is characterized by a fracturing with an overall NW-SE orientation. The D1 phase would result from a NE-SW shortening and would then lead to NW-SE oriented structures with the presence of tight isoclinal folds. The second phase of deformation D2 is present throughout the area. This D2 phase is characterized by conjugate normal faults of preferential NNE-SSW direction. The D2 phase would be due to NNW-SSE shortening leading to the setting of dextral NNE-SSW faults. Phase D3 is characterized by schistosity and E-W oriented foliation in the metasediments at Zoguiné and in the Toulépleu metatonalite. Overall, the D3 deformation would result from NS shortening that creates E-W structures. The D4 phase is located in the Zoguiné zone and originates from WNW-ESE fracturing that creates E-W dextral shears. This D4 deformation phase intersects the structures of the previous phases (D2 and D3). Finally, we have the emplacement of dolerite dykes within the aforementioned lithologies.

6. Conclusion

This study was initiated in this department to improve our knowledge of the petrographic, and structural characteristics of the Toulepleu-Ity furrow from the localities of Toulepleu, Zogouiné and Guéya. The petrography is made of magmatic rocks made of tonalites, microgranodiorites and dolerites. These rocks have been metamorphosed and also shown with gneiss, metasediments and chloritoschists. The microgranodiorite is posterior to the chloritoschist as it is intruded by the latter and is in contact with the metasediments. All of these rocks have a common basement which is gneiss. The last eburnean magmatic event of the zone is recorded in the dolerite. The deformation and metamorphism observed in the dolerite recall that the Eburnean event has been overprinted by others events. These formations have undergone a regional metamorphism ranging from greenschist facies to amphibolite facies characterized by the association of green chlorite-hornblende and significant hydrothermal alteration marked by quartz veins and veinlets. The structures observed are normal in echelon faults, schistosity, foliation, lineations, quartz veins, fractures, sigmoidal structures, folds, shearing and dolerite dikes. The orientation lies NE-SW to NNE-SSW in both ductile and brittle structures highlighting the incidence of the Eburnean tectonic and moreover two deformations : flattening and shearing. These structures indicate the presence of a shear zone striking N080°, potential of gold endowment structure in comparison to its importance in the others furrows in the Paleoproterozoic domain.

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