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Archean Tonalite-Trondhjemite-Granodiorite Suites Bearing Orthopyroxene Mineral of the Bounta Region and Their Sulfide and Oxide Iron Mineralization (Western Ivory Coast)

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Abstract

The mining company Sama Nickel-CI during its exploration activities in the Bounta area (Biankouma department, western Côte d'Ivoire) identified rocks with magmatic and metamorphic characteristics of felsic to mafic compositions mineralized in sulfide but unknown in the region. Thus, the petrographic characterization of these rocks of Bounta as well as the sulfides they contain, was carried out from macroscopic to microscopic observations. Petrographic analysis of these rocks has shown that these rocks are trondhjemite, tonalite and granodiorite (TTG) suites, composed of the main minerals (quartz, plagioclase, orthopyroxene, amphibole, feldspar) and accessory minerals (biotite, garnet) with magmatic textures supplanted by metamorphic textures. They were set up by fractional crystallization and would be products of Archean crustal anatexis formed from the partial melting of basaltic protocrust during the Liberian orogeny. The Bounta's series of trondhjemite, tonalite and granodiorite (TTG) contain speckles of sulfide (pyrite and pyrrhotite) which are disseminated in places and are relatively abundant, as well as iron oxides (magnetite) which are of low proportion.

Keywords

Petrography, Trondhjemite, Tonalite and Granodiorite of Bounta, Western Ivory Coast

1. Introduction

The trondhjemite, tonalite and granodiorite (TTG) suite constitutes magmatic rocks of felsic to mafic composition that are recognized worldwide for their mineralization (iron, gold, copper, etc.) [1] [2]. In Western Ivory Coast, in the village of Bounta (department of Biankouma), rocks with magmatic and metamorphic characteristics of felsic to mafic compositions mineralized in sulfide were observed during mapping and drilling campaigns carried out by Samanickel-CI mining company, which is prospecting for the discovery of a nickel-copper sulfide deposit. Such rocks have also been considered in the department of Sipilou as being gneisses, granulites and charnockites which host intrusive mafic and ultramafic rocks of the Yacouba complex, containing nickel and copper sulfides [3] [4] [5]. Hence the need to study the petrographic nature of these rocks with felsic to mafic compositions mineralized in sulfide observed at Bounta.

This article aims to characterize these Bounta rocks by petrographic study through macroscopic and microscopic observations, then compare them to those already described in the department of Sipilou and region of Man and finally, locate these rocks in the surrounding geological context.

2. Geological Setting

Bounta is a village located in the western of Ivory Coast, in the sub-prefecture of Santa, in the department of Biankouma (Tonkpi region) (**Figure 1**). This area is characterized by a humid tropical climate with forest type vegetation and wooded savannah, developed on a mountain relief. Outcrops are few and difficult to access.

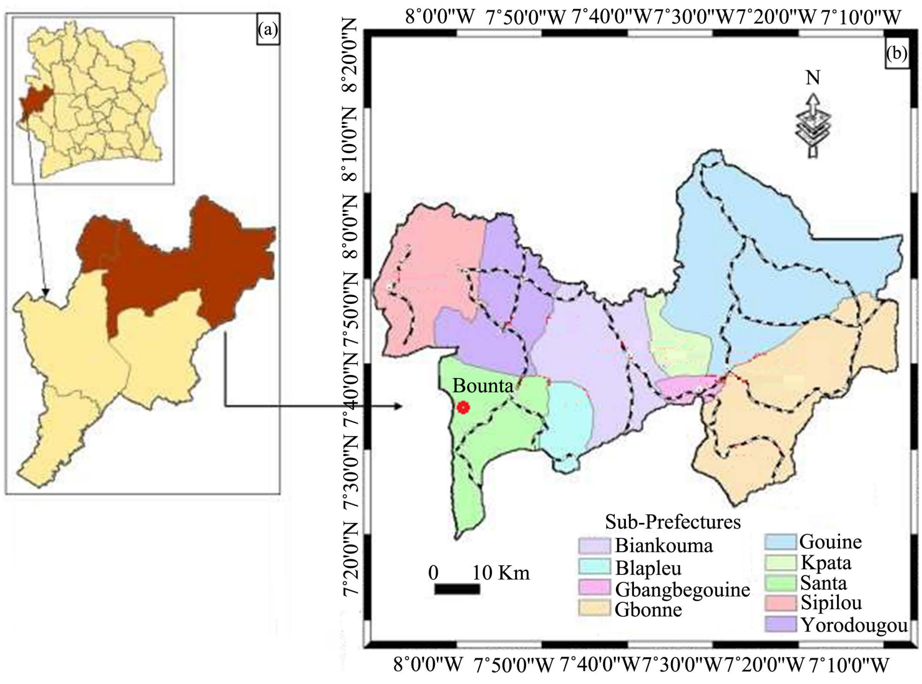

Figure 1. Location map. (a) Tonkpi region; (b) Bounta village.

The geological history of this region places it in the northern of the Kenema-Man domain located on the Man ridge belonging to the West African craton (**Figure 2(a)** and **Figure 2(b)**). This Archean domain was structured during two major orogenic cycles (Leonian 3.3 Ga to 3.0 Ga and the Liberian 2.9 Ga to 2.7 Ga). In Ivory Coast, the geological formations of this domain are migmatitic gneiss, migmatitic biotitite, orthopyroxene (OPX) bearing tonalitic gneiss, granodioritic gneiss, charnockite and metabasite (**Figure 2(b)**) [3] [6]-[14]. In the Bounta area the rocks are mainly consist of granulite, gneiss, charnockite, jotunite-enderbite (country rocks) and ultramafic-mafic rocks (peridotite, pyroxenite, chromitite, gabbro, gabbronorite, diorite, magnetite bearing quartzo-feldspathic formations) which constitute the Yacouba complex (**Figure 3**) [4] [15] [16] [17]. Structurally, reference [18] indicates from the drilling and geophysical data carried out in the region that these rocks are affected by vertical faults of direction (N-S, SW-NE, NW-SE). This author indicates the presence of shear zones oriented NE-SW and a regional foliation oriented NE-SW with dips of 70˚ to 90˚ towards the SE or NW. In addition, at Bounta, the conutry rocks (granulite/gneiss), generally have a subvertical dip which is in places subhorizontal

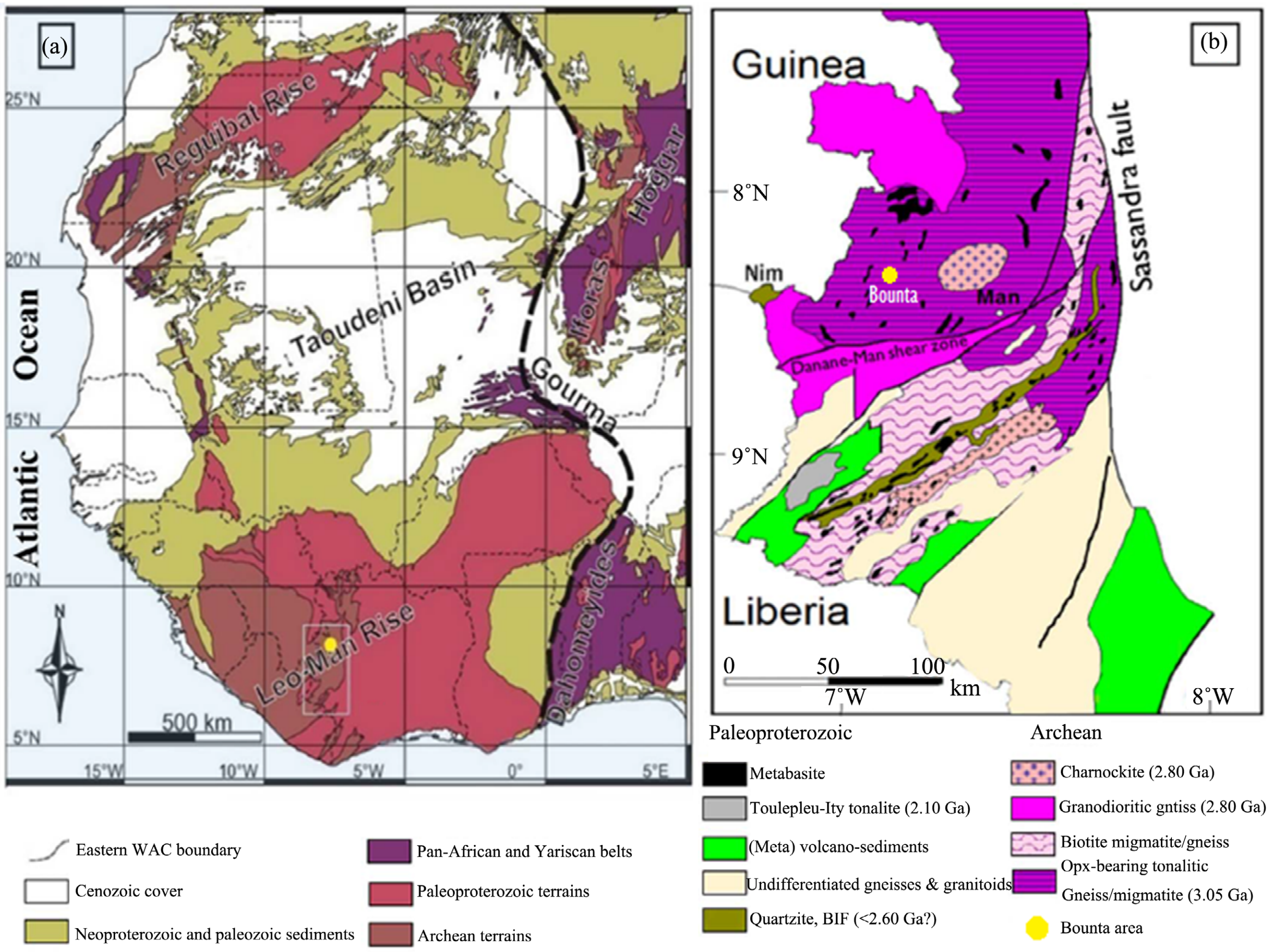

Figure 2. Schematic geological map of the study area. (a) West African shield (adapted from **Figure 1(a)** *in* reference [8]. (b) Man craton in western Ivory Coast (adapted from **Figure 2** *in* [9]; the inset shows the Bounta area (*in* reference [7]).

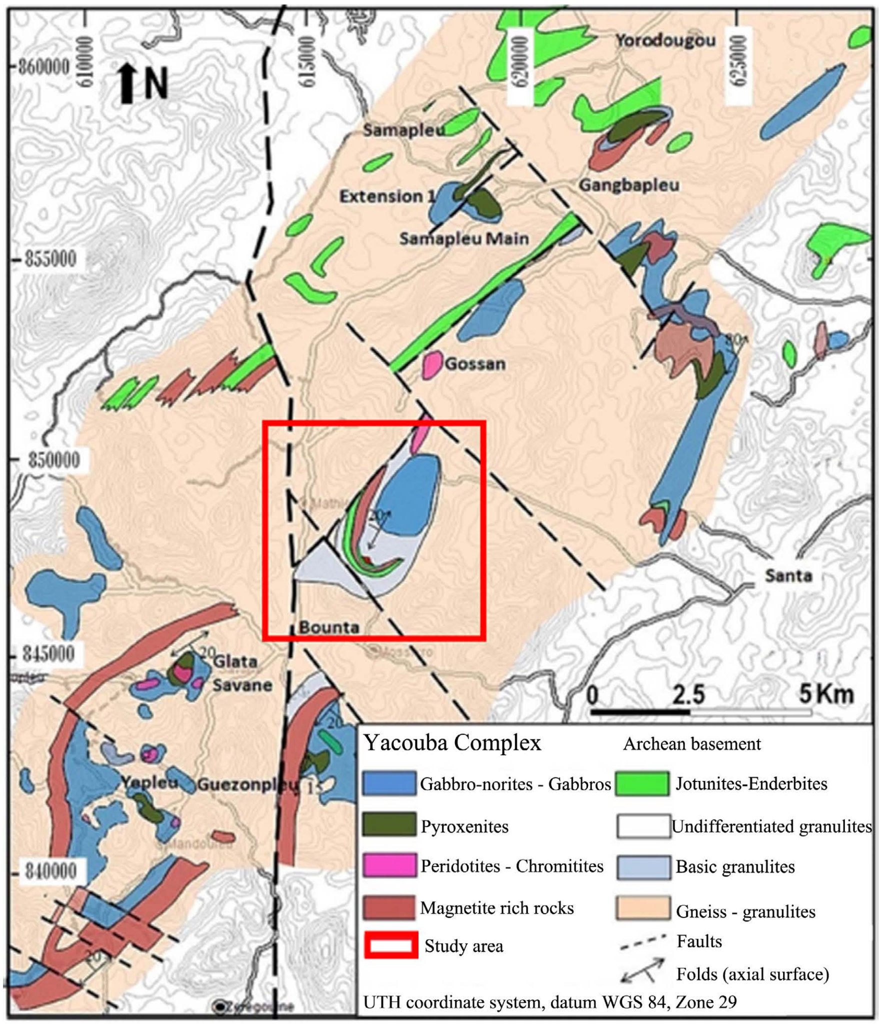

Figure 3. Schematic geological map of Yorodougou-Samapleu-Gangbapleu-Yepleu and Bounta villages in the Biankouma region including the Bounta study area (adapted from **Figure 2** *in* reference [6]).

or slightly dipping. Also, south of Bounta, magnetite bearing quartzo-feldspathic formations form thin, folded and dismembered layers oriented N030˚/15˚SE.

3. Analytical Methods

Bounta is located in a tropical zone containing lateritic layers which can reach more than 40 meters in thickness. The rarity and lack of outcrops led to the combination of data obtained by geophysics (magnetic maps) and hammer prospecting to carry out the mapping study.

The petrographical characterization of the Bounta rocks was performed using sampling methods and analytical techniques. Thus, the collection of rock samples was carried out on cores from drilling BN59-533316. This step allowed the macroscopic identification of about twenty rocks through the determination of the main parameters of the lithologies (color, texture, mineralogical composition, alteration, structure and presence of sulfide).

Thereafter, eight (8) rock samples were taken from the samples used for the confection of polished thin sections to refine the petrographical characterization of the different rocks using microscope. Silicate minerals of these rocks were studied in transmitted light on the Optika Jeulin type microscope at the geology Laboratory of the University of Man (Ivory Coast). Iron sulfides and oxides were observed in reflected light on the Leica DMLM type microscope at the archeology laboratory of the University of Franche Comté (France).

The different lithologies were determined with the Quartz-Alkali feldspar-Plagioclase diagram (QAP) of the igneous rocks of Streickesen and that of the metamorphic rocks of reference [19] by considering the mineral compositions, the textures of the samples observed macroscopically and microscopically.

4. Results

4.1. Mapping

The Bounta area is represented by a topography with increasingly marked reliefs as one moves towards the southwest with the mountain peaks oriented NE-SW. Due to the cover of lateritic alteration, more than 40 m thick laterite, in the Bounta area, the few outcrops observed implied that this study should be carried out using airborne geophysical data, drilling and hammer prospecting. The study area is covered by gneiss and granulite which constitute the framework of the mountain peaks oriented NE-SW and are the most abundant geological formations, therefore, considered as the country rocks (**Figure 4**). These rocks constitute massive and leucocratic rocks, characterized by a well-marked foliation in the case of gneiss with intercalations of diorite xenoliths, and locally large crystals of magnetite (crystal size up to 1.5 cm). These foliations have an overall NE-SW strike and a subvertical dip which in places is subhorizontal.

In the northeast of the map, diorite associated with gabbro/gabbronorite and pyroxenite constitute the mafic unit. This mesocratic to melanocratic, massive and homogeneous unit is dislocated in the form of dispersed lenses forming bands of variable width from a few meters to a few tens of meters within the gneiss and granulite with an overall NE-SW strike.

At the extreme northeast of the map, the unit formed by peridotite and chromitite constitutes the ultramafic rocks. It's in the company of diorite and gabbro/gabbronorite. In the southwestern part of the map, the observed diorite is intercalated with gneiss and granulite. Also, jotunite/enderbite formations are closely related to magnetite bearing quartzo-feldspathic formations which large dislocated blocks on the ground in the southwestern part of the map. All these formations (mafic, ultramafic) within the gneiss/granulite are generally NE-SW oriented.

The thick lateritic layers which generally supplant all the geological formations mentioned at Bounta consist of weathering products forming red-brown soils. These lateritic soils are composed of hematite, traces of manganese oxide, kaolinite and quartz with goethite in places.

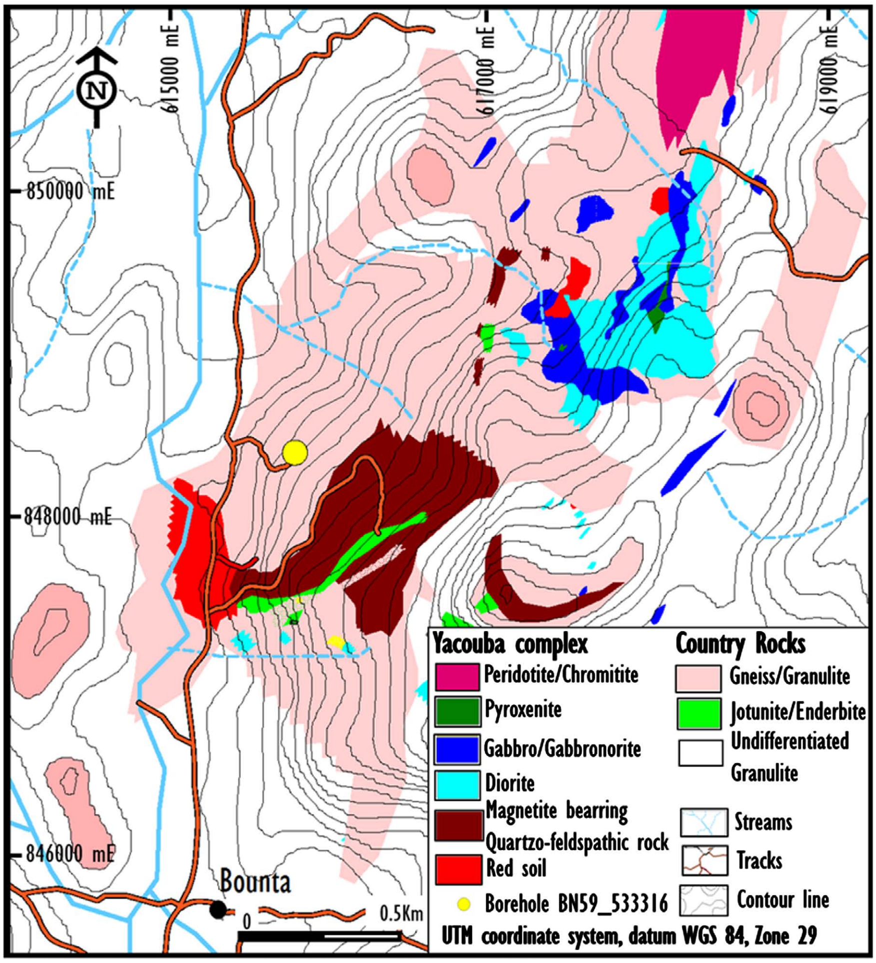

Figure 4. Schematic geological map of the Bounta study area.

4.2. Petrography

Owing to lateritic weathering in the Bounta study area, there are not too many outcrops and this makes it necessary to conduct the Bounta rocks study from the drilling data in addition to a few outcrops observed during mapping. The drilling BN59-533316 used for this study, crosscuts the granulite/gneiss unit, the tonalite-trondhjemite-granodiorite (TTG) suite and the mafic unit (**Figure 5**). The petrographic study relate to that of the TTG series. Drilling BN59-533316 shows the lithostratigraphy of the rocks intersected in the Bounta area and highlights a certain rhythmicity between the different units (granulite/gneiss, mafic and TTG). This lithological alternation between these geological formations could indicate a petrographic relationship between them.

According to the Bounta TTG petrography, ***Opx bearing trondhjemite*** (**Table 1**) is a massive white-colored rock speckled with gray (**Figure 6(a)**). It has an equant structure and is partially foliated in places, with a medium grain size. Under the microscope, this rock presents a grainy magmatic texture with locally minerals such as Opx and amphibole which have less marked preferential orientations. Its mineralogical paragenesis consists of quartz, plagioclase, Opx,

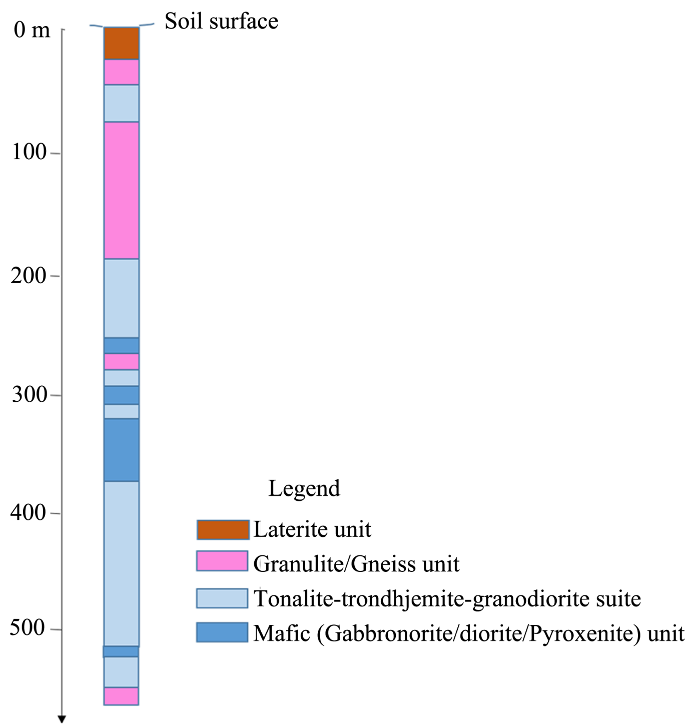

Figure 5. BN59-533316 drilling log (Azimuth = 200˚ and Dip = 75˚) proposing stratigraphic succession of Bounta area lithologies.

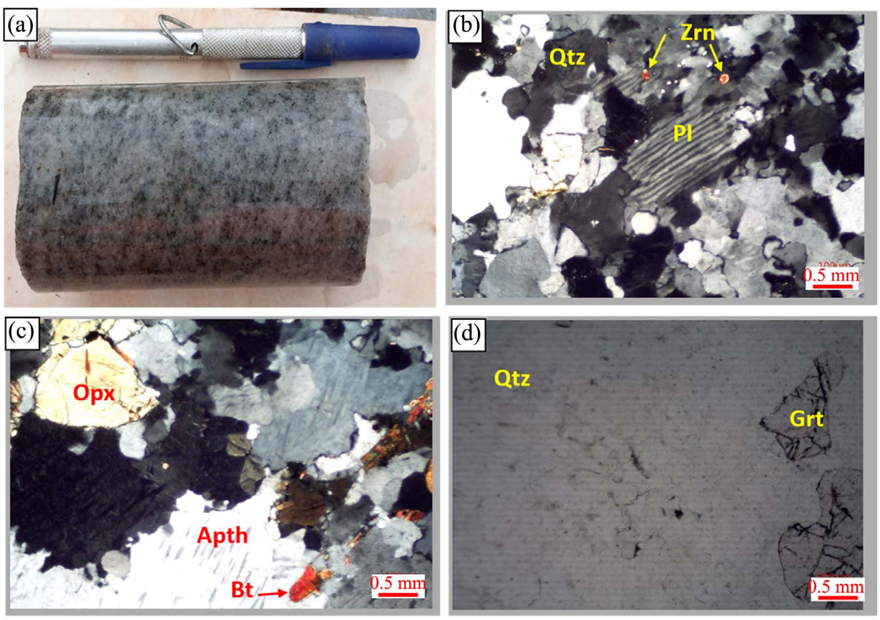

Figure 6. Photomacrograph and photomicrographs of pyroxene trondhjemite (a) Core from the sample (BN3); (b) Sample (BN3) showing the characteristics of minerals (plagioclase, quartz, zircon) and recrystallization texture of quartz crystals in analyzed polarized light; (c) Sample (BN22) indicating the characteristics of minerals (orthopyroxene, biotite, antiperthite) and undulating extinction of quartz crystals in analyzed polarized light; (d) Sample (BN8) showing the characteristics of minerals (quartz, garnet) in unanalyzed polarized light. Pl = plagioclase, Qtz = quartz, Opx = orthopyroxene, Bt = biotite, Apth = antiperthite, Grt = garnet, Zrn = zircon.

Table 1. Mineral parageneses of TTG series and Bounta biotitite.

Lithologies	Samples	Depth (m)	Modal percent of the minerals								
			Opx	Pl	Qtz	Amp	Bt	Apth	Grt	Sulf	Mag
Trondhjemite	BN3	221.50	15	30	42	5	3	3	-	<1	<2
	BN8	270.00	20	20	50	5	3	-	-	<1	<2
	BN22	553.60	10	30	45	5	3	2	4	<1	<1
Tonalite	BN10	283.00	20	40	14	15	7	2	-	<1	<2
Granodiorite	BN19	392.90	15	15	35	10	3	5	2	15	-
	BN20	402.20	20	14	30	15	-	5	5	20	-
Biotitite	BN5	251.00	5	25	3	10	55	-	-	<2	-
	BN7	264.60	10	10	15	10	50	3	-	<2	-

- = not observed, Opx = orthopyroxene, Pl = plagioclase, Qtz = quartz, Amp = amphibole, Bt = biotite, Apth = antiperthite, Grt = garnet, Sulf = Sulfide, Mag = mangetite.

amphibole, perthite, biotite, garnet and opaque minerals. Anhedral quartz (30% to 40% of the rock) of size of 300 μm to 7 mm, with a undulous extinction is the most abundant mineral in the rock. It forms small crystals associated with large crystals indicating a recrystallization texture (**Figure 6(b)**). Sodium plagioclase (20% to 30% of the rock), xenomorphic, of a size 500 μm to 6 mm with antiperthite crystals shows orthoclase exsolution lamellae included within the albite. Subhedral Opx (10% to 15% of the rock), micrometric to millimetric, colorless to beige-brown and orange polarization tint, is associated with quartz, plagioclase and altered in places (**Figure 6(c)**). The elongated biotite as well as the brown amphibole (hornblende), of millimetric size, making up less than 5% of the rock, are locally coronitic around the Opx. Colorless, subrounded garnet is present on some samples (**Figure 6(d)**). Zircon has been observed within antiperthites and quartz. Opaque minerals (probably sulfides or magnetite) are rarely observed.

Opx bearing tonalite (**Table 1**) is a massive rock, gray-white (**Figure 7(a)**), medium-grained, equant structure with locally mineral stretching lineation. This grainy textured rock is composed of plagioclase, Opx, amphibole, quartz, biotite, antiperthite, microcline and opaque minerals. The euhedral plagioclase (30% to 40% of the rock) is the most abundant mineral. Generally, comprised between 1 and 8 mm in size, it forms large crystals in some places. The subhedral Opx (20% to 25% of the rock), with a size between 500 μm and 6 mm, is regularly associated with plagioclase. Plagioclase and Opx crystals form triple points (**Figure 7(b)** and **Figure 7(c)**). The amphibole (15% to 20% of the rock) is subhedral, millimetric in size (0.5 to 6 mm), colorless to beige showing two cleavages (120˚ and 60˚) with an orange polarization tint (**Figure 7(b)** and **Figure 7(c)**). The quartz (less than 15% of the rock) with rolling extinction is anhedral, of very varied size (from 200 μm to 5 mm) forming small crystals associated with large

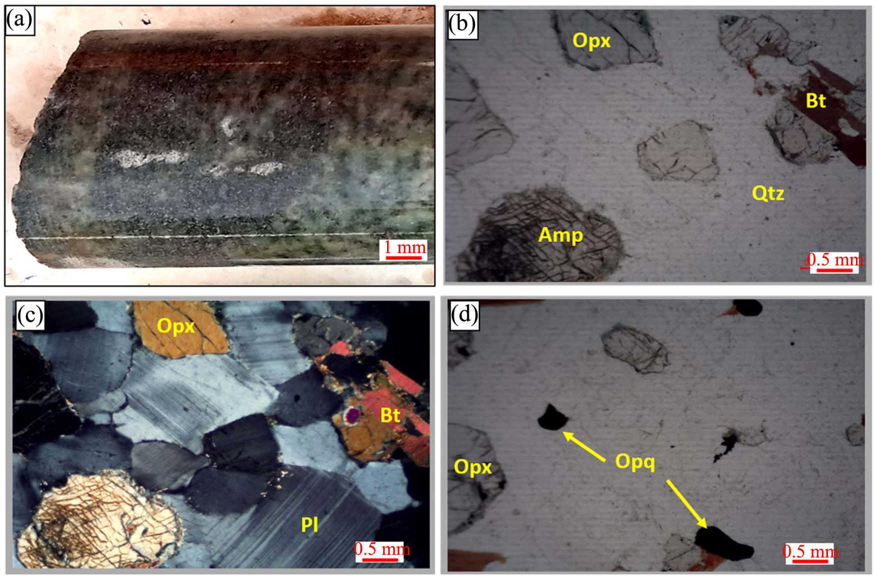

Figure 7. Photomacrograph and photomicrographs of pyroxene tonalite (a) Core from the sample (BN10); (b) Sample (BN10) showing the characteristics of minerals (orthopyroxene, amphibole, quartz, biotite) in unanalyzed polarized light; (c) Sample (BN10) showing the characteristics of minerals (orthopyroxene, amphibole, quartz, biotite) with triple points between minerals in analyzed polarized light; (d) Sample (BN10) indicating opaque minerals in unanalyzed polarized light. Pl = plagioclase, Qtz = quartz, Opx = orthopyroxene, Bt = biotite, Amp = Amphibole, Opq = opaque mineral.

crystals which are interstitial between the crystals of plagioclase and Opx. Brown biotite (less than 10% of the rock), subautomorphic, millimetric is present, as well as microcline, antiperthite and opaque minerals which are accessory (Figure 7(d)).

Opx bearing granodiorite (Table 1) is a massive rock, grey-white and green in places, fine to medium grained with an equant structure. Clearly visible sulfides are composed of pyrrhotite and pyrite (Figure 8(a)). This rock has a grainy texture and is composed of quartz, Opx, plagioclase, amphibole, biotite, perthite, garnet and opaque minerals. Quartz (30% to 35% of the rock) occurs as crystals of micrometric to millimetric size with rolling extinctions just like plagioclase (Figure 8(b)). The plagioclase (15% to 20% of the rock) is small size. The antiperthites (2% to 5% of the rock) are millimetric and associated with quartz and plagioclase. The Opx (15% to 20% of the rock) forms medium-sized crystals (1 to 7 mm) (Figure 8(c)) which show deformation kinks in places. All of these aforementioned minerals have recrystallization textures. Amphibole and biotite, each making up less than 10% of the rock, are subhedral, millimetric in size and locally coronitic surrounding the Opx. Accessory, subautomorphic garnet is present in some samples as well as opaque minerals (sulfides) which are interstitial between the Opx and quartz crystals (Figure 8(c) and Figure 8(d)). These sulfides can locally reach 15% to 20% of the rock.

The presence of garnet, undulating extinctions and deformation kinks indicate that these TTG, although having globally magmatic textures, could

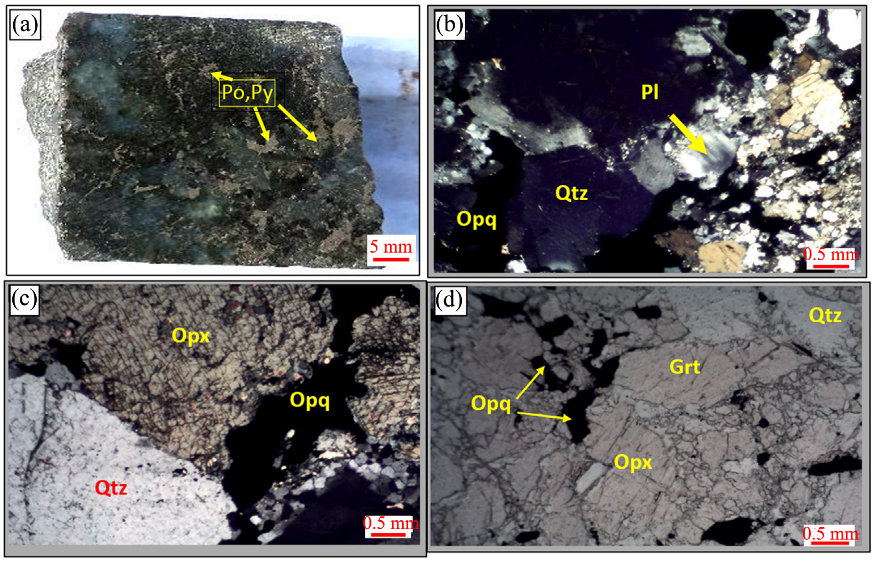

Figure 8. Photomacrograph and photomicrographs of pyroxene granodiotite (a) Core from the sample (BN20) showing pyrrhotite and pyrite; (b) Sample (BN20) showing the characteristics of minerals (plagioclase, quartz, opaque mineral) and recrystallization texture of quartz crystals in analyzed polarized light; (c) Sample (BN19) showing the characteristics of minerals (orthopyroxene, quartz, opaque mineral) in analyzed polarized light; (d) Sample (BN20) showing the characteristics of minerals (orthopyroxene, quartz, garnet, opaque mineral) in unanalyzed polarized light. Pl = plagioclase, Qtz = quartz, Opx = orthopyroxene, Grt = garnet, Po = pyrrhotite, Py = pyrite, Opq = opaque mineral.

correspond to metamorphic rocks. These rocks globally have a low proportion of sulfide (pyrrhotite, pyrite), generally in the form of disseminated speckles and interstitials between pyroxene, plagioclase and quartz minerals. They contain iron oxides (magnetite) in places.

Furthermore, centimetric to decimetric passes of ***Opx bearing biotitite*** intercalated within the TTG series and the basite unit were observed. This rock (Table 1) is massive, green-black with an equant structure. It is mainly composed of biotite with other minerals (plagioclase, quartz, pyroxene, garnet, sulfides) and has a granolepidoblastic texture with a preferential orientation of biotite minerals (Figure 9).

4.3. Deformation Structures

The Bounta TTG series seems to have undergone high temperature deformations materialized by characteristic microscopic and macroscopic structures. Macroscopically, the ***foliation*** is mainly observed within the Bounta TTG series and is revealed by alternating bands of light minerals (quartz, plagioclase, feldspar) and bands of dark minerals (pyroxene, amphibole, biotite) (Figure 10(a)). Also, ***mineral lineation*** is observed in these rocks through stretching of minerals in a preferential direction marked by dark minerals (pyroxene, amphibole, biotite) (Figure 10(b)).

Under microscope, the characteristics of deformation at high temperature are represented by the ***mosaic recrystallization*** which is showed by triple joints

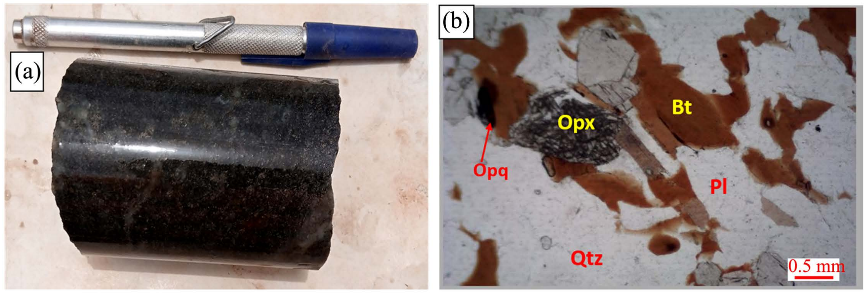

Figure 9. Photomacrograph and photomicrograph of biotitite (a) Core from the sample (BN7); (b) Sample (BN7) indicating the characteristics of minerals (biotite, orthopyroxene, plagioclase, quartz, opaque mineral) in unanalyzed polarized light. Bt= biotite, Pl = plagioclase, Opx = orthopyroxene, Qtz = quartz, Opq = opaque mineral.

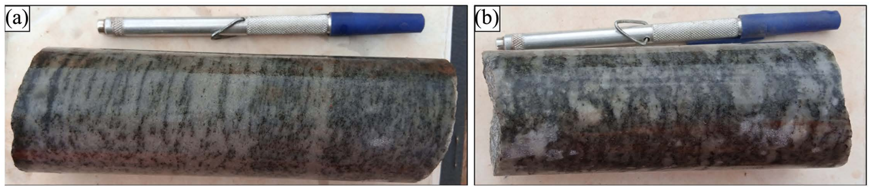

Figure 10. Photomacrographs of deformation structures of the Bounta TTG series (a) Foliation observed in the BN4 sample; (b) Mineral lineation observed in the BN2 sample.

between the minerals, forming angles of approximately 120˚ between them (**cf.** Figure 7(c)); the ***deformation kinks*** materialized by the breakage of the mineral in analyzed polarized light observable within the crystals of plagioclase and pyroxene ; the ***undulating extinction*** which is revealed by a rolling extinction in analyzed polarized light observable within the quartz, the plagioclases (**cf.** Figure 6(c)) and in places the Opx and finally the ***recrystallization textures*** characterized by the juxtaposition of microcrystals and phenocrystals of quartz and plagioclase (**cf.** Figure 6(b) and Figure 8(b)).

4.4. Sulfide and Iron Oxide Mineralization

The TTG observed in the Bounta area generally contain low proportion sulfide speckles which in places can be abundant. These sulfides are disseminated and interstitial between silicate minerals (pyroxene, plagioclase and quartz) (Figure 8(a)). In places, they form wide beaches and/or veinlets which cut through the silicate minerals. The paragenesis of the sulfides is composed of pyrrhotite, pyrite and rarely chalcopyrite and that of the iron oxides which are composed of magnetite and incidentally of ilmenite (Figure 11(a) and Figure 11(b)).

5. Discussion

5.1. Petrography of Bounta TTG

The granulite/gneiss unit having already been characterized by [3], mafic unit under study, petrography of trondhjemite, tonalite and granodiorite (TTG) from Bounta indicates that these three geological formations are composed of the same main minerals (quartz, plagioclase, orthopyroxene, amphibole, feldspar)

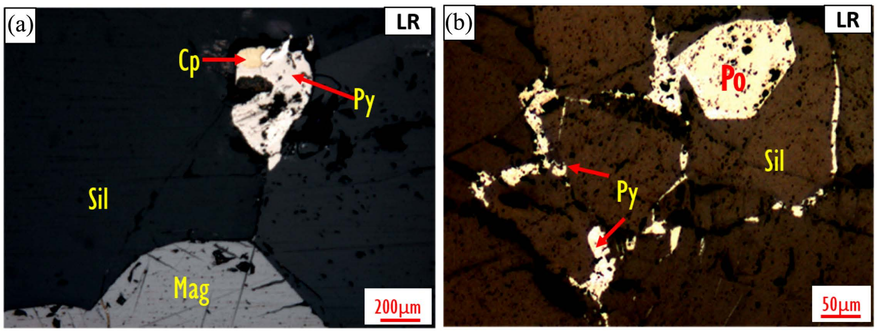

Figure 11. Photomicrographs of sulfide and iron oxide mineralization from the Bounta TTG. (a) Disseminated crystals of iron oxide (magnetite) and sulfide (pyrite and chalcopyrite); Disseminated and interstitial sulfide (pyrrhotite) crystals with exsolutions of pyrite. LR = lumière réfléchie, Sil = silicate, Po = pyrrhotite, Py = pyrite, Cp = chalcopyrite, Mag = magnétite.

and accessory minerals (biotite, garnet) in proportions variables according to lithology. These rocks have globally magmatic textures supplanted by high temperature deformation textures (recrystallization texture, undulating extinction, deformation kinks) [20]. In the field, as well as in borehole BN59-533316, these TTG series varied from decimetric to metric thicknesses. They follow each other step by step as if they were closely linked and come from the same magma. Furthermore, the foliations observed within the TTG appear to be magmatic. All these observations indicate that the TTG of Bounta could have formed from the crystallization of a magma by fractionation of minerals during the formation of these rocks [21] [22]. Indeed, it was observed that the variable compositions of TTG suites are caused by fractional crystallization in TTG plutons after emplacement related to source depth [23].

Furthermore, the Bounta TTG series contain speckles of sulfide (pyrite and pyrrhotite) which are disseminated in some places and are relatively abundant, as well as iron oxides (magnetite) which are of low proportion.

5.2. Origin and Comparison of TTG of Bounta to Those of the Sipilou-Man Regions

In the department of Sipilou located at about 18 km NE of Bounta, geological formations were described with the same petrographic and structural characteristics as the Bounta TTG as charnockites and gneisses [3]. According to reference [24], charnockites are orthopyroxene granites and TTG. The ubiquity of orthopyroxene within the Bounta TTG series is observable. Therefore, these rocks could correspond to rocks of the charnockite series [24] [25]. Thus, the Bounta TTG would correspond to opdalites and enderbite according to the QAP diagram of the charnockite series [19].

According to these authors [24] [25], charnockite is a catazonal metamorphic rock known in Precambrian basements and considered as a product of crystallization from an anatectic magma. The authors [1] [2] indicated that TTG are generated by partial melting of hydrated metabasalts and are therefore anatexis products. Reference [11] showed that TTG from the region of Man (western Ivory Coast) are anatexis products of the Archean crust. They formed during the Liberian orogeny from a partial melting of a basic source containing garnet and hornblende and this source left residues of garnet and hornblende within the newly formed TTG.

Therefore, the presence of garnet and amphibole (hornblende) within the TTG of Bounta, in addition to the petrographic characteristics mentioned above, indicate that these rocks could be anatexis products.

Indeed, the authors [3] [17] obtained an age, 2.8 Ga on metamorphic zircons, on the Sipilou charnockites which have the same petrographic characteristics as the TTG of Bounta. In addition, they obtained Archean ages (3.6 to 3.3 Ga on inherited zircons) on the granulite/gneiss unit associated with these charnockites. These authors hypothesize that the charnockites would have formed from the partial melting of the granulite/gneiss unit which would come from a basaltic protocrust in this region. Otherwise, the TTG of the Man region and the Sipilou department were metamorphosed to the granulite amphibolite facies of the regional metamorphism of the Liberian orogeny which was dated to 2.8 Ga [3] [4] [11] [26].

Thus, considering the petrographic and structural observations of the Bounta TTG; the lithostratigraphic relationship between the units (granulite/gneiss and mafic) and the TTG series; the ages obtained by the authors [3] [17] on these rocks in the region, the Bounta TTG series could be considered as products of Archean crustal anatexis. They would have formed during the Liberian orogeny. Liberian metamorphic event which involved the old basement and its cover in the transformation is to the origin of these TTG.

5.3. Economic Value of Bounta TTG Suites

The Tonalite-Trondhjemite-Granodiorite (TTG) suites by their characteristics, mineralogical compositions are similar to granitoids ([1] [2]) and are used in many quarries. Their homogeneity, compactness, cohesion and mineral resistance (particularly quartz) enjoy great renown due to their resistance to erosion. TTG are used in the construction of multiple major public works (masonry, dams, roads, seaports, bridges). In the department of Biankouma, quarries containing these TTG series are used for the construction of road infrastructures, schools and public works. Furthermore, if the pyrrhotite sulfides contained in these TTG suites are in abundance, they could be used in the manufacture of sulfuric acid which can then be used in the sulfide nickel treatment process [27]. In the event of a possible discovery of a nickel sulfide deposit in the region (Sipilou-Biankouma), the mining company Samanickel-CI could use it for the extraction of nickel if this is part of their nickel ore treatment process.

6. Conclusions

The study of the petrography of rocks with felsic to basic compositions mineralized in sulfide observed at Bounta has shown that these rocks are trondhjemite, tonalite and granodiorite (TTG) suites. These TTG of Bounta are composed of the same main minerals (quartz, plagioclase, orthopyroxene, amphibole, feldspar) and accessory minerals (biotite, garnet) with magmatic textures supplanted by metamorphic textures. They would correspond to opdalites and enderbite according to the QAP diagram of the charnockite series. The Bounta TTG would have formed from the crystallization of a magma by fractionation of minerals during their formation and could be considered as products of Archean crustal anatexis. They would have formed during the Liberian metamorphic event which involved the old basement and its cover in the transformation during the Liberian orogeny.

The TTG series of Bounta show the same petrographic characteristics as the TTG of the Man region and the Sipilou charnockites. Furthermore, the Bounta TTG series contain speckles of sulfide (pyrite and pyrrhotite) which are disseminated in places and are relatively abundant, as well as iron oxides (magnetite) which are of low proportion. Subsequent analyzes on the geochemistry of the minerals and rocks of the Bounta TTG should make it possible to be more precise on the nature and origin of these rocks.

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Conflicts of Interest

All authors have read and agreed to submit this work to a scientific publication journal. The authors declare no conflicts of interest.

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