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Fouimba and Goma Mounts Greenstone Belts Litho-Structural Analysis Related to Côte D'Ivoire Birimian Geodynamic Setting and Implying in West-Africa Craton Gold Deposits

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Abstract

Mount Fouimba and Mount Goma (Seguela) greenstone belts petro-structural studies combine remote sensing, geophysics, petrography and structural analysis. In view of establishing mapping details of paleoproterozoic geological formations, geological setting rocks observed are essentially magmatic formations, such as two-mica granite, granodiorites, and porphyritic basalts; and a few metamorphics which are metatonalite, amphibolites and amphibo-lopyroxenites. Remote sensing, such as Landsat 8 OLI satellite imagery and geophysical data, has been combined to show regional NNE-SW shear zone. Tectonic structures and microstructures have enabled to identify two main deformation phases: D1 phase corresponding to compression, and D2 is a transpression phase. Mechanisms responsible for deformations are respectively flattening and transpression. Geological formations derived from mantle origin but contain crustal components, and their tectonic setting occurred during subduction.

Keywords

Petro-Structural, Mapping, Greenstone Belt, Birimian, Séguéla, Côte D'Ivoire

1. Introduction

Known for its diamondiferous fields fed by kimberlite and lamprophyre dykes, the Séguéla zone, located in the center-west of Côte d'Ivoire, presents in these greenstone belts (VRC), a certain number of structural features, stratigraphic, lithological, magmatic, and metamorphic, which at first sight, seem to favor the construction of important mineral concentrations. These many particular features have recently attracted the attention of major mining companies, in particular the RoxGold company, which acquired a mining exploration permit, covering an area of 350 km^2, and comprising the two main mountains of the said area, in particular the GOMA and FOUIMBA mountains. Furthermore, it is clear that Côte d'Ivoire does not have, to date, detailed geological maps covering the whole country, and making it possible to understand all these features mentioned above, because few detailed studies have been carried out. It is therefore clear that the establishment of detailed geological mapping of the Ivorian lands is more than a necessity. It is therefore in this impulse of necessity that the present study aims to highlight, and in detail, all the petro-structural characteristics of the geological formations of the Séguéla area, and this, by means of cartography at 1/50,000.

2. Cadre and Geological Setting

2.1. Location

The city of Séguéla is located in the center-west of Côte d'Ivoire, between longitudes 6˚30'00''W and 7˚00'00''W and latitudes 7˚45'00''N and 8˚15'00''N, with an average altitude above sea level of 350 m. Distant from Abidjan, the economic capital, 516 km, Séguéla is above all the capital of the Worodougou region, and covers an area of 11,427 km^2 (**Figure 1**).

2.2. Geological Setting

West African Craton (WAC) is according to Bessoles (1977), subdivided into three distinct zones (**Figure 2**): northen area with Reguibat shield consisting of Archean formations (3.0 - 2.7 Ga) separated from the Paleoproterozoic formations (~2 Ga) by the Zednes Fault (northern extension of the Sassandra Fault), and outcropping in Algeria, Morocco and Mauritania. Man or Leo shield formed by Archean series of the Liberian Shield, and the Paleoproterozoic (Birimian) formations covering Ghana, Côte d'Ivoire, Guinea, southern Mali, Burkina Faso, and western Niger. Liberian basement and Birimian series are separated by an Archean-Proterozoic transition zone (Papon, 1973), corresponding to a large complex fault: the Sassandra submeridian fault (Bessoles, 1977; Caby et al., 2000). Central area are characterised by Kayes and the Kenieba-Kédougou windows. Precambrian basement is a characteristic part of the Man shield and is essentially composed by western Archean domain and eastern Proterozoic domain. Archean-Proterozoic transition zone in Ivory Coast is, according to Bessoles (1977) and Caby et al. (2000), materialised by large complex fault called the Sassandra Submeridian Fault, with N-S to NNW-SSE direction. Kouamelan (1996) subdivide transition zone into three sub-domains, including the Boundiali domain or Northern domain, located north of parallel 9˚. Séguéla-Vavoua

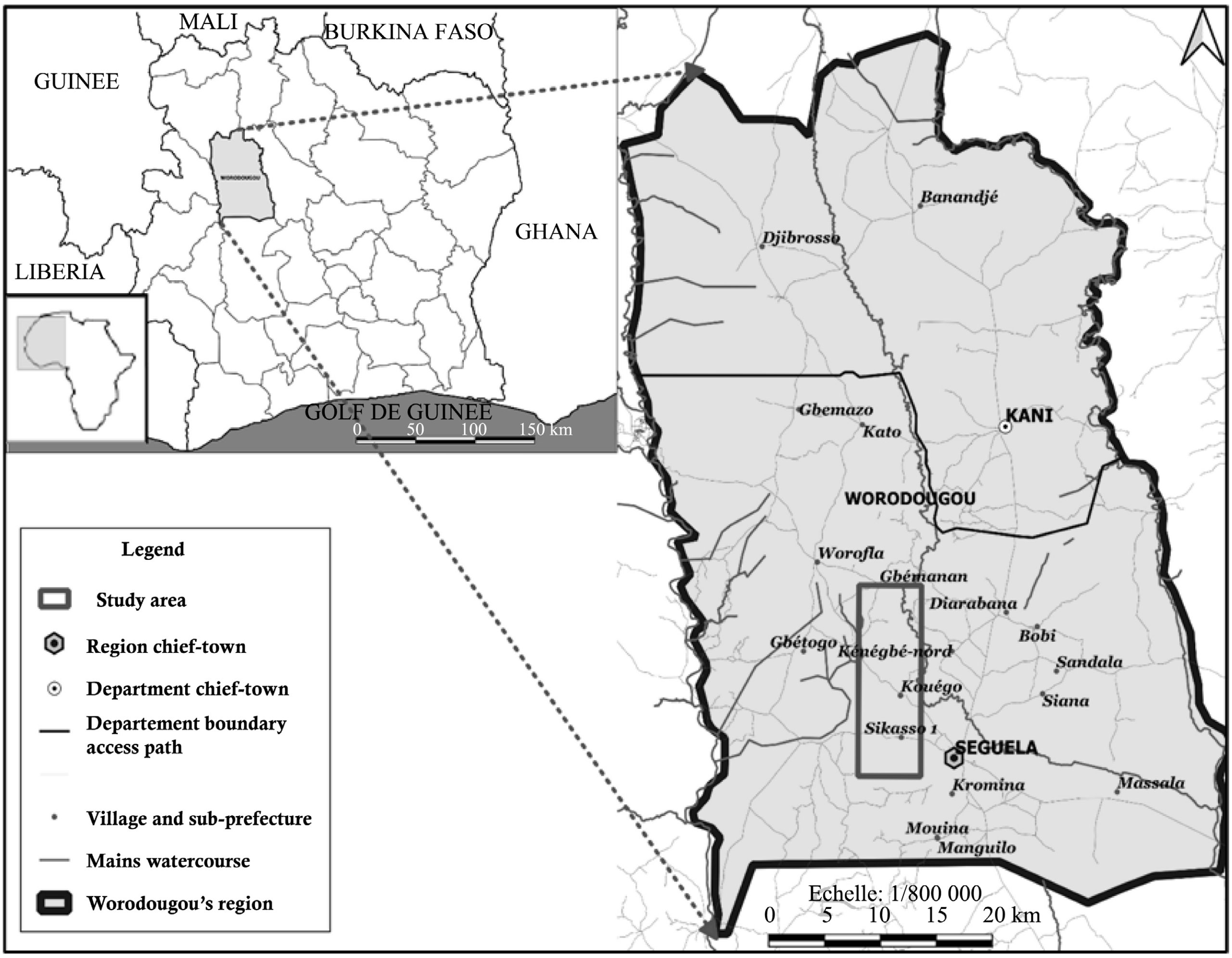

Figure 1. Location map of the study area (excerpt from the administrative map of Côte d'Ivoire, 2013), Ministry of Urbanization and Sanitation.

domain is located located between parallels 7˚ and 9˚, in which the present study area is located; and the SASCA domain or Southern domain, which extends from parallel 7˚N, to the Atlantic coast. Study area is based on thread-like trench called Séguéla-Vavoua, oriented N-S, and the geological formations encountered there are essentially composed of volcano-sedimentary units (greenstone belt) generally oriented N-S to NE-SW. Rocks are essentially migmatites, metagranites, metagranodiorites, metamonzonites, amphibolites, lamprophyres and tonalites (Figure 3).

3. Methodology

Methodology chosen for the petro-structural study and detailed mapping of the geological formations of the present study area is multidisciplinary. It includes indirect methods using remote sensing data (Landsat 8 OLI image) and airborne geophysics (aeromagnetic data processing and interpretation). In addition, there are direct methods that started with a field trip, which preceded a number of analytical works in the laboratory. These include macroscopic petrography and

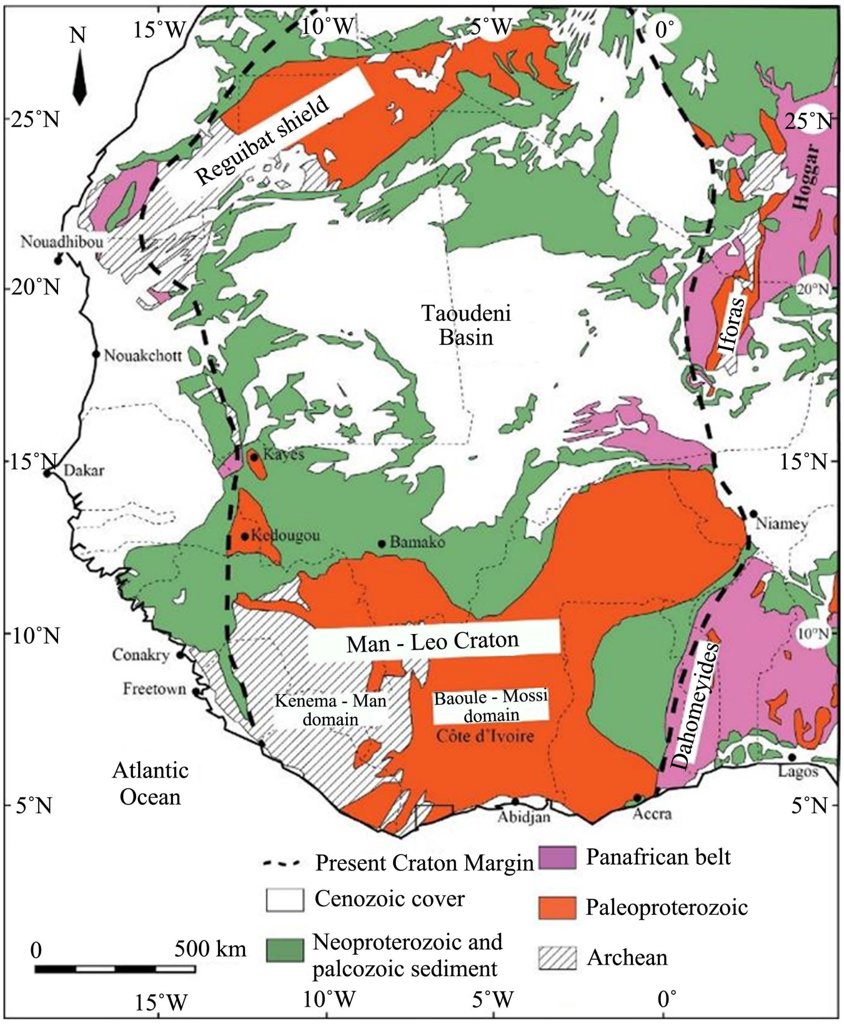

Figure 2. Geological map of the West African craton (Berger et al., 2013 modified).

microscopic analysis combined with meso- and micro-structural analysis. Several samples of various rocks were selected during the field mission. Thin sections of these rocks were prepared at the Geology, Mining and Energy Resources Laboratory (GRME) of the University of Félix HOUPHOUËT BOIGNY-Abidjan. These thin sections were studied under a petrographic microscope to identify the main minerals and the nature of the rock.

4. Results

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

4.1. Tele-Analytical Data

Two main types of tele-analytical data were used in this thesis. These include satellite imagery data and aeromagnetic data.

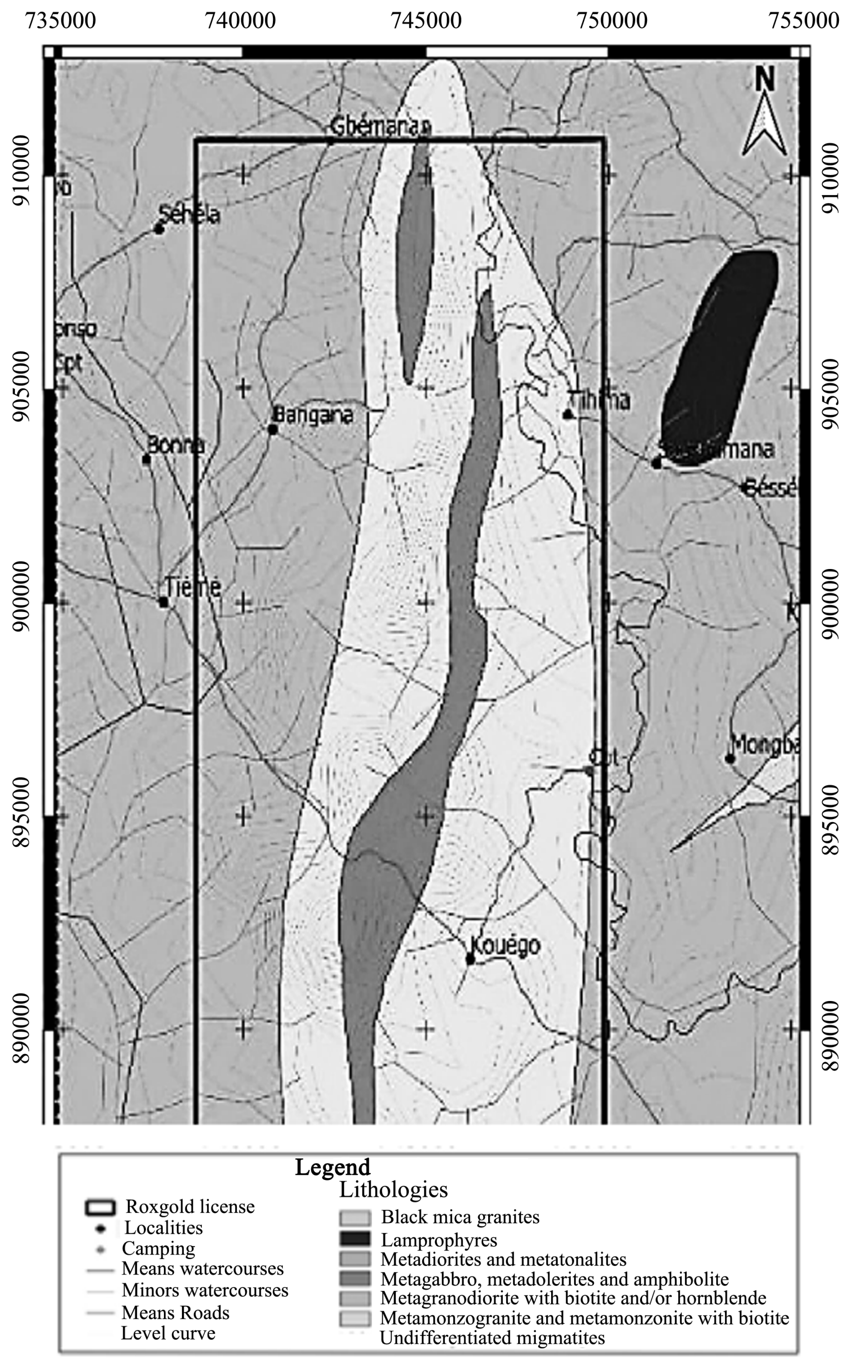

Figure 3. Geological map to 1/200,000 of the study area (extract of the MANKONO and SEGUELA leaft; Tagini, 1972, modified).

4.1.1. Satellite Imagery

Satellite images and systematic analysis of lineaments obtained gave 4 majors structures directions, the main direction is oriented NNE-SW, secondary direction is NE-SW, tertiary is oriented WNW-SE and the quaternary is oriented NNW-SSE. In fact, the lineaments between [N0˚ - N45˚] constitute about 28.88%; the lineaments between [N46˚ - N90˚] constitute about 25.26%; the lineaments between [N90˚ - N135˚] constitute about 23.64%; and the lineaments between [N135˚ - N180˚] constitute about 22.22%. These so-called major lineament directions are distributed very evenly over the entire study area, and for the most part do not occupy any preferential quadrants in the study area (**Figure 4**).

4.1.2. Aeromagnetic Data

Reduced magnetic field map at the equator Analysis and interpretation of equatorial reduced field map has structurally identified the major structures in study area (**Figure 5**).

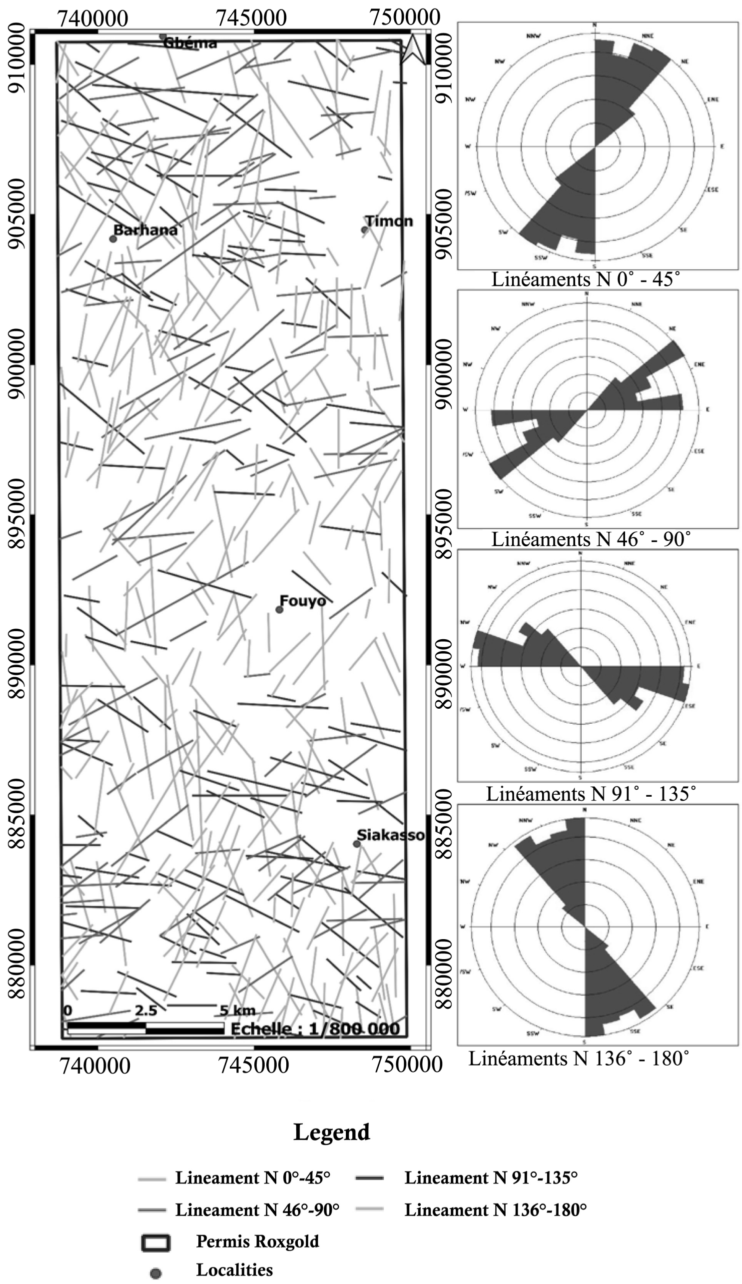

Figure 4. Thematic map of the lineament network of the study area and associated directional rosettes (481 lineaments).

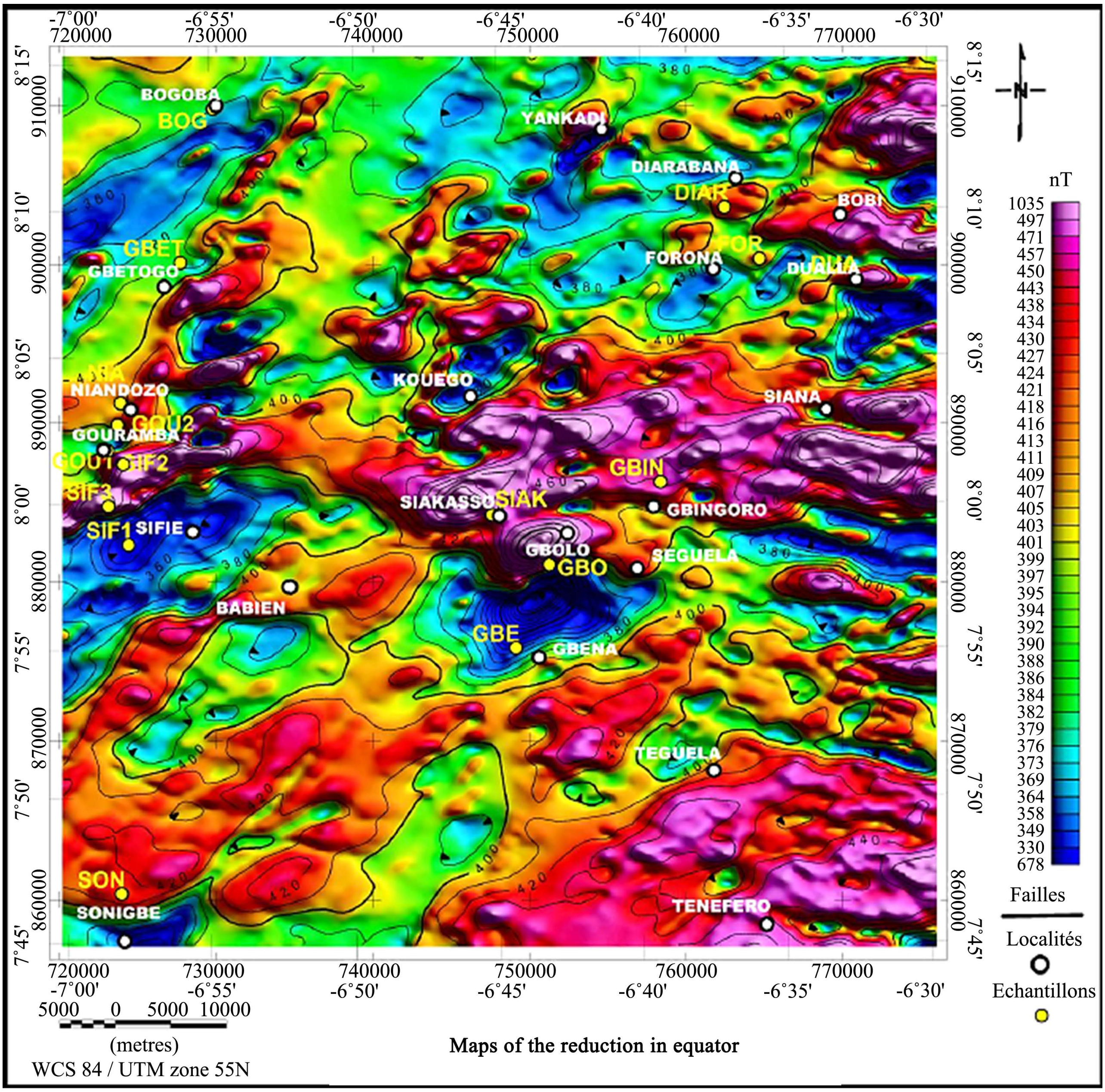

Figure 5. Map of the reduction at the equator coupled with the major structures of the study area.

4.2. Petrography Data

Geological survey carried out in the study area revealed a range of rock outcrops from which samples were taken for a more detailed petrographic study. Samples were taken for a more detailed petrographic study. Two main types were identified: magmatic and metamorphic.

4.2.1. Magmatic Rocks

They are essentially composed of two-mica granites, leucogranites, pink granites, granodiorites and porphyry basalts. Mineralogical analysis has revealed regional deformation, materialised by the stretching of biotite and muscovite. It should be noted that biotite-muscovite granites are the most abundant.

1) Biotite-Muscovite Granite

They are observed in the following area (Gbena, Gbingoro, Kuego, Mongbaran, Besséla, Kénégbé, Niandozo…). Different deposit presented like slab, block or dome crossed by fractures, pegmatites and quartz veins. It is moderately to heavily altered (Figure 6(a) and Figure 6(b)) illustration show granite samples. Illustration 6C, 6D, 6E and 6F show minerals observed in the two-mica granites. Some biotite and muscovite phenocrysts are observed in samples.

2) Potassic Granite

Located in the vicinity of the two-mica granites (Gbingoro), they have almost the same characteristics as the latter except for a much higher proportion of orthoclase and microcline (Figure 7(a) and Figure 7(b)) show a slab and a sample of pink granite respectively. Minerals compositions are shown by (Figures 7(c)-(f)).

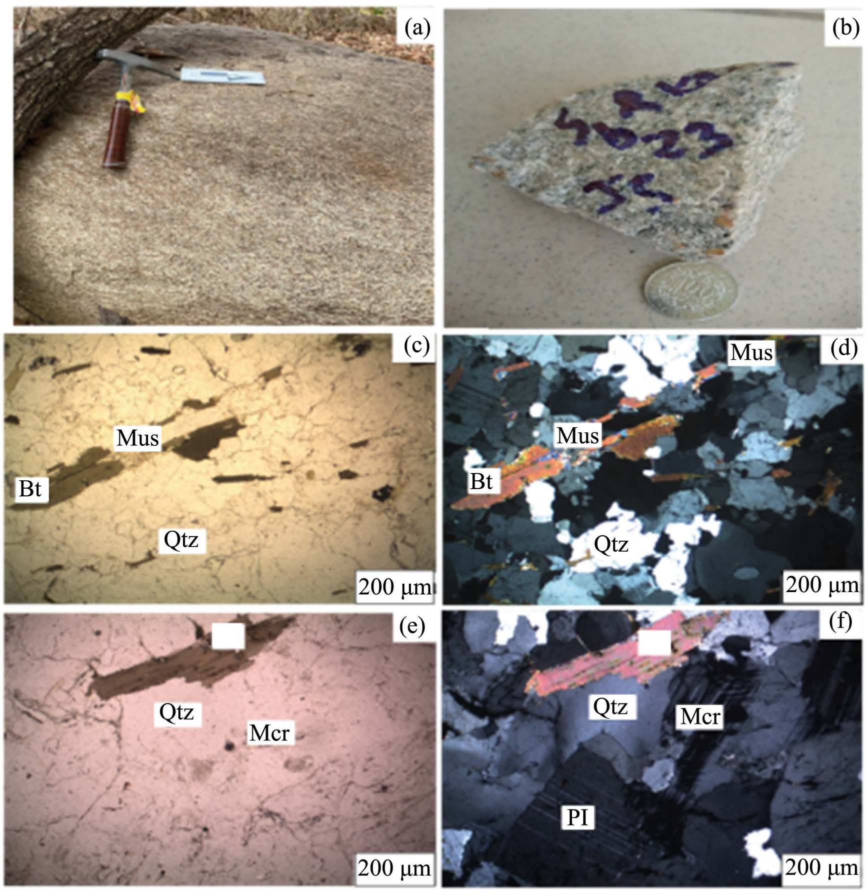

Figure 6. Aspects macroscopiques et microscopiques des granites à deux micas. (a): Bloc de granite à deux micas, (b): échantillon macroscopique de granite à deux micas, (c): assemblage quartzo-feldspathique + minéraux de biotites et muscovites (LPNA), (d): assemblage quartzo-feldspathique + minéraux de biotites et muscovites (LPA), (e): Minéraux étirés de biotites associés aux quartz et feldspaths (LPNA), (f): Minéraux étirés de biotites associés aux quartz et feldspaths (LPA); Qtz: Quartz, Pl: Plagioclase, Mcr: Microcline, Bt: Biotite, Mus: Muscovite.

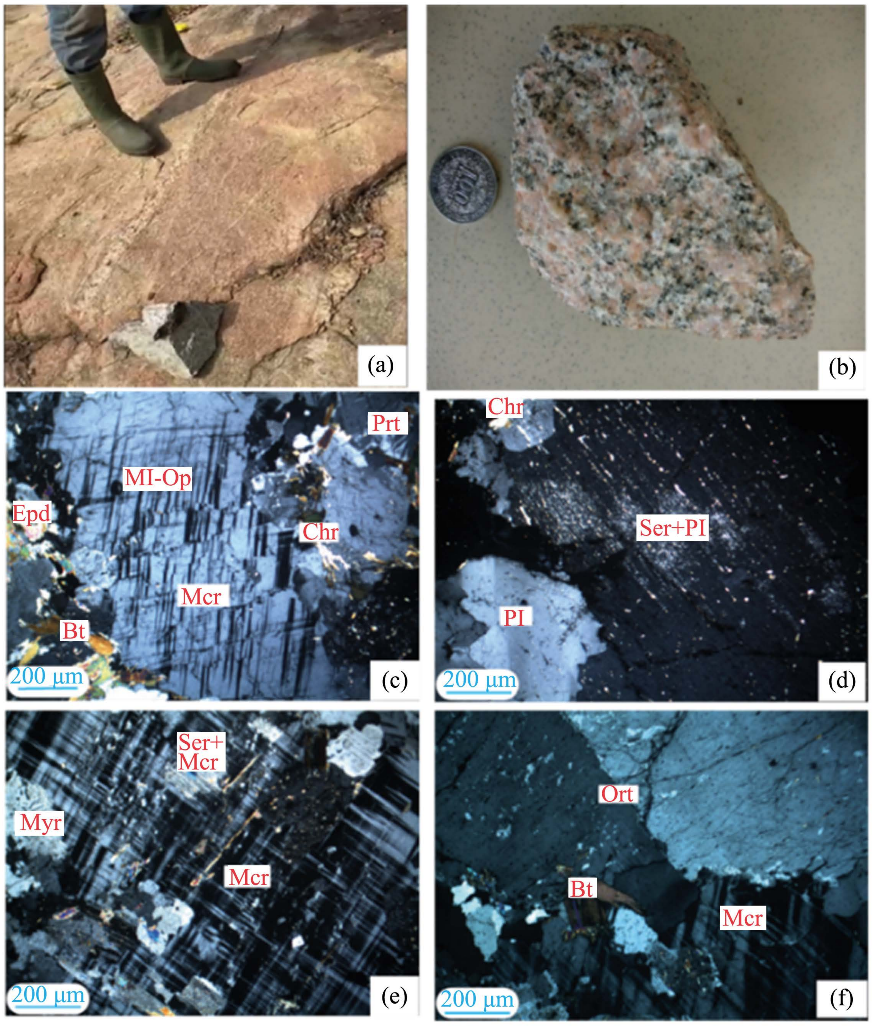

Figure 7. Macroscopic and microscopic aspects of potassic granites. (a): Potassic granite slab, (b): macroscopic sample of potassic granite, (c): microcline phenocrysts associated with biotites, chlorites and sericites, (d): progressive sericitisation of plagioclases, (e): sericitisation and myrmekites in microcline, (f): biotite minerals associated with orthocrysts and microcline phenocrysts Qtz: Quartz, Pl: Plagioclase, Mcr: Microcline, Bt: Biotite, Ml-Op: Opaque mineral, Sr: Sericite, Epd: Epidote, Myr: Myrmekite, Chl: Chlorite.

3) Granodiorite

Granodiorite outcrops are generally slabs and boulders. They were observed mainly at Souroumana, Dar-es-Salam, Gbetogo, Dirabana and Dualla. Samples are mesocrate, altered, and deformed with very stretched minerals (**Figure 8**).

4) Porphyry Basalt

Mount Fouimba and Goma, basalt appears as blocks model. Generally, we observe mi crolitic texture, plagioclases, microcline and orthopyroxènes (**Figure 9**).

4.2.2. Metamorphic

Metatonalites, amphibolites, and amphibolo-pyroxenites, samples have been taken on Mount Fouimba.

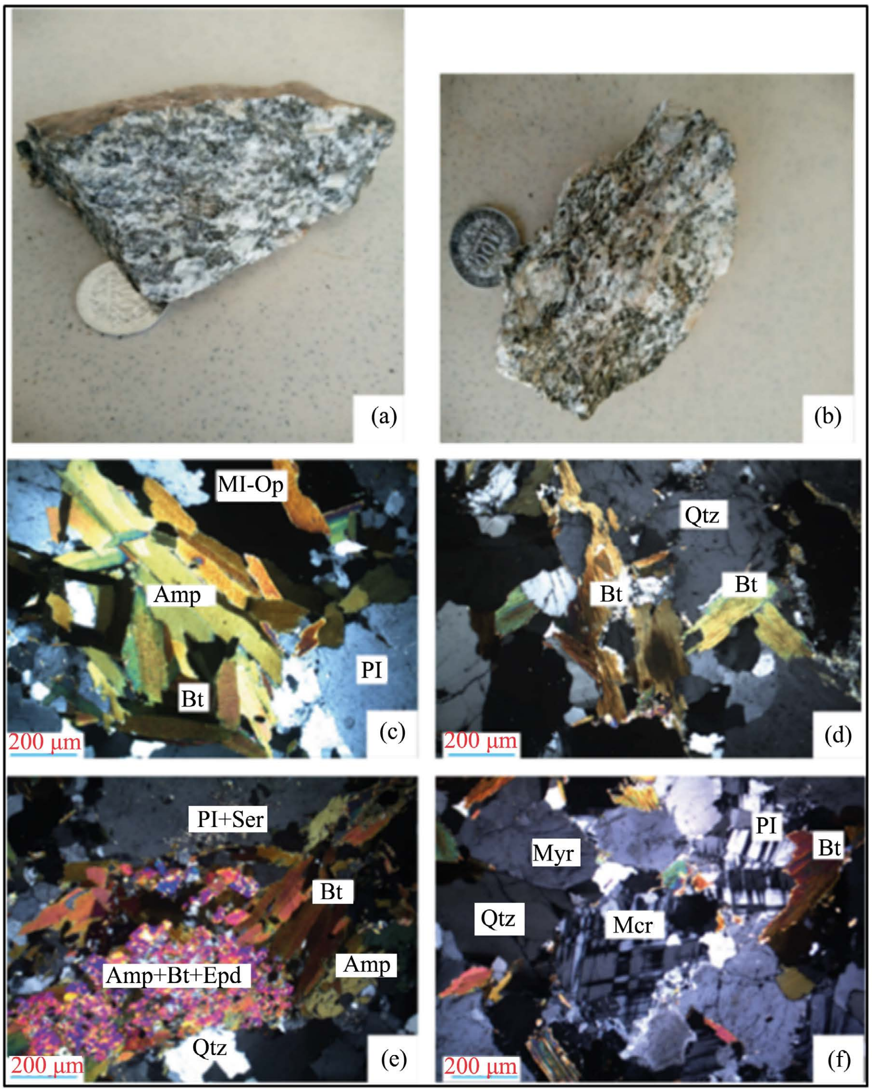

Figure 8. Macroscopic and microscopic aspects of Granodiorites. (a): macroscopic sample of undeformed granodiorite, (b): macroscopic sample of deformed granodiorite, (c): Amphibole rods and oriented biotites, (d): Quartzo-feldspar assemblage + biotite minerals, (e): Amphibole rods and oriented biotites associated with epidotes, (f): Quartzo-feldspar assemblage and biotite minerals. Qtz: Quartz, Pl: Plagioclase, Mcr: Microcline, Bt: Biotite, Amp: Amphibole, Ml-Op: Opaque mineral, Sr: Sericite, Epd: Epidote, Myr: Myrmekite.

1) Metatonalite

Metatonalite has been observed in Sifié, Béna and Forona. Bena sample shows contain leucozome minerals like quartz and feldspars. Melanozome minerals are represented by biotite and amphibole (**Figure 10**).

2) Amphibolite

Samples observed mainly on the Fouimba and Goma mountains. Green hornblemde, orthopyroxene, chlorite and quartz are observed in the sample (**Figure 11**) have mainly grano-nematoblastic texture and respectivily brown hornblende, orthopyroxene and clinopyroxene minerals.

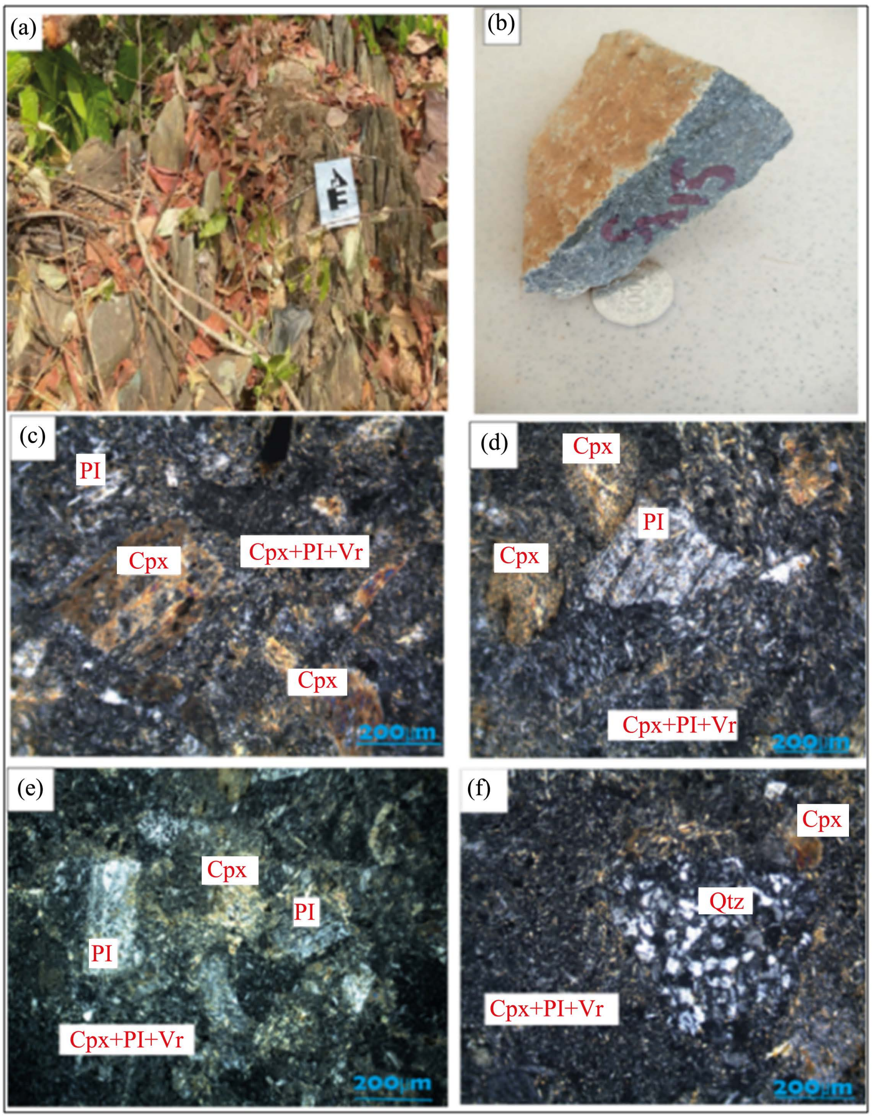

Figure 9. Macroscopic and microscopic aspects of basalt. (a): Block of basalt, (b): macroscopic sample of basalt, (c): phenocrysts of clino-pyroxene associated with plagioclase and glass, (d) phenocrysts of clino-pyroxene and plagioclase associated with glass, (e): automorphic minerals of plagioclase and clino-pyroxene, (f): neoformed clino-pyroxene, plagioclase, and glass + Quartz assemblage. Cpx: Clino-pyroxene, Pl: Plagioclase, Qtz: Quartz, Op: Opaque minerals.

4.3. Structural Data

Brittle tectonic structures mainly include faults, fractures and cleavage, and ductile structures, such as foliations, veins, tension cracks, boudins and fractures.

Tectonic analysis is prouved by schistosities and foliations which are directed to NNE-SW to NE-SW. In addition, echelon cracks, asymmetrical boudins, shear zone, veins, folds and C/S fabric, are associeted to this training. Tectonic analysis is prouved by schistosities and foliations which are directed to NNE-SW to NE-SW. In addition, echelon cracks, asymmetrical boudins, shear zone, veins, folds and C/S fabric, are associeted to this training. Faults and fractures identified

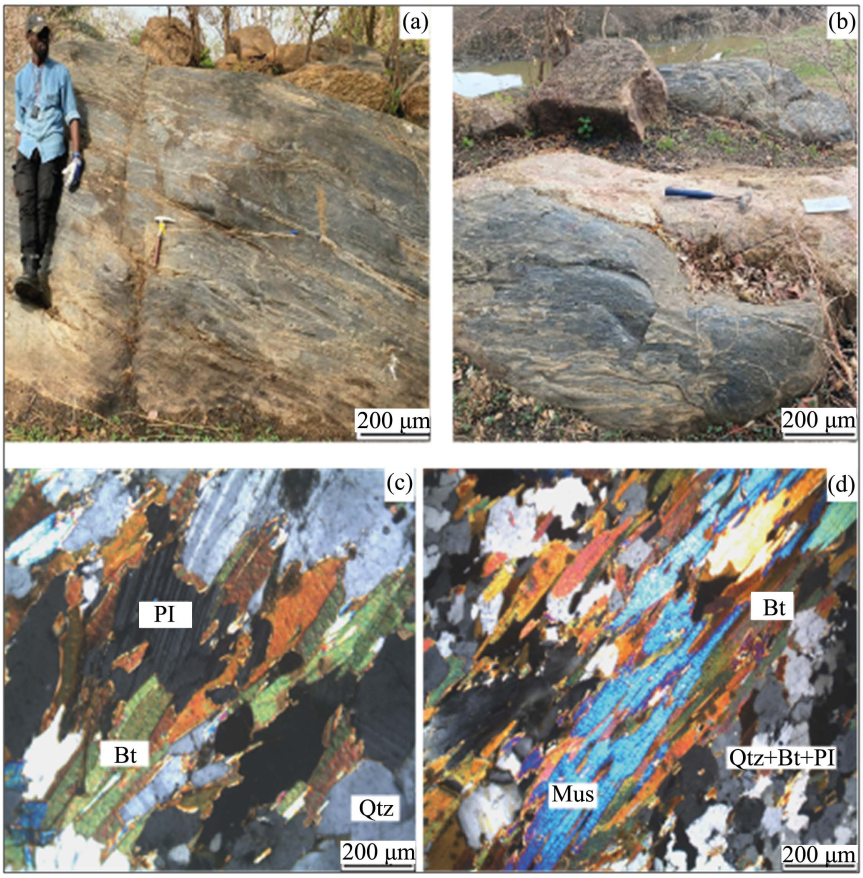

Figure 10. Macroscopic and microscopic aspects of metatonalitis. (a): outcrop of metatonalite, (b): outcrop of metatonalite with a 1.6 m wide pegmatite vein, (c): oriented biotite rods associated with plagioclase and quartz, (d): extensive stretching and orientation of biotite and muscovite minerals associated with plagioclase and quartz Bt: Biotite, Pl: Plagioclase, Qtz: Quartz, Mus: muscovite.

are generally oriented: N10˚, N40˚, N80˚, N120˚ and N170˚ (Figure 12). Shear-zone tectonic elements are characterized by sheared veins and veinlets; sheared veinlets; C/S factories (Figure 13). Ductile deformations products are represented by mineral stretching lineations; N010˚ foliation and pegmatite N040˚ and N130˚ stress crack; N270˚ folds axis and N080˚ foliation deflections (Figure 14). Tectonic and microtectonic structures have led to highlight D1 and D2 birimian deformations.

Structural analysis has enabled us to highlight all structures and/or deformations by means of tele-analysis and data collected in situ. Tele-analysis data reveal that the lineaments studied are characterised by four major directions, the main one oriented NNE-SW, the secondary one NE-SW, the tertiary one WNW-SE and the quaternary one oriented NNW-SE. The macro- and micro-structural data confirm its different orientations. The analysis and interpretation of these structures have made it possible to define two main deformation phases: D1 and D2 (D2a and D2b). The first corresponds to a compressional phase (flattening) materialized throughout the study area by schistosities and

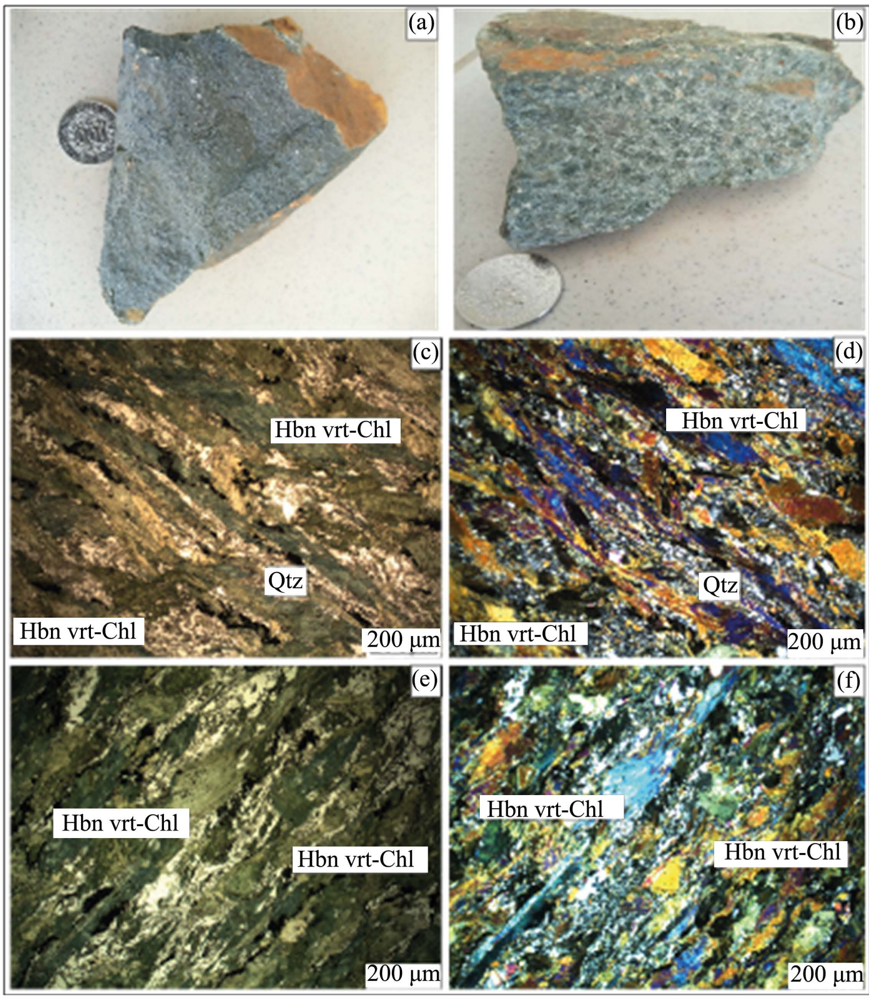

Figure 11. Macroscopic and microscopic aspects of Amphibolites. (a): macroscopic sample of medium-grained amphibolites, (b): macroscopic sample of porphyritic amphibolites, (c): highly polarised green hornblende minerals not analysed (LPNA), (d): highly oriented green hornblende minerals in analysed polarised light (LPA), (e): green hornblende and quartz mineral assemblage (LPNA), (f): green hornblende and quartz mineral assemblage (LPA), Hnb-vrt: green hornblende, Qtz: quartz, Chl: chlorite.

foliations-oriented NNE-SW to NE-SW. The second phase corresponds to a transpression or transtension phase with the main stresses-oriented WNW-ESE. It is subdivided into phase D2a (compressive), materialized by echelon cracks, asymmetrical boudins, etc., and phase D2b (shear), materialized by sheared veins, winding figures, C/S fabrications, etc.

The compilation of the results of the field studies and the results of the tele-analytical studies (Landsat 8 and aeromagnetic images) made it possible to establish and/or propose a structural (Figure 15) and lithostructural (Figure 16) sketch of the study area. On this lithostructural sketch, in accordance with the results of the above-mentioned work, the formations are generally oriented NS to NNE-SSW. The plutonic formations (granitoids) are the most important ones and show weak to intermediate magnetic signatures. They outcrop from the

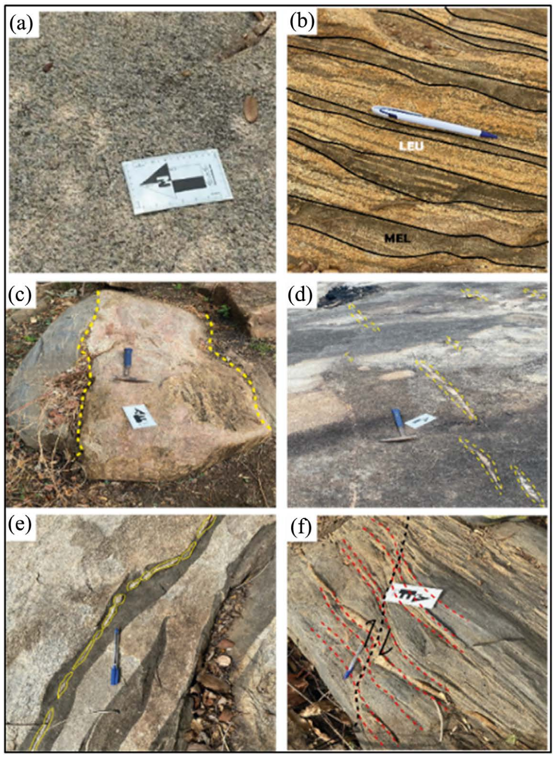

Figure 12. Structures with ductile or plastic deformations. (a): Mineral stretching lineations; (b): N10˚ directional foliation; (c): N10˚ directional pegmatite vein; (d): N130˚ directional stress crack; (e): N40˚ directional stress crack; (f): N80˚ axis oriented foliation deflections.

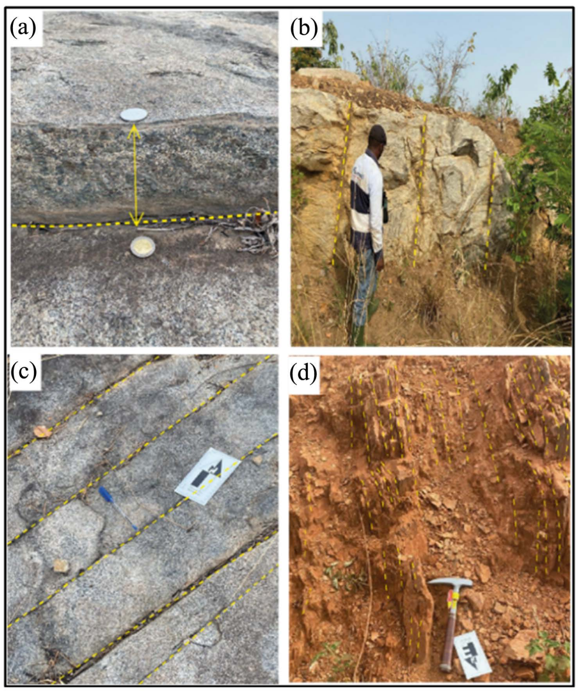

Figure 13. Structures with brittle or fragile deformations. (a): Fault mirror; (b): Fractures of direction N130˚; (c): Fractures of direction N40˚; (d): Schistosity of fractures of direction N20˚.

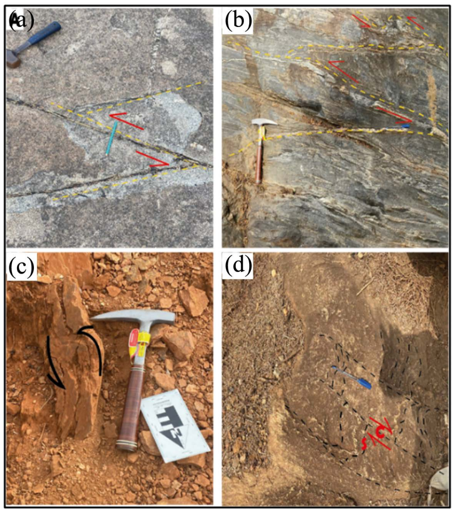

Figure 14. Characteristic structures of the Shear-zone in the study area. (a): sheared veins and veinlets; (b): sheared veinlets; (c): sinister winding objects; (d): C/S factories.

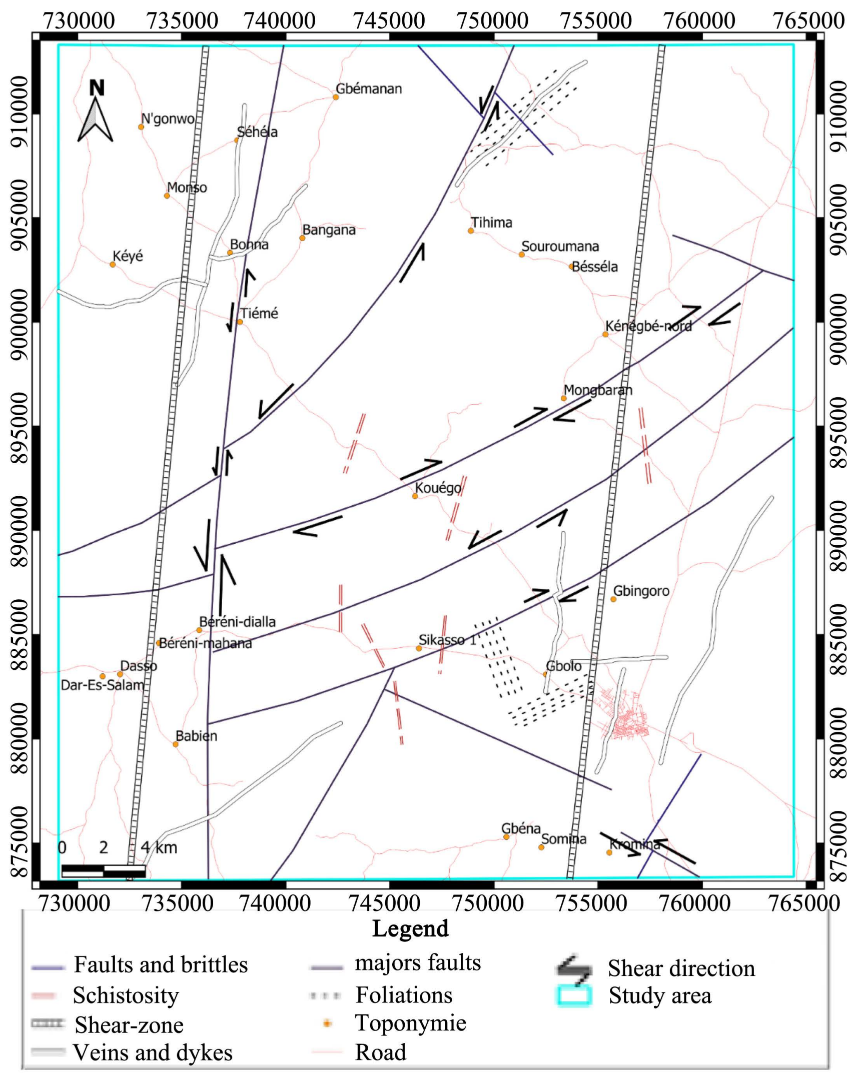

Figure 15. Proposed structural synthesis map of the study area.

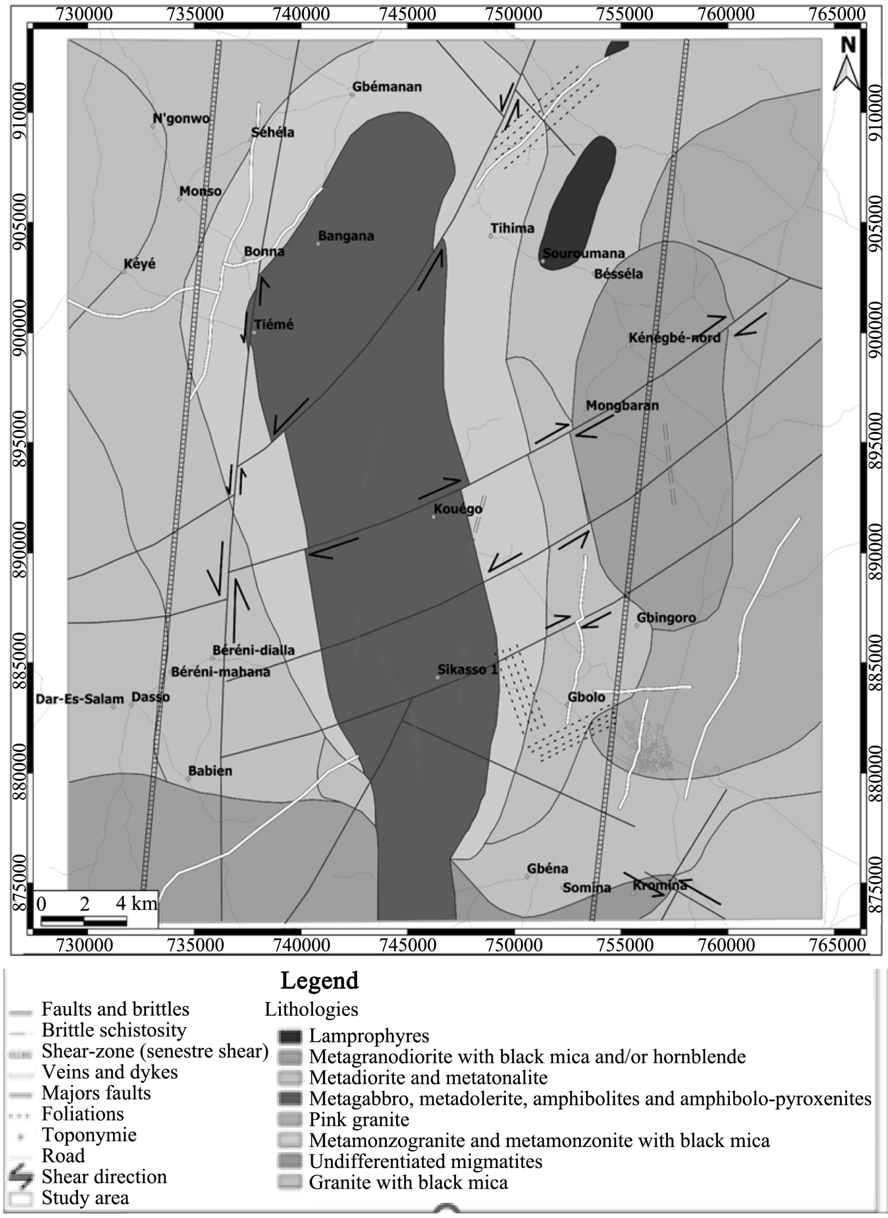

Figure 16. Proposed lithostructural synthesis map of the study area (Scale: 1:50,000).

north-east to the south-east of the study area and intrude effusive volcanics (basalts) and/or metamorphic volcanics (amphibolites, amphibolo-pyroxenites, metatonalites).

Tectonic analysis is prouved by schistosities and foliations which are directed to NNE-SW to NE-SW. In addition, echelon cracks, asymmetrical boudins, shear zone, veins, folds and C/S fabric, are associeted to this training. Tectonic and microtectonic structures have led to highlight D1 and D2 birimian deformations. Shear-zone tectonic elements are characterized by sheared veins and veinlets; sheared veinlets; C/S factories. Ductile deformations products are represented by mineral stretching lineations; N010˚ foliation and pegmatite N040˚ and N130˚ stress crack; N270˚ folds axis and N080˚ foliation deflections.

5. Discussion

5.1. Petrology

Two micas-granites are similary to those described by Allialy (2006). They can be assimilated to the granodiorites identified by Kouamelan (1996). Furthermore, Ouattara (2015) describes granodiorites in Bonikro gold deposit mineralogical composition and have undergone the same hydrothermal alteration. Amphibolites observed and analysed have affinity with those described by Allialy (2006), and Adingra (2020). Amphibolo-pyroxenites, they were identically described by Pria (2014), in the eastern part of the Toumodi region.

5.2. Structural Geology

Structural study has shown that it has been mostly affected by brittle tectonics with mostly birimian directions. At the outcrop scale as well as at the microscopic scale (polished thin sections), these regional structures are characterised by sigmoidal figures, lineations of mineral stretches, boudins, foliations, C/S structures and schistosities.

Sigmoidal figures, or winding figures, are also characteristic markers of the shearing that occurred in this area. Most part, they indicate senestial shear (dexter in places) and therefore highlight different stresses direction that led to shear zone. Assertion was also underlined by Kouadio (2017), and by Houssou (2013), during the various structural syntheses carried out respectively in the Grand Bereby and Divo areas. Fracture schistosity has been observed with respectively directions such as N10˚, N20˚, and N170˚. Mainly affects mafic and ultramafic rocks localised in shear-zone.

Furthermore, Tagini (1971) points out that WNW-ESE (N120˚ to N170˚) fractures characterise suture zone, resulting from generally southward thrusting during Paleoproterozoic to Archean. Collisional tectonics degrees decreases as one moves away from Archean basement edge, i.e. towards the East. Around this zone, first tangential phase (D1) is organised, which occurs between the deposition of a sedimentary Lower Birimian (B1) and predominantly volcanic Upper Birimian (B2) (Feybesse et al., 1989), and essentially responsible for structural organisation between Proterozoic and Archean. Second, transcurrent phase (D2) could explain presence of the major submeridian accident with a sinister offset shown. It should also be pointed out that these previous structures were also highlighted by the various remote sensing and airborne geophysical methods applied and allowed major fractures identification.

6. Conclusion

In view of all this, we can conclude that it should be noted that the various works carried out within the framework of the 1/50,000 mapping of the Mount Fouimba and Mount Goma VRC in the Séguéla area have enabled a better understanding geology setting. This study is therefore a contribution to detailed mapping. Various methods applied have enabled all petrographic facies to be highlighted, as well as all the structures observed. Two main rock families were thus detected. These include magmatic rocks (granites with two micas or leucogranites, pink granites (with orthoses and/or microclines), granodiorites of porphyritic basalts), and metamorphic rocks (metatonalites, amphibolites and amphibolo-pyroxenites). Mostly affected by greenschist to amphibolite facies metamorphism, the study area is also marked by a very significant hydrothermal (pervasive and vein) and meteoric alteration. Pervasive hydrothermal alteration is illustrated by carbonation, sericitisation, chloritisation, epidotization, silicification and sulphudation, while the vein hydrothermal alteration is illustrated by veins and veins of quartz, carbonates, etc. Meteoric (surface) alteration is very important.

Conflicts of Interest

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

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